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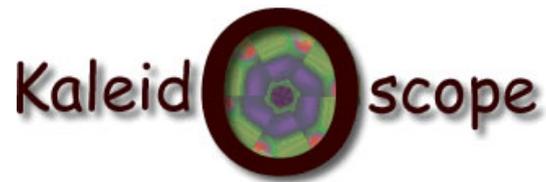
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future of learning with digital technologies

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KALEIDOSCOPE JEIRP

“Interaction between learner’s internal and external representations in multimedia environment”

D21-01-01-F

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0 Introduction

0.1 Scope and Structure

This document is the "State of the art" report of the JEIRP "Interaction between learner's internal and external representations in multimedia environment".

The scope of the document is twofold:

- (a) To set the conceptual framework and present in an organized manner the basic theoretical issues (concepts and methods) of the research field, and
- (b) To analyze representative cases, highlighting the way that these theoretical issues apply in the design of multimedia instructional software/artifacts.

The document comprises eleven (11) chapters. The chapters introduce the reader both to the abstracted and elaborate knowledge of the domain and to the discussion of how theoretical concepts fruitfully apply in the design process. Chapter 1 is strongly theory oriented presenting a core of well established theoretical issues (concepts and methods). All other chapters extend this core either by elaborating the theoretical considerations (such as chapters 2, 3) or by focusing on the pedagogical benefits resulting from domain and instructional approach specific representations (chapters 4, 5, 6), or by making a theory-informed analysis of the representations that are employed in various multi-representational instructional systems (chapters 7, 8, 9, 10, 11).

0.2 Why do we care about representations?

The interaction between learners' internal and external representations is in the core of any instructional and learning effort. Learning (or in other words: developing internal knowledge representations) happens when perceiving and cognitively processing information from appropriate external representations. These may appear either as instructor-developed constructs for conveying to the learners the experts' knowledge on the topic or as student-generated and negotiated artifacts for constructing knowledge. Either way the efficient use of external representations is of major concern in the learning process, since the quality of learning and transfer strongly depends on it.

Instructors, traditionally, make extensive use of both linguistic and static visual representations available on printed material. In technology enhanced learning environments, however, the opportunity emerges for employing also dynamic, immersive, adaptive, interactive, and collaboration-supporting representations for learning. Representations can also be more effectively used in multiplicity in order to complement each other, constrain misinterpretations of single representations and support learner's constructing deeper (more abstract) domain knowledge. These new possibilities and respective instructional software development efforts are flooded with questions on how to appropriately design technology supported external representations in order to promote learning in all its important cognitive, collaborative, social and motivational aspects.

The work in this JEIRP focuses on these research issues and this document sets the starting point in describing the current state-of-the-art with respect to theory-building and design. Beyond this, the project will aim at extending the understanding of representations by addressing specific issues of major interest.

0.3 Chapters and Authors

Chapter 1: "An introduction to concepts and methods relative to the interaction between learner's internal and external representations in multimedia learning environments", Stavros Demetriadis, Ton de Jong, Giuliana Dettori, Frank Fischer, Tania Giannetti and Jan van der Meij.

Chapter 2: "Representations and problem solving", Giuliana Dettori and Tania Giannetti, ITD/CNR-IT.

Chapter 3: "Examples of using multiple representations", Jan van der Meij and Ton de Jong, UTWENTE-NL.

Chapter 4: "Current Perspectives on the Pedagogical Value of Algorithm Visualization", Stavros Demetriadis and Pantelis Papadopoulos, AUTH – GR.

Chapter 5: "The Interaction between Internal and External Collaboration Scripts in Computer-Supported Collaborative Learning", Ingo Kollar & Frank Fischer, KMRC – DE.

Chapter 6: "Representation, note-taking and memorization", Márta Turcsányi-Szabó and Lajos Brazovits, ELTE-HU.

Chapter 7: "Internal and External representations in advanced multimedia study materials: case "SQL Fundamentals"", Bruno Zuga, Atis Kapenieks, Armands Strazds and Nadja Pizika, UTRIGAS-LV.

Chapter 8: "Extension of external representation to Interactive and Multisensory Simulation of Physical Objects", Claude Cadoz and Aurélie Arliaud, ICA/INPG-FR.

Chapter 9: "Psycho-physiological parameters in the interaction between learners' internal and external representations", Judith Hovorka and Marianne Koenig, DUK-AT.

Chapter 10: "Case Study: Analysis of LEGO RoboLab Programming Environment in the Light of Different Representations", Olga Timcenko, LEGO-DK.

Chapter 11: "Motivation and Representation in Educational Games", Athanasios Karoulis & Savvas Demetriadis, AUTH-GR.

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CHAPTER 1: An Introduction to the Concepts and Methods for Analyzing the Interaction between Learner’s Internal and External Representations in Multimedia Environments

Stavros Demetriadis, Ton de Jong, Giuliana Dettori, Frank Fischer, Tania Giannetti and Jan van der Meij

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Abstract. In this chapter we set the conceptual framework for the analysis of the interaction between learner’s internal and external representations. To do so we present and discuss some major theoretical issues in the field, including properties and dimensions of representations, theoretical views that guide our current understanding on how to make efficient use of external representations (such as computational effectiveness, dual coding and cognitive load theory), cognitive models of multimedia learning, functions of multiple representations, problems and types of student’s support when using multiple representations, and the use of external representations in collaborative learning. In the concluding section an overview in the form of a table can become a useful tool for designers and instructors to analyze and self assess the use of representations in their instructional multimedia systems.

Keywords: Internal and external representations, functions of multiple representations, cognitive models of multimedia learning.

1.1 Representations for learning

1.1.1 Introduction

A representation, generally, is something that stands for something else (Palmer, 1978). It is some sort of model of the thing (or things) it represents. It is a symbolic structure which stands for a respective structure of a “real” world system¹. When students analyse a problem situation or the behaviour of a physical phenomenon, they rarely interact directly with the real object of interest, but rather use a representation of it, that is, something which describes the system, but is not the system itself. Analogously, when the object of study are abstract entities – as it is the case in mathematics – dealing with representations is crucial, since it is only by handling representations that it is possible to perform some activity on abstract entities, though their learning can take place a conceptual level² (Duval, 1993).

The main function of a representation is to render the quantitative and/or qualitative relationships between the components of a system (or abstract object, or problem situation) more explicit and better

¹ A real world system may be a physical or an artificial system. It can also be a hypothetical system where certain user-selected assumptions apply. The world “real” is put here in brackets to emphasize that most of the times the representations refer to the model that we use to describe what we conceptualize as reality.

² When dealing with representations of abstract objects, as in mathematics, there is always the risk to confuse the objects themselves with their representations, since abstraction is difficult to conceive. The educational use of representations in such cases, hence, though mandatory, requires particular care on the didactical level (Duval, 1993).

understandable, and, consequently, to help decrease the level of uncertainty which would hinder learning or problem solving. Representations can be based on a variety of expressive formats, which have been widely used in education much before the development of ICT, either in alternative to each other or in parallel. The ability to use different kinds of representations is typical of human intelligence (Gagatsis, 2000). It probably derives from humans' multifaceted capability of abstractions, which leads us to consider information from various perspectives, differentiating contexts and highlighting different sets of features as essential characteristics of the knowledge or situation at hand. It is not by chance that the word "represent" in natural language has both the meaning of "giving/making a picture, sign, symbol or example of" and "act or speak for".

Representations are always "symbolic" at some extent, not only when they make use of some explicitly recognizable system of symbols (e.g. mathematics symbols, graphs, diagrams etc.) but also when they appear mostly pictorial, since their purpose to highlight a selection of relevant elements makes them not merely pictures of the considered object but in fact gives its elements a symbolic role.

Instruction is always in need of appropriate representations for presenting the content to be learned. In the instructionist-objectivist paradigm where the basic assumption is that objective knowledge about the world has to be somehow conveyed to the learner, external representations are used to "anchor" learning activities by presenting the hypothesized structure of the system under study. In the constructivist arena where knowledge is considered as much more negotiable and emphasis is given on the learner's self construction of knowledge, learners are encouraged to articulate and negotiate their knowledge representations using appropriate cognitive tools, e.g. building a concept map.

In this introductory chapter we present the most important theoretical issues which shape our current understanding about the use of representations for learning. The reader will be guided through the fundamental concepts and methods which help us categorize the various forms of representations and relate them to other significant aspects of learning.

1.1.2 An evolutionary view of cognition in relation to representations

A relatively recent work in the field of evolutionary psychology (Donald, 1991) hypothesises that human cognition has progressively developed through four different, increasingly complex stages, from episodic (ape-like) to mimetic (based on physical action), mythic (spoken), and theoretical (written) cognition. These stages correspond to increased capabilities of representation, progressively including both the ability to represent abstract concepts and that to make representations based on different expressive formats.

Several studies (Lurija, 1976; Goody, 1977; Ong, 1982; Olson 1996) focus in particular on the development of the written stage of cognition from the mythic one, highlighting how the creation of writing systems, because of their representational potentiality, do not appear merely as external aids to human memory, but as powerful tools supporting reflective thought, able to bring into consciousness the structural properties of speech. Analogously, it can be argued (Zhang, 1997) that the invention of written Arabic numbers has been instrumental in the development of mathematical topics, like algebra, which heavily rely on advanced abstract thinking. In this respect, the development of structured sign systems for

representing language and numbers can be seen as a first important example of technology empowering the human mind.

At present, the development of ICT has dramatically increased our representational possibilities (consider e.g. dynamic representations, automatic translations among different representational codes, ease of using different media and codes, possibility to keep track of the construction steps of representations, etc.). This representational ease, as suggested by Kaput and Shaffer (2003), will possibly (if suitably exploited) lead us to a fifth stage of cognitive development, starting an evolution of the writing-based, theoretical culture towards a new, virtual one, supported by, and supporting, a more capable human mind.

1.1.3 External representations (ERs)

Representations are called *external* when they are external in relation to the learner's sensory and cognitive system and can be constructed by using some representational format, called in the literature *codes* or *registers* (Duval, 1993). These terms indicate the specific expressive formats in which information is displayed to the learner, such as pictorial, symbolic, textual. Hence, a *representational code* is any appropriate code which can be used to create meaningful communication and learning, such as written and oral language (text & speech) and static or dynamic visuals (images, graphics, animation, video).

Such a code can be categorized as *descriptive* (a system of signs for constructing descriptions of real world, such as natural languages) or *depictive* (a code that depicts reality by analogy, such as images and graphics).

Examples of external representations include textual descriptions (e.g., definitions given in natural or technical language), tables of data, mathematical expressions, graphs, animations, narration, audio cues, video clips. In a learning environment an external representation is being developed on purpose, in order to convey some meaning. It can be instructor-side generated (built by the instructor itself, the instructional designer or the producer of learning material) or learner-side generated (built by the individual student or the collaborating peers or by the students while negotiating their knowledge with the teacher).

External representations always make use of some modality in order to address a specific human sensory input. *Modality* refers to the specific sensory channel which is used while perceiving the external stimuli. There are representations which use the aural, visual and/or tactile modality. To build, therefore, an external representation for learning means to make use of a representational code and a specific modality in order to develop a meaningful message for learning. "Meaningful", in this context, refers to the ability of the "receiver" of the representation to efficiently decode the structural relationship that the representation conveys and connect it to previous knowledge.

In the realm of technology enhanced learning, several different representations of a same object or situation can easily be developed based on different representational codes. Software tools offering representations which make use of different communication modality are usually called multimedia learning environments (MLEs). It is important to note, in this respect, that the term "multimedia" is often erroneously used with the meaning of "multiple representations". The two terms, however, do not coincide, since multiple representations may be produced even using one single representational code. For

example, using the textual code one can produce representations such as verbal definitions, tables of data and equations.

The relation between representations and multimedia is addressed by Schnotz and Lowe (2003), who point out that "the term multimedia refers to the combination of multiple technical resources for the purpose of presenting information represented in multiple formats via multiple sensory modalities". These authors note that, when using multimedia resources, it is important to distinguish three different levels:

- *technical* level, which refers to the technical devices used to perform the representations (e.g. computers, networks, displays, etc...);
- *semiotic* level, which refers to the representational format used (e.g. texts, pictures, and sounds);
- *sensory* level, which refers to the sensory modality of sign reception (e.g. visual or auditory modality).

Failure to differentiate these three levels can give rise to misunderstandings which lead the educators to a poor use of multimedia and an ineffective use of the representations involved. A common misconception consists in treating multimedia primarily in terms of the information technology involved, neglecting the other two levels, whose proper understanding requires cognitive and educational competence, rather than technical one. Another common misconception consists in presuming that the technical medium itself can have an impact on learning, which, on the contrary, has been shown to be a simplistic approach to multimedia, if the semiotic and sensory aspects are disregarded. The research on learning and instruction, hence, should rather exploit the potentiality of multimedia by focusing in particular on their semiotic and sensory levels, that is, by emphasizing the impact on cognition and learning of the different forms of external representations which are offered or allowed in the considered environments.

1.1.4 Internal representations (IRs)

Internal representations (IRs), on the other hand, are cognitive constructs internal to learners' cognitive system. Learners are generally supposed to develop such internal structures when perceiving and cognitively processing information stimuli from external representations during the learning process. On these internal representations learners base their performance when engaged in problem solving activities.

Cognitive psychologists distinguish between *perception-based* representations and *meaning-based* representations (Anderson, 1995). The former are representations which "tend to preserve much of the structure of the original perceptual experience" while the latter are "quite abstracted from the perceptual details and encode the meaning of the experience" (Anderson, *ibid.*, p. 106).

One significant theoretical construct related to the perception of information (and therefore to perception-based representations) is the idea of *dual-coding*. According to Dual Coding Theory there are separate brain "channels" for processing the verbal and visual information and this results to separate representations for these two kinds of stimuli. Paivio (e.g. 1986) is often cited as the initiator of the theory, being based on studies which proved that human memory is significantly enhanced when verbal material is presented accompanied by relative visuals. Generally dual coding is strongly promoting the

notion that verbal and visual information are processed by different mental circuitry of the brain and this view has significant implications for designing multimedia leaning environments. Many studies (e.g. Mayer, 2003) have focused on how verbal and visual material could be most effectively presented to learners and create optimal learning conditions.

Of great significance for learning is how learners develop more abstracted representations (meaning-based representations), focusing on the most important features of the learning experience independent from the superficial perceptual characteristics. Such representations include propositional networks, schemata, scripts and mental models.

- *Propositional network*: A propositional network is a way to internally represent information contained in propositions by analyzing the meaning of the proposition into elementary meaningful statements. Such a statement is usually represented in space as a diagram of nodes interconnected with links. Nodes represent ideas and the links between nodes are the associations between the ideas.
- *Semantic network*: This is a structure similar to propositional network for the internal representation of conceptual knowledge (i.e. knowledge about the general categorical element which we use to describe the entities of real world). In a semantic network the concepts are represented by nodes in a hierarchical fashion and each concept is also associated with properties which may be true or false.
- *Schema*: The notion of a schema comes from artificial intelligence and computer science and it is similar to the structure of a record in a data base and the fields that the record includes. Schemas are structured collections of knowledge with slots (the attributes of the concept) and fillers (the values that an attribute can take). Although schemas focus on conceptual knowledge they are not confined to concepts (for example there are problem solving schemas).
- *Script*: A schema representation proposed by Schank & Abelson (1977) to account for people's knowledge of everyday situations where a series of actions should be executed in order to successfully accomplish the overall activity. They pointed out that many circumstances involve stereotypic sequences of actions. Scripts are event schemas which people use to reason about prototypical events. So, the difference with schemas is that schemas are not considered as possessing a time sequence.

1.1.5 On the relationship between external and internal representations

The terms "external" and "internal" (or "mental") representation are widely used by many authors, often relying on the intuitive meaning of these words, without defining their nature and extent in univocal way. On the side of mathematics education, more attention has been usually devoted to external representations, since they are concrete objects which can be observed and analysed, while internal ones can only be guessed, based on student's behaviour. On the other hand, on the cognitive psychology side, more attention was traditionally given to internal representations, while external ones have been given a

more central functional role in relation to internal cognitive mechanisms only relatively recently (Scaife & Rogers 1996, Zhang 1997).

Though the relationship between these two levels of representation may seem obvious and univocal, there is no generally accepted view on it, as can be seen just considering a few examples:

- Zhang (1997) argues that internal and external representations have different natures; he attributes to the external ones a fundamental role, while regarding the internal ones as memorization of them, filtered by the characteristics of the representation itself. He defines external representations as knowledge and structure of any kind (e.g. written symbols, objects, diagrams, etc) which materially exists. On the other hand, he defines internal representations as knowledge and structure in a person's memory, which includes propositions, schemas and other forms. He claims that internalization, i.e. the effort of transferring some external representation into one's own mind, does not always take place; in particular, is not necessary if external representations are always available, and is not possible if the external one is too complex. He argues, however, that external representations do not need to give rise to internal ones in order to contribute to problem solving activities, since they can directly provide information and, together with internal representations and memorial information, activate mental operations which lead to solve problems.
- Cifarelli (1998) seems to identify the two levels, as though internal representations would include only what the students are able, or willing, to put on paper or on screen. In the mentioned study, which refers to a problem solving situation, representations are viewed as conceptual organizations of actions, working as interpretative tools apt to support understanding during the problem solving activity.
- Goldin (1998) bases his analysis of external and internal representations on the concept of representational system, which he defines as a set of primitive characters or signs, together with rules for combining them into permitted configurations. In his view, internal representational systems mediate actions on external task environments (e.g. steps within external representational systems, translations from one representational system to another, or construction of entirely new representations). They may show some structural resemblance to external ones, or be independent of them. Goldin identifies five categories of mature internal representational systems:
 - verbal/syntactic
 - imagistic
 - formal notational (mathematics)
 - planning, monitoring and executive control
 - affective representation
- Thomas et al (2002) acknowledge that the two levels do not always coincide, and claims that it is only possible to infer information on the internal representations by analyzing the external ones.

- Lesh, Post and Behr (1987) consider the external representations as the observable materialization of students' internal conceptualizations.
- Stylianou (2002) argues that the act of visualization is a translation from external to mental or vice versa; when a new diagram is made (e.g. in mathematical problem solving), it grants the solver the possibility to extract additional information from its analysis.

1.1.6 Why use representations of real systems?³

In learning environments we often find representations of real systems. In this environment students do not study the system itself but a representation of the real system. In some cases the system itself is not available or not suitable for teaching. In other cases (the representation of) the real system has to be enhanced, for instance by representations of forces, before it can be used for learning.

De Jong (1991) and van Joolingen (1993) give several reasons for using a representation instead of real objects:

- (1) Objects are not always (easily) perceivable or available,
- (2) Experiments to determine the structure of reality are not always possible,
- (3) The duration of processes is sometimes too long or too short, and
- (4) Using real objects can involve the risk of damage and personal safety.

A simulation-based learning environment uses dynamic representations to represent a real system. De Jong (1991) and van Joolingen (1993) give the following reasons for using simulations in education:

- (1) Simulations can visualize processes that would otherwise not be observable, like very small scale processes,
- (2) Simulations can enable experiments that would otherwise be too expensive,
- (3) Simulations slow processes can be accelerated and very fast processes slowed down to speeds that are comprehensible for learners, and
- (4) Simulations can be used for training on systems that would otherwise be too dangerous to work with.

These authors also mention additional reasons for using simulations:

- (5) Simulations can provide an environment for learning independent of time and space,
- (6) Simulations can be used for training on systems in which, in real life, an inexperienced trainee could cause dangerous situations, and
- (7) Simulations can be used to create ideal or abstract situations that do not occur in the real world. The latter can also be a reason for using a representation of a real system.

A real system can be represented by for example a picture of the system or a text describing the system. Also (mathematical) models of the real system can be used to describe the behaviour of the real system.

³ In this and the following section we strongly focus on issues of external representations for learning. So the single term "representation" refers only to external ones.

Especially simulation environments make use of mathematical models, in which the variables of the model are represented numerically or graphically. The simulation model itself is mostly not visible to the learner. The real system then is represented by a model which itself is also represented. Examples of representations where the real system cannot be shown are atomic systems and the flow of current in an electrical circuit.



Figure 1.1. Representations of learning environments

A problem with using representations of reality is that students have to make a translation from the real system to the representation of the system and also a translation from the representation to the real system again. When using multiple representations the student also has to translate between the representations. Translating between the representations primarily means that the student has to identify and understand the relations between the representations. In simulation-based learning environments students have to make two translations: from the representation they study the domain with to the simulation model (equations) and from the simulation model to the real system.

1.2 Characteristics of representations

1.2.1 The structure of a representation

Palmer (1978) proposes that any particular representation should be described in terms of:

- (1) The represented world
- (2) The representing world
- (3) What aspects of the represented world are being represented
- (4) What aspects of the representing world are doing the modeling
- (5) The correspondence between the two worlds.

A world, X , is a representation of another world, Y , if at least some of the relations for objects of X are preserved by relations for corresponding objects of Y . A real system can be described by different representations, depending on the relations and the objects the representations represent. Different representations of the represented world can model the same set of objects in different ways.

Representations are:

- *Non-equivalent*, if each representation models different relations of the represented objects.
- *Informationally equivalent*, if each representation models the same relations in different ways.

- *Completely equivalent*, if representations model the same relations in the same way. Completely equivalent representations may appear different because of the context they are used in and/or operations performed on them.

Palmer (ibid.) concludes that the learner should always realize that a representation is not the real system. Information discovered in the representation should always be translated (back) to the real system.

1.2.2 Dimensions of representations

De Jong et al. (1998) describe five dimensions of representations that information (learning material) can take: perspective, precision, specificity, complexity, and modality.

- *Perspective* refers to the particular theoretical viewpoint taken in presenting material. De Jong et al. (ibid.) give us an example that the different parts of an engine can be considered from a functional perspective that describes the functions of specific parts or a topological perspective that describes the location of the different parts in the engine.
- *Precision* refers to the level of accuracy in the description (mainly qualitative vs. quantitative). According to de Jong et al. (ibid.) the precision with which information is presented expresses the level of accuracy or exactness of the information. Precision defines the distinction between precise, quantitative, information and less precise, qualitative, information.
- *Specificity* (Stenning & Oberlander, 1995) is concerned with the properties of representation systems, and refers to how far the conventions used in a graphical system demand specification of classes of information. The specificity approach describes a way in which information can be enforced within the most fitting representational system.
- *Complexity* refers to the amount of information present in a representation. Often a sequence from simple to complex is used to present information in learning environments. In simulation-based learning environments the models are often sequenced from simple to complex, that is, first the learner can only control a few variables of the model and gradually more variables under learner control are introduced. In the work by Sime (1998) we can find three characteristics that are related to complexity: granularity, generality, and scope.

Granularity refers to the grain size of the model, i.e. the amount of detail within the representation.

Generality refers to the width of applicability of the knowledge for the purposes of problem solving.

The *scope* of a model determines the breadth of the representation and is a term used to define the extent of the model and the limits of its representation.

- De Jong et al. (1998) describe *modality* as "the form of expression that is used for displaying information" (p. 15). They consider modality as the representation format and give examples of modalities such as: text, animations, diagrams, graphs, algebraic notations, real life observations, formula and tables. However, this interpretation of the concept of modality is

much closer to what we already have named "representational code". So, in the context of this chapter by "modality" we strictly refer to the various sensory modes for presenting information (acoustic, visual, tactile).

1.2.3 Forms of dynamic representation

Another very common way of describing representations is in relation to their behaviour in time, where we usually distinguish between *static* and *dynamic* representations. A static representation remains unchanged in time (text, images, graphics) while a dynamic one alters somehow the content transmitted to the learner (animation, video, speech). By the term "animation" we refer to the visual representational code which utilizes onscreen movable two or three dimensional graphics to represent processes of physical or artificial systems which somehow evolve in time. The core idea for using animation for learning is the expectation that the change-in-time feature of the system will be represented coherently by some respective change in time of the animated visuals. This mapping function is expected to enable learner to develop effectively and efficiently a more appropriate dynamic mental model of the system. According to Lowe (2003) the changes in animated displays may be "form" changes (transformations) which refer to changes of properties of the objects (e.g. size, shape and color), "position" changes (translations) with objects moving from one position to another, and "inclusion" changes (transitions) when objects appear or disappear from the display).

Brown (1988) proposes that *persistence* is a dimension of animated visuals and that "the persistence dimension ranges from displays that show only the current state of information to those that show a complete history of each change in the information." (ibid., p. 34). Ainsworth and VanLabeke (2004) expect persistent animations to significantly support students overcoming the difficulties that they face when processing information from animated representations, since a persistent representation allows learners to inspect the previous states of the animated process, thus avoiding any memory overload resulting from efforts to remember and base their inference on transient forms of representation.

These authors contend that we should distinguish between three categories of dynamic representations, each one with its own informational and computational properties: time-persistent, time-implicit and time-singular representations.

- A *time-persistent* (T-P) representation includes (somehow) the axis of time and enables learners to observe the way that one (or more) variable varies in time by presenting the current and all other values computed so far, of the variable. A velocity vs. time animated graph of an accelerated motion would be a typical example of a time-persistent dynamic representation.
- A *time-implicit* (T-I) representation, on the other hand, does not contain any time axis or any other way of explicitly involving time in the representation but it presents the way that the relationship between two variables evolves in time. Typical example is the phase space graph of a system where X and Y encode two interrelated variables (for example, one input and one output variable) and where the time factor is only implicitly (not accurately) included and represented by the way that the animated graph evolves.

- Finally as *time-singular* (T-S) representations are considered those which display the values of one (or more) variables at a given single instant of time (therefore they do not contain any historical information of the animated process). An example of this category could be a speedometer of an onscreen moving object simply presenting the instantaneous speed of the object. This type of representation contains less information compared to T-P and T-I representations.

1.2.4 Types of representations

In analyzing the various possible situations where representations can be introduced to support learning, some authors (see e.g. Presmeg, 1986) identify several main types of representations used by students:

- Concrete, pictorial imagery;
- Pattern imagery, depicting relationships;
- Icons or symbolic elements, such as numbers, expressions and formulae;
- Kinesthetic (manipulable) imagery, involving some kind of manipulation or activity;
- Dynamic imagery, including animations and also static representations structured so to express motion or transformation.

We wish to note that static representations expressing motion or transformation are more typically used in traditional learning environments than in technological ones. Animated and manipulable representations, on the other hand, have been made available by the advancements of information technology. In particular, direct manipulation on a screen helps highlighting some properties of the represented entities (Dreyfus, 1991), more than it would be possible in a pen and paper environment, where pictures need to be at least partially redrawn when they are modified. Representations to be directly manipulated by the students can often be obtained also by means of physical objects (e.g. use of real coins to learn to count and make arithmetic operations). However, changing from an inert medium to an interactive one may change profoundly the nature of the interaction (Kaput, 1995), especially since interactive means provide consistent feedback (Tall & Thomas, 1991). In this respect, technology affords stronger and more fluent means for generating mental representations than does activity with physical objects.

What kinds of representation result most suitable to support understanding and mental activity obviously varies according to several factors: the student's personal learning style and cognitive development; the level of experience in the production and interpretation of representations; the knowledge field under consideration; the complexity of the task at hand.

1.3 Multiple representations

In learning environments often more than one representation is used to teach a topic. In books texts are clarified by accompanying pictures or graphics. In the classroom the teachers explain what they are teaching by drawing a diagram on the blackboard. In multimedia learning environments animations are used with voice-over explaining what is presented. In simulation learning environments numerical in- and

outputs are used together with graphs and animations, for example, to teach the relation between braking power and braking distance.

We speak of *multiple representations* when two or more representations are used to represent real systems or processes. These representations can represent different aspects of the real system or can represent the same aspects in another way.

An illustration of a simulation-based learning environment using multiple representations is shown in fig. 1.2. The figure shows the interface of a simulation concerning the braking distance of a scooter with different begin speeds, different braking power, different masses, and different road conditions.

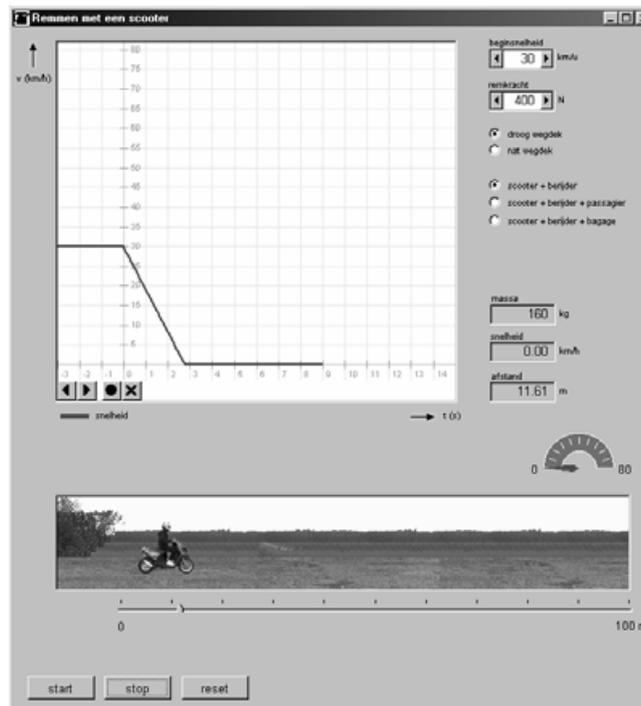


Figure 1.2. Example of using multiple representations: simulation braking distance scooter

In this simulation representations with different *representational codes* are used. The different representations represent the subject matter content in different perspectives. In the simulation window (left) *numerical input fields* are used for setting the begin speed and braking power. *Radio buttons* are used for setting the road condition and the mass of the scooter. The student can make a selection of two or three options. *Numerical output fields* are used for mass, current speed, and distance. A *graph* is used for representing the actual (real time) speed against time. With *action buttons* under the graph students can scroll the graph and store or erase the current run. Action buttons are also used to start, stop, and reset the simulation. They are located in the left bottom corner of the window. *Animations* are used for representing the braking scooter (scooter riding in landscape) and for showing the actual speed (speedometer). Beneath the animation of the scooter riding in the landscape a *slider* represents the braking distance of the scooter.

In this simulation the representations are partially informationally equivalent. For example, the magnitude of the begin speed is shown in an input field, in the graph, and in the animation of the speedometer. The

begin speed is also visible in the animation of the scooter, but the magnitude cannot be read of this representation.

The goal of this simulation is to teach the students the influence of the begin speed, road conditions and mass of a scooter on the braking distance. In this case simulation multiple representations are used because one representation would become too complex (and probably impossible to construct) to interpret.

1.3.1 Purposes of using multiple representations and the resulting benefits

The ability to use different kinds of representations is typical of human intelligence (Gagatsis, 2000). It probably derives from humans' multifaceted capability of abstractions, which leads us to consider information from different perspectives, differentiating contexts and highlighting different sets of features as essential characteristics of the knowledge or situation at hand. It is not by chance that the word "represent" in natural language has both the meaning of "giving/making a picture, sign, symbol or example of" and "act or speak for". Though powerful tools to cope with abstraction, representations are abstractions themselves.

Several kinds of representations (often called "*registers*" in the literature (Duval, 1993)) are widespread in all contexts, and have been widely used in education much before the development of Information and Communication Technologies (ICT), either in alternative or in parallel. Three primary reasons justify the creation and use of different registers to support human thinking:

- *Expressive limitations*: all representation registers have some expressive limitations, which make them more or less suitable to different situations.
- *Manipulation costs*: representation registers have different manipulation costs (in terms of time and effort), hence resulting more or less convenient for different kind of operations (for instance, pictures are more convenient to express relations, languages to support operations);
- *Individual differences*: people show a variety of different mental structures and learning styles, which make them prefer to make use of a register or the other.

There are different purposes for using multiple representations in simulation-based learning environments. Based on a classification of Ainsworth (1999b) we distinguish the following purposes:

1. *Using multiple representations when one representation is insufficient for showing all aspects of the domain*

Many domains can only be understood by showing the domain through different representations. By only showing a graph of a process, for example, the process itself is not shown. By providing a second representation showing the process that is represented, learners can give meaning to the graph.

2. *Using multiple representations when one representation should become too complex if it had to show all the information*

In a simulation-based learning environment the simulation model is frequently divided into small pieces because exploring the complete simulation model would be too complex for learners to understand. The

same applies for the representations representing the simulation model, e.g. a graph or a diagram. Often more than one representation is necessary to represent the (complex) simulation model in order to be understandable for learners. Using multiple representations allows designers to create representations that are more readable.

3. Different learners exhibit preferences for different representations

Learners have different preferences for representations. For one learner a formula is the preferred representation to understand the domain, for another it is an informationally equivalent graph. By providing multiple representations learners can explore the domain by using the representation(s) of their choice.

4. Using multiple representations when the learner has multiple tasks to perform

In many learning environments learners have to perform a number of different tasks to achieve a particular goal. The goal in simulation-based learning environments often is that learners learn to understand the underlying model by exploration. Frequently the underlying model is explored by performing different tasks on multiple representations representing some aspects of the simulation model. Mostly one representation is not sufficient to support the different tasks that the learners have to perform. Particular representations facilitate performance on certain tasks. Gilmore and Green (1984) proposed that performance would be facilitated when the form of information required by the problem matches the form provided by the notation. They called this the match-mismatch conjecture. Research by Bibby & Payne (1993) gave empirical support for this conjecture. They gave subjects instructions on how to operate a simple control panel device using (informationally equivalent) tables, procedures, or diagrams. Students had to perform a number of different tasks, including detecting faulty components and altering switch positions. There was no best representation, but there were significant interactions between task and representation. Subjects working with tables and diagrams identified faulty components faster, but those working with procedures were faster at deciding which switches were mispositioned.

5. Using multiple representations when more than one strategy improves performance

When learners can choose between multiple representations to perform a task, they may be able to compensate for weaknesses associated with one particular strategy by switching to another (Ainsworth, 1999b). Multiple representations may assist them in doing so.

6. Using the particular properties of representations

One of the most common reasons to use multiple representations in learning environments is to obtain the different computational advantages of each of the individual representations (Ainsworth, 1999). Each type of representation has its own particular properties. By using representations with different properties the representations can complement each other. Specific representations can be used to hold specific information. Different types of representations may be useful for different purposes as they differ in their representational and computational efficiency (Larkin & Simon, 1987). If the context of a problem has to be represented the best representations to use are text or pictures. Other representations like graphs or tables are not useful for this type of information. If qualitative information has to be shown, diagrams are the best representations. Diagrams can hold information that supports computational processes by indexing of information (Larkin & Simon, 1987). For showing quantitative information diagrams are less

useful; graphs, formulas, and alphanumeric representations are better representations here. Graphs show trends and interaction more successfully than alphanumeric representations. An example is the distinction between an equation like ' $y=x^2+2x+5$ ' and the informationally equivalent graph. The equation fails to make explicit the variation, which is evident in the graph. Graphs are important tools in enabling learners to predict relationships between variables and to show the nature of these relationships (McKenzie & Padilla, 1984). According to Cox & Brna (1995) the cognitive effects of graphical (external) representations are to reduce search and working memory load by organising information by location. For example, tables make information explicit and can direct attention to unsolved parts of a problem (e.g., empty cells of a tabular representation).

7. Using multiple representations to show the domain from different perspectives

For example, showing the engine of a car from different perspectives (mechanical, electrical).

8. Using multiple representations to vary the precision of the domain

One representation (e.g. an animation) could show a general picture of the domain without numerical inputs and outputs. Learners could explore the domain qualitatively with this representation (e.g., when variable A increases, variable B decreases). A second representation could show the same information with numerical inputs and outputs giving a more detailed view on the domain. The representations could be presented together or in sequence.

9. Using multiple representations to vary the domain complexity

When the domain is complex, model progression could be used to sequence the learning material from simple to complex. At first the representations could show only some aspects of the domain and later on more aspects (variables) could be introduced. Also, when using multiple representations, one representation could show the whole system and other representations could zoom in on separate aspects to vary the complexity.

10. Using multiple representations to constrain the interpretation of a second unfamiliar representation

In a multi-representational learning environment one representation can constrain the interpretation of another representation. An animation, for example, can constrain the interpretation of a graph. There is a strong tendency among learners to view graphs as pictures rather than as symbolic representations (Kaput, 1989; Mokros & Tinker, 1987). When the animation shows a car riding up a hill with constant power, it constrains the interpretation of the speed shown in a line graph. The animation can show learners that the line graph is not representing a valley but the speed of the car; they can see that the car slows down going up the hill and that it accelerates going down the hill. The purpose of the constraining representation is not to provide new information but to support the learners' reasoning about the less familiar representation (Ainsworth, 1999).

11. Using multiple representations to exploit the inherent properties of a representation to constrain interpretation of a second representation

Sometimes a more abstract or unfamiliar representations can be used to constrain interpretation of a second representation. Ainsworth (1999b) gives an example that the ambiguity permitted in the propositional representation 'the knife is beside the fork' is completely permissible. However, an

equivalent image would have to picture the fork either to the left or to the right of the knife. When the two representations are presented together, interpretations of the first may be constrained by the second.

12. Using multiple representations to promote abstraction

It is expected that when learners build references across multiple representations they acquire knowledge about the underlying structure of the domain represented. Ainsworth (1999b) refers to a study by Schwarz (1995) where the use of multiple representations generated more abstract understanding. In this study, the multiple representations were provided by different members of a collaborative pair. With a number of tasks, Schwartz (ibid.) showed that the representations of collaborating peers were more abstract than those created by individuals. An explanation of these results is that the abstracted representation emerged as a consequence of requiring a single representation that could bridge both individuals' representations.

However "although there is some evidence that multiple representations can lead children to a more abstract representation, little is known about how to design for abstraction or the conditions under which abstraction might be beneficial" (Ainsworth, 1999b).

13. Using multiple representations to support extension

"When supporting extension with multiple representations, the emphasis is placed on teaching children how their existing knowledge can be extended to new representations. For example, learners may know how to interpret a velocity time graph in order to determine whether a body is accelerating. They can subsequently extend that knowledge to see acceleration in such representations as tables, acceleration-time graphs, tickertape etc. This process can be considered extension if a learner proceeds from understanding how one representation expresses the concept to understanding how a second representation can embody the same knowledge." (Ainsworth, 1999b, p. 12).

14. Using multiple representations to teach the relations between representations

When two or more representations are presented together, the relations between those representations can be taught. By using techniques as dynamic linking and color coding relations between multiple representations can be made visible. Adding assignments can also help in teaching the relations between the representations.

15. Using multiple representations to make it possible to manipulate variables

This is a more practical use of multiple representations. Multiple representations have to be used to be able to manipulate variables for showing their effect in e.g. a graph. In the graph itself the variables cannot be manipulated. Other representation (e.g. numerical inputs and outputs) are needed for manipulation.

Ainsworth (1999a) summarizes most of the above under the three main functions which can be supported when using multiple representations in learning settings: Complement, Constrain and Construct.

- *Complement*, refers to the use of multiple representations which are complementary to each other either in the information that each conveys to the learner or in the cognitive processes that each supports. In a multi-representational environment, where complementary representations are employed, an improved performance is expected because learners can

benefit from the various advantages offered by the representations, independent of their individual differences and the specific task they face. There are several studies which indicate how informationally equivalent representations can support different inferences (Ainsworth, 1999a).

There are at least three different situations when the use of multiple representations to support complementary cognitive processes is suggested:

- When different learners exhibit preferences for different representations (a multi-representational environment allows learners with different level of knowledge and expertise to use the most familiar to them representation).
- When the learner has multiple tasks to perform (performance is enhanced if the code of the representation provides similar structuring of the information as required by the task).
- When using more than one strategy improves performance (a multi-representational environment allows learners to switch between various strategies and representations as they deem appropriate).

There are also two cases where multiple representations can be efficiently used to support complementary information:

- When using just one representation would result in a complex presentation of excessive information. In this case information can be distributed to various non-redundant representations which would allow learners to avoid any information processing overload and concentrate on different aspects of the task at hand.
 - Alternatively one could employ representations which allow a certain degree of redundancy by sharing some information. The reason for doing this is to support learners efficiently combine information from complementary representations thus reaching new interpretations and understanding of the domain.
- *Constrain*, refers to the use of multiple representations for avoiding possible misinterpretations of any unfamiliar representation. Ainsworth (1999a) identifies two possible ways for supporting this function:
 - A familiar representation can be used to constrain the interpretation of an unfamiliar one. In such a case the learner is supported to correctly interpret the semantics of the unfamiliar representation by connecting to the respective aspects of the familiar one.
 - The inherent properties of a certain representation can be used to constrain the interpretation of a more ambiguous one. Pictures, for example, by explicitly presenting the spatial relationships between objects can constrain the interpretation of statements (i.e. verbal

representations which are more ambiguous) where this relationship can not be depicted.

- *Construct*, finally, means to use appropriate multiple representations for supporting learners to develop deeper (more abstract) understanding of the domain. Multiple representations can be used to “promote abstraction, encourage generalization and teach the relation between representations” (Ainsworth, 1999a, p. 141).
 - *Promote abstraction*: by presenting to learners multiple representations of a domain it is hoped that they will effectively connect between the various representations, identify invariant characteristics, and develop understanding of the domain based on deeper structural features.
 - *Support extension (generalization)*: this is the case when learners possessing already some initial knowledge from a certain representation extend their domain understanding by exploiting that knowledge in order to gain some insight on how another representation, that conveys the same knowledge, is structured. For example, a student learning physics may already have understood how to interpret a velocity time graph and, based on this understanding, acquires new knowledge from other representations (tables, graphs, etc.) where the velocity time relationship is also embodied.
 - *Teach relations among representations*: in this case multiple representations are used simultaneously in order to guide learners to identify the relationships between them (i.e. translate between the representations). For example, in a case where a simulation is used for learning kinematics, there are present onscreen more than one representations (e.g. the moving object, a velocity-time, distance-time or acceleration-time graph, tables of related values, etc.) and the students have to spend some time focusing on the relation between them.

Petre, Blackwell, and Green (1998) give five reasons for using multiple representations. First, users can use the representations separate from each other to perform (part of) a task. To solve different problems and perform subtask different representations can be used. Petre et al. call this "the simple case". Second, "multiple identical representations" can provide different views on a domain. Third, a "bridging representation" may assist the user to understand a representation that is strong in expressing the problem, but that is less congenial to the user. The bridging representation helps the user to reason about the first. The fourth reason Petre et al. give is "heterogeneous inference" (Stenning & Oberlander, 1995). In this case the user needs to study two or more representations simultaneously to understand the problem. The

fifth reason to use multiple representations is that having to make translations between representations forces reflection beyond the boundaries and details of the separate representations. Petre et al. call this "useful awkwardness" and point out that there is little known about this process. They emphasize that translating between representations can both be provocative or obstructive, but that we cannot at present predict when this is the case.

1.3.2 Problems with multiple representations

The richness and ease of the representational possibilities offered by ICT has increased awareness of the multiple forms in which information can appear, hence widely increasing the possibilities to make use of multiple representations. As in many other fields, however, also in the case of representations "more" does not mean automatically "better". Presenting two presentations is not automatically better than one (Petre et al., 1998). In fact, all else being equal, one representation is likely to be better than two. A single representation uses less screen space, avoids problems of switching from one representation to the other and of finding the right place in each one, avoids problems of working which bit of one is equivalent to which bit of the other, and so on. And since many problems can be solved with minimal resources, using a single representation is bound to remain a popular option for some conditions. Programmers would rely on a single representation if it were sufficient, but when one is not, then users must learn how to do "inter-representational reasoning", working between the two representations, comprehending the correspondence between them, and keeping track of both at the same time (Petre et al., *ibid.*).

The amount of literature that flourished on this topic points out that the use of multiple representations does not always lead to better learning but, in fact, entails several problems (see e.g. Janvier, 1987; van Someren et al, 1998; Even, 1998; Hitt, 1998; Ainsworth, 1999; Gagatsis, 2000; Seufert, 2003). In particular, the use of multiple representations entails a preparation, in order to:

- Become familiar with the syntactic use of different registers or formal languages;
- Understand the nature, potentialities, costs and limits of each of them, so to use the most proper one in each situation;
- Make meaningful connections between them, so to be in condition to build a multi-perspective mental view of the considered topic, and avoid disorientation;
- Make translations among them. This implies a work of analysis and reformulation, since different representations usually highlight different aspects and can not be translated straightforwardly from one register to the other, since some elements usually need to be dropped and others to be added, in order to obtain a final product which results meaningful and not redundant. Translating implies also to be able both to interpret representations and to produce them.

Van der Meij and de Jong (2004) point out that when learning with multiple representations learners are faced with four tasks:

- *Understand the syntax*: First, they have to understand the syntax of each representation. They must learn the format and operators of the representations. For example, the format of a graph

would include attributes such as lines, labels, and axes. Examples of graph operators are finding the gradients of lines, minima and maxima, and intercepts.

- *Understand what is represented:* Second, learners have to understand which parts of the domain are represented. In a simulation about a car in motion, for example, the learner has to relate the slope of the line in a speed-time graph to the right property of the moving car. A relevant question would be: Does the line represent the acceleration of the car or does it represent the speed of the car? In addition, the operators of one representation are often used inappropriately to interpret a different representation. This results in common mistakes such as viewing a graph as a picture (see Mokros & Tinker, 1987).
- *Relate the representations:* Third, learners have to relate the representations to each other if the representations are (partially) redundant. They do this by linking the surface features of different representations. When a numerical representation and a graph have to be related, learners must find the corresponding variables in both representations.
- *Translate between the representations:* Fourth, learners have to *translate* between the representations, which means that they have to interpret the similarities and differences of corresponding features of two or more representations.

A number of studies have reported problems that novices have in learning to relate representations and to translate between them. Tabachneck, Leonardo, and Simon (1994) reported that novices, learning with multiple representations in economics, did not attempt to translate information between line graphs and written information. Experts, in contrast, tied graphical and verbal representations closely together. Similar results were reported by Kozma (2003), who reviewed experimental and naturalistic studies which examined the role of multiple representations in understanding science. He looked at the differences between expert chemists and chemistry students in their representational skills and in their use of representations in science laboratories. Experts coordinated features within and across multiple representations to reason about their research. Students, on the other hand, had difficulty moving across or connecting multiple representations, so their understanding and discourse were constrained by the surface features of individual representations. One of the main problems learners have with using multiple representations is translating between representations with different representational codes (Ainsworth, 1999).

A specific problem with multiple sources of information is the split-attention problem as studied by Chandler and Sweller (1991) and Mayer and Moreno (1998). When learning with separated representations, learners are required to mentally integrate disparate sources of information which may generate a heavy cognitive load (Sweller, 1988, 1989). This may leave less working memory resources for actual learning.

1.3.3 Types of student's support and the role of prior knowledge

A multi-representational learning environment is expected to give students many resources to improve their knowledge acquisition. In particular, offering different representations to describe a problem solving situation can be fruitful as it allows students to choose between them on the basis of the adopted strategy

of resolution. However, several factors seem to affect this possibility of choice to the detriment of its benefits. Two important concerns regarding student's learning in multi-representational environments proved to be: (a) how to support student's translating between the representations, and (b) how to take into account student's prior knowledge.

Ainsworth (1999) suggests that when multiple representations are used to support complementary roles and information, the learning environment should automatically perform translation between the representations if translation is necessary for learning the domain. This frees the learner from this task, which might tax working memory. On the contrary, it may be appropriate to present the representations sequentially to discourage attempts at coordination if translation between the representations is not necessary to learn the domain (e.g., when aspects of a domain can be learned separately from others). When multiple representations are used to constrain interpretation, the relations between representations should be made very explicit. This could be achieved either by *automatic translation* or *dynamic linking*. If neither representation is used for these actions, the relations between the representations should be made explicit by visual cues, such as like highlighting correspondent components. If learners are required to link the representations themselves, representations that are easily coordinated should be selected. These are representations with more or less the same modalities (Ainsworth, Wood, & Bidy, 1998). Van Labeke and Ainsworth (2002) implemented these design principles in the DEMIST learning environment. Prior knowledge of the didactical field proved also to be a critical element to take into account. As indicated by Seufert (2002), in understanding a problem solving situation by handling a representation of it, students have firstly to search and identify relevant elements and relevant relations among these elements (process called intra-representational coherence formation). In addition, if two representations are presented in parallel, e.g. a text and a picture, learners need also to find correspondence and relation between the two elements of the two given representations (inter-representational coherence formation). Generally, learners with low prior knowledge have problems caused by the cognitive overload of these processes. Furthermore, supporting learners in the processes of coherence formation by adding semantic aids seems also to be biased by their prior knowledge. Both *directive help*, that is, indicating to students relevant elements and relations among elements within each representation, and *non directive help*, that is, enabling learners to discover the relevant aspects in a self-directed manner, proved to be ineffective for students with low prior knowledge. In particular, the empirical study carried out by Seufert, shows that:

- Directive and non-directive help seem to affect different learning processes. In particular, directive help supports recall performance and comprehension.
- Learner's prior knowledge seems to interfere widely: learners with "low prior knowledge are obviously not able to use the given help for structure mapping. It seems that they would need additional instruction on the content".
- Learners with a medium level of prior knowledge can profit from the given kind of help: directive help is more suitable for recall, whereas comprehension can be supported with directive as well as non-directive help.
- Learners with high level of prior knowledge do not seem to be influenced by help of any kind.

The role of subject's prior knowledge in connection with multiple representations was investigated also by Kozma (2003). This author focused in particular on the learning of complex domains, exemplified by chemistry. The results of his experimental research highlighted differences between expert chemists and novice chemists in their representational skills and their ability to use representations to acquire knowledge. As in many psychology studies, the main findings were:

- Experts were able to cluster apparently dissimilar problems into large meaningful groups based on underlying principles, while novices tended to organize their groups on surface characteristics.
- Experts moved across different representations and used them together, while students had problems to make connections among different representations.
- Experts used different representations for different purposes.

The results of the research suggest some design principles that could increase connections among representations and support deep understanding of students:

- Provide at least one representational system with features that explicitly correspond to the entities and processes that underlie physical phenomena
- Have students use multiple, linked representations in the context of collaborative investigations
- Engage students in collaborative activities in which they generate and coordinate representations to explain the results of their studies

1.4 Representations and problem solving

1.4.1 The importance of appropriate representation in problem solving

Declarative and *procedural* knowledge are two complementary forms of knowledge. The former refers to the students' ability to declare their knowledge about the facts and concepts of the ontology they use to describe the real world system. The latter originates in problem solving activities and is related to students' ability to act as problem solver and decompose the problem in subgoals of simpler form for which the solver possesses "operators". An *operator* is the kind of action which can be applied on available data at a certain problem state in order to transform it into another problem state. So the solution of a problem can be considered as a sequential application of appropriate operators.

Generally the course towards the solution of a problem can be described as a sequence of states (problem states) which constitute the problem space. A state is a representation of the problem in some point at this course towards the final state which is considered as the solution. Successful problem solving depends heavily on using such problem representation so that appropriate operators can apply.

Research has indicated that selecting the appropriate problem representation is a skill that distinguishes novices from domain experts. When novices are introduced in a domain they tend to focus on the superficial features of the representations and therefore develop an initial understanding different from the one that characterizes experts' performance and which is based on the more abstract domain relevant principles. For example Chi, Feltovich and Glaser (1981) have illustrated how novice students

categorized physics problems based on surface features while experts could classify the same problems according to deeper thematically relevant characteristics. Anderson (1995) emphasizes that this change in problem representation underlies the acquisition of expertise in a number of domains including computer programming (experts think of a specific code structure, for example iteration, in terms of abstract language independent from the superficial characteristics of any specific programming languages).

1.4.2 Affordances⁴ (roles) of representations

Representations are generally acknowledged to be powerful tools to support problem solving, both when provided by the teacher to scaffold the activity of weaker solvers, or when constructed by the solvers themselves to support their own reasoning. They do not simply convey to learners available information but by structuring this information appropriately they may serve various roles during the learning process.

From one or the other of these points of view, they show different affordances, such as:

- giving a different description of a problem situation, which results more meaningful for the problem solver, (e.g. a visualization depicting the situation and the data of a given text, in early arithmetic problem solving, or a diagram highlighting the relations between a problem's elements);
- summarizing the available information (e.g. by drawing a figure in geometrical problems);
- structuring the reasoning activity (e.g. by means of schemas, tables and diagrams);
- unblocking the mental activity of weaker students (Dettori & Lemut, 1995);
- supporting conjectures (e.g. by depicting the possible evolution of some situation);
- supporting the construction of proofs (e.g. by representing intermediate steps of a solution process) (Callejo, 1994);
- limiting abstraction (e.g. by drawing geometrical constructions, or by writing symbolic formulae to support algebraic processing);
- encouraging the self-explanation process as an effective metacognitive strategy that helps learners to reach a deeper understanding. In particular, Ainsworth & Loizou (2003) observed a greater self-explanation effect in students using diagrams rather than plain texts.

1.4.3 Representational competence

Computerized learning environments can assist students in making cross-translations between different symbol systems through the display of multiple coordinated representations (Ardac & Akaygun, 2004). Multiple symbol systems can provide useful external representations for novices that experts can provide

⁴ The term affordance was first used by Gibson (1979), who defined it as «a property of things in some environment which is relevant with respect to the action that an agent has to accomplish in that environment and which constitutes, therefore, an opportunity for that action to take place». This definition was later criticized by other authors who gave different definitions of this term, giving more attention to different aspects of this concept (see e.g. Vera & Simon (1993): «Affordances are in the head, not in the external environment»). Such different definitions appear to subsume different ideas of internal and external representations. In this report, we use the term affordance as originally defined by Gibson.

by themselves. Computers have the capability of presenting information in different, but coordinated, symbol systems (Kozma, 1991). All these multiple ways for coding and presenting information in learning settings call for attention on the ability of the students to efficiently and fruitfully handle information and knowledge in the form of multiple representations. Relative to these concerns are the notions of "representational" competence and meta-representational" competence.

According to Kozma and Russell (1997), representational competence, that is, expert performance in handling representations, can be defined in terms of a set of representational skills which allow one to represent something in multiple ways. In the literature this concept refers, more extensively, to the process of constructing representations, as well as to deal successfully with the given ones in a problem solving or learning situation and, if necessary, to translate any of them into a form which is more suitable to the task at hand.

The topic of representational competence, and approaches to improve it, are deepened in Chapter 2.

1.5 Theories and models of learning in multimedia environments

1.5.1 Theoretical considerations

Theoretical advances on the use of representations for learning, such as the theories on computational effectiveness, dual coding, cognitive load and multimedia design, offer to the researcher significant tools for exploring the role of the representations from various viewpoints.

Theories of *computational effectiveness* have specific attention for the inferences learners make in order to understand a task or domain from a representation. The argument here is that some representational codes facilitate some inferential (learning) processes better than others. In their classical article Larkin and Simon (1987), for example, found that with diagrammatic representations in physics (in this case a "pulley problem") 'search' processes are much easier performed than with textual representations. This idea, that different representations that have the same "content" can still offer different processing opportunities is called "computational effectiveness" (Larkin & Simon, 1987) or "*specificity*" (Stenning & Oberlander, 1995). For example, graphical representations are often seen as computationally more effective than text in communicating material as evidenced in such advantages as *locality* (Larkin & Simon, 1987), *emergence* (Kulpa, 1995), and *inexpression* (Stenning & Oberlander, 1995) but specific advantages of textual representations are also reported (Stenning & Oberlander, 1995). Other studies that illustrate the relation between representation and inferential, learning, or problem solving processes are Zhang and Norman, (1994), Scaife and Rogers (1996), Cox and Brna (1995), and Ainsworth and Loizou (2003). An initial overview can be found in de Jong et al. (1998).

Dual coding (Paivio, 1990), as already mentioned, is the principle which proposes that texts are processed and encoded in the verbal systems whereas pictures or graphics are processed both in the image and verbal systems. Dual coding was seen as a way to explain why memory for pictures may be better than memory for texts. Also, if well designed, the combination of text and pictures should lead to better results than the use of one representation; for instance, learners may remember a text better when it is simultaneously presented as a visual text and an oral text. Using the capacity of both memory systems leads to *more* information being processed than when using only one of the systems. In addition, it also

yields *better* results because the simultaneous processing renders the connectivity of the two systems. This referential connectivity in turn contributes to the construction of a strong mental model (Paivio, 1990; Mayer, 1999).

Cognitive load theory (Yeung, Jin & Sweller, 1998) assumes a limited capacity working memory. Following cognitive load theory instructional procedures should (1) prevent cognitive overload, (2) reduce the amount of cognitive processing not directly relevant to learning and causing *extraneous* cognitive load, and (3) promote cognitive processing directly relevant to learning (i.e., schema construction and automation) and causing *germane* cognitive load. The theory indicates that presenting information in more than one representation houses two dangers: redundancy and split attention effects (Sweller, 1994). The *redundancy hypothesis* predicts that offering the same information twice requires the double processing which takes up unnecessary memory space. *Split attention effects* occur when learners must attend to different sources of information simultaneously. According to Sweller (ibid.), this obstructs learning because the learner then has to process two distinct information sources at the same time. A specific case in using more than one representation concerns the use of more than one *modality*. The so-called '*modality effect*' states that whenever pictorial information is accompanied by an explanation, the explanation should be presented in an *oral* modality rather than in a written, *visual* modality. With spoken text the visual channel is not overloaded. As a result, extraneous load is decreased compared to the situation in which text is presented visually. A large number of studies have found superior learning results when visual text in multimedia instructions was replaced with spoken text.

Multimedia design theories focus primarily on the effectiveness of multiple-representational codes. Ainsworth (1999; Ainsworth, Bibby, & Wood, 1998) recommends the use of multiple representations so that the information varies between representations in the multi-representational system, and each representation serves a distinct purpose. According to multimedia design theory, multiple external representations are commonly used for one of three main purposes: (1) to support different ideas and processes, (2) to constrain interpretations, and (3) to promote deeper understanding. The purpose of the multiple representations affects all design decisions, such as the representational code that is used for each representation, the amount of representations, the redundancy between representations, the possibility to make automatic translations between representations, and, finally, the ordering and sequencing of the presentations. For instance, in order to promote deeper understanding and to facilitate abstraction, multimedia design theory states that there should be a minimum number of representations to highlight the invariances, a maximum amount of redundancy, a scaffolded option for automatic translation, and a co-presence of all representations.

Of the theories mentioned above, the computational effectiveness approach concentrates on information in a single representational code, dual coding and cognitive load theory cover both single and multi-representational codes, and the multimedia design theories focus on multi-representational codes. What is mostly absent in the theories proposed is an explanation in terms of affordances that single or multi-representational codes offer for concrete learning processes. The computational effectiveness approach presents some first results in this respect, the dual coding and cognitive load theories do not address specific learning processes in detail, and the multimedia design approach concentrates on processes that relate and integrate different representations.

Of special importance, within the corpus of all related theoretical considerations, are the efforts made towards modeling the way that humans cognitively process the external representations in order to develop internal ones. These theories situate themselves at the very core of our understanding about the interaction between learners' internal and external representations. In the following two sections we present two prominent cognitive models of multimedia learning. We believe that the issues addressed by these models and their subtle but essential differences give rise to very interesting research questions.

1.5.2 A cognitive model of multimedia learning based on dual coding

There is strong evidence that the use of multiple representational codes can (under certain conditions) significantly enhance learning outcomes as evidenced in problem solving activities (Mayer, 2003; Mayer & Moreno, 2002; Najjar, 1995). One major condition is that the code systems used for representation should support effective dual coding of information as prescribed by dual coding theory (Paivio, 1986).

Dual coding theory postulates that incoming information is processed by a double cognitive circuitry where one channel is devoted to verbal information (linearly organized) (text, speech, narration) and another channel to the process of visual information (spatially organized) (images, graphics, etc.). In a series of experiments Mayer and colleagues found that pictures support comprehension when texts and pictures are explanatory, when verbal and pictorial content are related to each other, when verbal and pictorial information are presented closely together in space or time and when individuals have low prior knowledge about the subject domain but high spatial cognitive abilities (Mayer, 1997). Clark & Mayer (2003) indicate that the use of narrated commentary simultaneously with presented animation (as opposed to the use of on screen written comments accompanying animation) can enhance learning since the two code systems address different channels. Based on these evidence Clark & Mayer (ibid.) present a cognitive model emphasizing the role of the dual channels (visual and verbal) and the three fundamental cognitive processes (select, organize, integrate) for building mental models (i.e. internal representations).

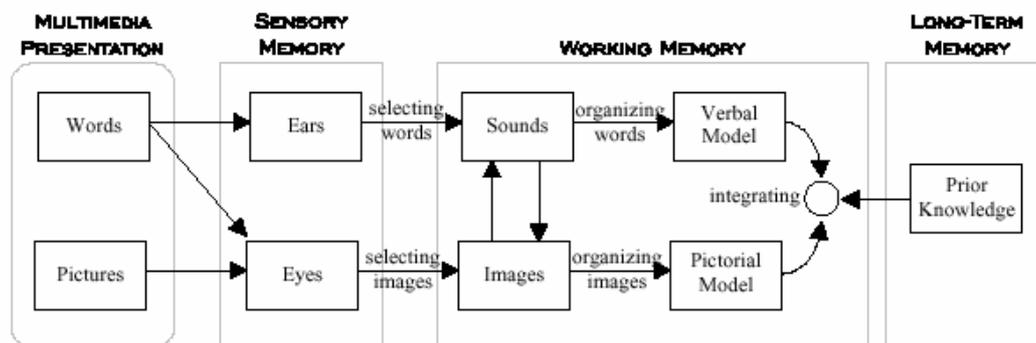


Figure 1.3. A cognitive model of multimedia learning based on dual coding theory (Mayer, 2003)

According to the model, better conditions for learning are created when external stimuli address both the verbal and the visual channel (for example, when text explanations are accompanied by appropriate images) without however overloading the visual channel (as in the case, for example, when fast advancing animated images and written messages are presented on screen simultaneously).

Stimuli from external representations enter learners' cognitive system and undergo a three phase processing (see fig. 1.3 from left to right).

- *Selection*: stimuli are filtered and some of them are selected for further processing (so drawing learners' attention to the important aspects of the external representation is crucial).
- *Organization*: verbal and visual elements are being organized in learners' working memory so that two distinct models (a verbal and a pictorial one) are developed.
- *Integration*: the two cognitive structures (verbal and pictorial models) and learners' prior knowledge are integrated to produce new knowledge trails which are stored in long term memory.

So, this cognitive model is strongly based on the notion of the dual coding of information in learners' cognitive system.

Clark & Mayer (2003) emphasize that good design of multimedia e-learning environments should provide support for learners to:

- (a) *Select* what is important information for learning. For example, designers can use graphical elements (such as color, arrows, etc.) to highlight and draw attention to important onscreen information.
- (b) *Manage* the limited capacity of the working memory in order to more efficiently rehearse information coming from auditory and visual sensory channels, and
- (c) *Integrate* information in verbal and pictorial mental models with pre-existing knowledge in long term memory.

For supporting the learners' effective cognitive process of information these authors propose a series of design principles that the instructional designer should apply in order to provide better learning conditions when using multiple and multimodal representations.

- *Contiguity* principle: place corresponding verbal information (text) and visual information (images and graphics) close enough, so that the cognitive mapping between verbal and visual elements is efficiently supported.
- *Modality* principle: present verbal information using the aural modality (i.e. use narration) rather than the visual modality (on screen text). This principle should be applied especially when dynamic visuals (animation) and respective explanatory verbal information are presented to learner simultaneously and the presentation conditions do not permit the learner to adapt the speed of presentation. Presenting verbal information in the form of narration allows for dual coding of the information without overloading the visual channel, thus providing better learning conditions.
- *Redundancy* principle: avoid presenting verbal information in both textual and narrative form especially when graphics are presented at the same time. Such a presentation would overload visual channel thus hurting the dual coding of information. Applying this principle, however, should be avoided in many special situations (for example, when there are no images present

or the learner has ample time to efficiently process the multiple forms of presented information or when presenting written text is critical such as in the case where the learner faces difficulties to understand spoken words).

- *Coherence* principle: beware of the use of what you might think as interesting (though extraneous) material for learning (such as entertaining stories, background music or detailed descriptions). Including such material can impoverish the learning outcomes.
- *Personalization* principle: the way that you address your learners matters! Using conversational style in your text (e.g. using first or second person friendly style instead of the typical third person formal style) provides better learning conditions.

1.5.3 A cognitive model supporting the notion of structure mapping

Schnotz & Bannert (2003) also present a cognitive model for multimedia learning, introducing however a different perspective regarding the way that multimodal information is integrated in learners' cognitive system. They question the parallelism between text processing and picture processing assumed in Mayer's model, because texts and pictures use different sign systems resulting in fundamentally different forms of representations which are referred to as descriptive and depictive representations and which have different uses for different purposes: Whereas descriptions are more powerful in representing different kinds of subject matter, depictions are better suited to draw inferences (cf. Johnson-Laird, 1983; Johnson-Laird & Byrne, 1991).

According to Schnotz and Bannert (ibid.), text comprehension and picture comprehension are goal-oriented processes of the human cognitive system, in which the individual actively selects and processes verbal as well as pictorial information in order to construct mental representations that seem to be suited to cope with present or anticipated demands. On the basis of an experiment they conclude that dual coding is not a satisfactory basis for the development of a comprehensive theory of text and picture comprehension. The dual coding theory does not take into account that a subject matter can be visualized in different ways and that the form of visualization affects the structure of the mental representation. Furthermore, it assumes that adding pictures to a text is generally beneficial for learning, that is, it neglects that pictures can also have negative effects because a picture may interfere with mental model construction.

Based on the distinction of descriptions and depictions as fundamentally different forms of representations Schnotz and Bannert (2003) argue for an alternative model of learning from text and pictures. They call it an integrated model of text and picture comprehension. This model distinguishes between descriptive (textual) and depictive (imagery) information which enters learners' brain using two distinct channels (see figure 1.4 from down upwards). Information undergoes appropriate organizational processes in order for surface structures at first (for example text surface representation) and deeper structures afterwards (for example propositional networks and mental model) to be developed.

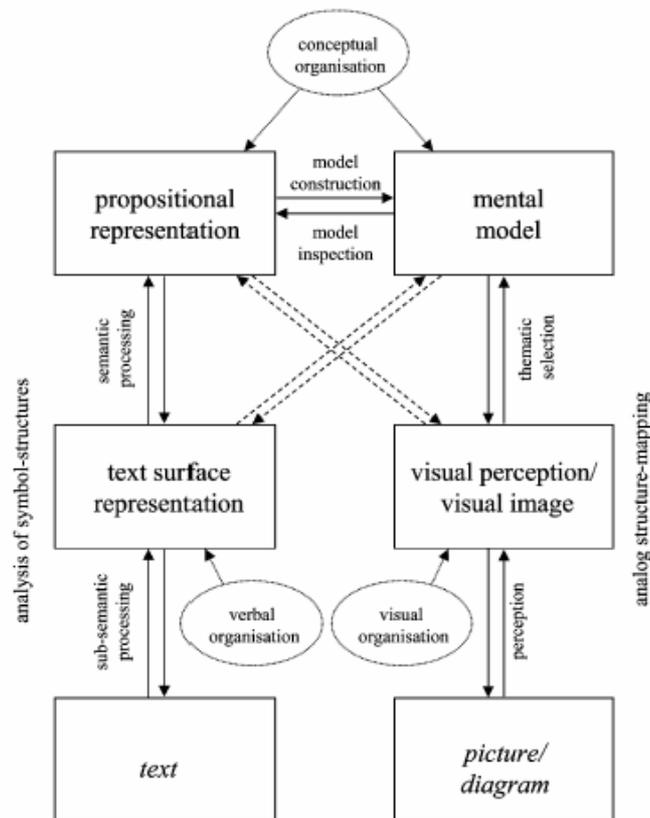


Figure 1.4. The Schnotz and Bannert (2003) cognitive model of multimedia learning

Schnotz and Bannert's model considers picture comprehension as a process of analogical structure mapping. According to the researchers one significant characteristic of the stimuli processing is that the structure of external visual representations (images) is mapped onto the structure of internal respective ones (mental model) and so efficient learning in multimedia environments depends on the use of appropriate images (structure mapping effect). Another characteristic is that the two structures of propositional representation and mental model interact, which means that there is continuously a mental model construction from propositional networks and reversely a model inspection based on the propositions developed based on the mental model.

The model allows us to explain why the form of visualization used in a picture affects the structure of the mental model created during picture comprehension. The surface structure of the picture is mapped (at least partially) onto the structure of the mental model and, thus, affects the computational efficiency of this model for specific tasks. The model allows us to explain why adding pictures to a text is not always beneficial, but can also have detrimental effects on the construction of task-appropriate mental representations. From the perspective of practice, the finding of the Schnotz and Bannert study emphasize that in the design of instructional material including texts and pictures the form of visualization used in the pictures should be considered very carefully. The question is not only which information is to be conveyed. One must also ask whether the form of visualization used in the picture supports the construction of a task-appropriate mental model.

1.5.4 An expanded (cognitive – motivational) model of multimedia learning

The models presented in the two previous sections focus only on the cognitive aspects of multimedia learning. Elements of a multimedia environment, however, can also possess a non-cognitive but motivational quality. Advances in current research call for attention on the motivational aspects of learning too (e.g. Astleitner & Wiesner, 2004), emphasizing that models of multimedia learning should also account for the way that specific representational codes and representations may motivate students.

Several studies have already explored the motivational function of multimedia instructional elements (e.g. Tang & Isaacs, 1993; Astleitner & Leutner, 2000; Keller, 1997) identifying differences in their motivational value. For example, video information is more appealing to users compared to audio due to its dynamic pictures and colors (Tang & Isaacs, 1993). Demetriadis, Triantafyllou & Pombortsis (2003) also indicate that visual dynamic media (animation and digital movies) capture students' interest and generate subjective feelings of better learning while digital movies can enhance the perceived authenticity of the educational setting something that also increases students' interest.

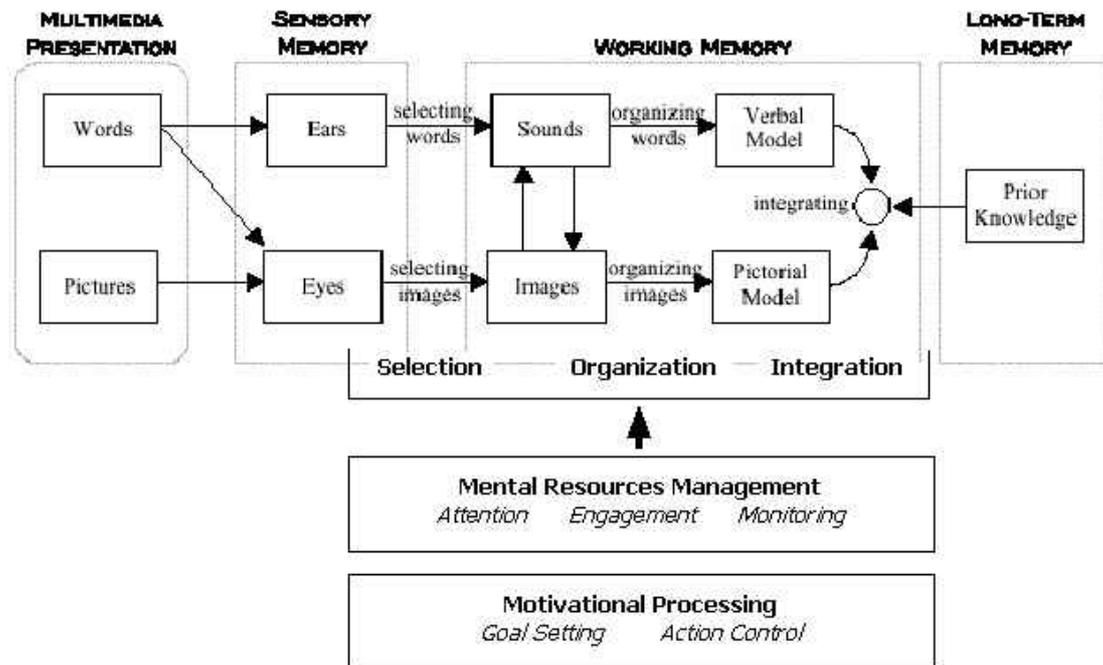


Figure 1.5. The expanded cognitive-motivational model of learning in multimedia environments (adapted from Astleitner & Wiesner (2004))

Astleitner and Wiesner (2004, p. 11) identify at least three reasons why motivational elements are important: "(a) motivation is influencing learning significantly, (b) motivational processes need memory resources and therefore increase or decrease cognitive load, and (c) there is a more or less direct connection between cognitive and motivational variables".

These authors suggest that Mayer's (2003) cognitive model of multimedia learning should be expanded to integrate also motivational aspects of memory usage and learning. In this expanded model (see figure 1.5)

the cognitive activities (selection, organization and integration) and, therefore, the development of internal knowledge models (verbal and pictorial) are influenced by the processes of mental resources management (attention, engagement and monitoring). These processes in turn are controlled by motivational processing functions (goal setting and action control).

The attention and engagement parameters represent the capacity of learner's working memory and the number of mental activities, respectively, which are devoted to a certain task within a given period of time. Monitoring is a feedback loop function that causes changes in attention and engagement, based on the evaluation of the success of the task related mental activities. Goal setting is a decision taking process aiming to identify the most favorable combination of task related expectancies and values and set this specific task as an objective for fulfilling. Finally, action control is the process of "protecting" a given intention for fulfilling a certain goal, from alternative counter-productive intentions.

Overall, the model makes explicit that the characteristics of the representations used in a multimedia instructional environment (modalities, representational codes, etc.) may affect students' goal setting and action control processes thus increasing or decreasing working memory resource allocation (attention and engagement in the task) which, in turn influence the efficiency of their cognitive activities.

1.6 External representations in collaborative learning

We distinguish essentially three different perspectives on the relationship between external representations and collaboration.

- Collaboration as a tool to improve individual processing of the external representation.
- External representation as a product of collaborative processes.
- Using external representation to facilitate collaboration and collaborative learning.

1.6.1 Collaboration as a tool to improve individual processing of the external representation

Theoretically, this tradition is rooted in work on the individual processing of external representation as elaborated in the first part of this chapter. In this case, collaboration upon the representation is a tool to improve cognitive information processing of the individual. There is surprisingly little research on how collaboration can be used to better process ready-made external representations, like, e.g., computer animations. Typically, external representations are used to provide a representation of e.g., scientific phenomena and the background knowledge necessary to explain the phenomena under consideration. Small groups are set up to discuss two or more different theories to explain a phenomenon (e.g. Bell, 2004).

1.6.2 External representation as a product of collaborative processes

In this case learners are the constructors or "designers" of information structures (e.g. Suthers & Hundhausen, 2003)). Typical research questions are if learners collaborate better and learn more when they are supported by a content-specific as compared to a content-independent external representation tool (Fischer, Bruhn, Gräsel & Mandl, 2002). Similarly, the instructional use of collaborative hypermedia

design is based on the assumption, that the co-creation of informational structures improves elaboration and understanding (Zahn & Finke, 2003). Beyond research on collaborative learning with ERs (i.e., collaborators solve problems together ideally with a joint focus of attention), there is also research on cooperative learning with ERs (i.e., cooperation partners divide the tasks but help each other in accomplishing them). In a prototypical scenario, one learner would create an external representation which then is used and modified or criticized by another learner (e.g., Janetzko & Fischer, 2003). In the same line of thinking, ERs constructed by one group of learners can be used as a basis for further collaborative learning by other groups (e.g., Scardamalia & Bereiter, 1994).

With respect to what is represented externally, empirical studies emphasize domain-specific knowledge on concepts and procedures as well as more domain-general strategic knowledge (like, e.g., on scientific reasoning).

1.6.3 Using external representation to facilitate collaboration and collaborative learning.

Some approaches focus on how external representations can be used to facilitate collaboration and interaction. Theoretically, these approaches are often rooted in the field of cooperative learning or collaborative knowledge building. From this perspectives, external representation serve the function to facilitate the mechanism of individual cognitive change through specific interaction processes. From a distributed cognition perspective, external representation in a collaborative situation can be conceptualized as joint problem space (Teasley & Roschelle, 1993), that help learners to coordinate their activities in collaboratively solving a problem. From a Piagetian perspective, external representation of prior knowledge states might help to identify similar or dissimilar preconceptions (Dillenbourg, 2002). The latter can be regarded as productive in the sense of evoking socio-cognitive conflict and its resolution - aspects that are from this perspective seen as crucial for conceptual change to happen. Similarly, externalisation by constructing external representations together might foster productive conflict (Nastasi & Clement, 1992). From a Vygotskian perspective, external representation may serve in creating a Zone of Proximal Development in the sense that they enable learners to participate effectively in a type of discourse that would be somewhat above their actual level of competence. This might be accomplished, e.g., by using external representations of processes of learning and of collaboration that guide and constrain interaction and cognition (e.g., Kollar et al., 2004). Typically, the represented cognitive, metacognitive or collaborative process should be internalized at least in part. There are, for example, several studies on guiding the process of collaborative argumentation by specific types of external representation (e.g., Bell, 2004; Kirschner et al., 2003; Stegmann, Weinberger, Fischer & Mandl, 2004). A central goal of the according instructional approach is, that students not only elaborate the domain concepts more deeply through this guided discussions (representational guidance, Suthers & Hundhausen, 2003), but that argumentative knowledge and skills should be acquired as well (Kollar et al., 2004). Recently, research on feeding back information on ongoing group processes to facilitate further interaction has been conducted, e.g., with a focus on the concept of group awareness.

From this third perspective, factual knowledge on characteristics of the group members as well as procedural aspects with respect to actual or optimal group processes are typically represented externally.

1.7 Degrees of freedom in interacting with the external representation

When learners interact with external representations, they can be provided with different degrees of freedom (or degrees of coercion, to put it the other way round, Dillenbourg, 2002) with respect to their learning processes. The ways by which external representation reduce degrees of freedom may be characterized by distinguishing affordances and constraints (Greeno et al. , 1998).

(1) *External representation may just provide affordances* ("Aufforderungscharakteristika"), without any built-in characteristics to make sure that the external representation is actually used in the intended way. An example for a high degree of freedom, is to provide individual learners with domain-specific concept cards in a computerized concept mapping tool (a) without a mechanism to ensure that students fill in these cards and graphically relate them to other concept cards and (b) without controlling, if the learner's entries and the relations drawn actually make any sense (Gräsel, Fischer & Mandl, 2001). We will refer to this use of external representation as the *affordance function of an external representation*.

(2) *An external representation can reduce the degrees of freedom substantially* by constraining the types of learning activities that can be performed. An example can be seen in the approaches on structured communication interfaces, where the types of interactional contributions in a computer-mediated collaborative environment are limited by the system and a selection between the available communicative moves is enforced by the system (e.g., Baker & Lund, 1997). An external representation may control activities and their sequence in the learning process even more in the sense of a stencil. For example, when a simulation-based representation tool requires the learner to fill in several variable values in a specific sequence before it performs a new step, or if a graphical representation of a Toulmin-like argument structure enforces learners to write something in each text field (claim, data, warrant, qualifier) before an argument can be submitted to a discussion (Stegmann, Weinberger, Fischer & Mandl, 2004). We refer to the use of external representation to guide learning and collaboration processes by limiting the possible activities as *constraining function*. In the extreme case, when this constraining function only leave the learner with one degree of freedom (do what the external representation suggest or do nothing at all), we might even refer to it as *enforcing function*.

1.8 Conclusions

From what has been presented so far it should have been made clear that the use of external representations for learning in multimedia environments is not a simple issue that should go without significant consideration from instructional designers. Instead it has been illustrated that representations may possess various properties, serve different roles, appeal to diverse learners' capabilities, and function in multiple ways towards the provision of an effective and efficient learning environment.

Our effort in this chapter focused on presenting the fundamental theoretical principles which shape the field, that is the most significant concepts and methods emerging from our current level of knowledge. We believe that it would be useful to also display these core issues in the form of a list that would assist any interested instructional designer to critically review and assess a multi-representational learning

environment with the purpose of identifying points susceptible to improvements and possible redesign (See Table 1.1).

How to use Table 1.1 (a note for multimedia designers): The following table provides a guiding overview of the issues presented in this chapter to support designers easily identify and address them when reviewing their instructional multimedia software. The interested reader should take into consideration each entry of the table, refer to the corresponding text in the body of this chapter and elaborate (preferably writing a few sentences) how the specific issue is exactly realized in the multi-representational system under analysis.

Table 1.1 A guiding overview of the theoretical issues

Theoretical Issue	What to consider
1 Multiple Representations	What are the representations used in your learning environment? (Provide a brief description of the interfaces used and present an annotated screen dump)
2 Description of the representation, the representational code & the modality	How could the representations be described in terms of : <ul style="list-style-type: none"> • The represented world • The representing world • What representational codes are used? • What modalities are used? • Aspects of the represented world being represented • Aspects of the representing world which are doing the modeling • Correspondence between the two worlds.
3 Types of representations to be used by students	How could the exact type of representation be described? <ul style="list-style-type: none"> • Concrete (pictorial imagery) • Pattern imagery (depicting relationships) • Icons or symbolic elements (numbers, expressions and formulae); • Kinesthetic (manipulable) imagery (involving some kind of manipulation or activity) • Dynamic imagery (including animations and

- also static representations structured so to express motion or transformation)
- Other (describe)
- 4 Equivalence of representations Are the representations used:
- Non-equivalent,
 - Informationally equivalent, or
 - Completely equivalent?
- 5 Affordances (roles) of the representations What are the affordances (roles) that the representations are expected to provide?
- Describing a given text
 - Summarizing the available information
 - Structuring the reasoning activity
 - Unblocking the mental activity of weaker students during problem solving
 - Supporting conjectures
 - Supporting the construction of proofs
 - Limiting abstraction (e.g. by drawing geometrical constructions, or by writing symbolic formulae to support algebraic processing).
 - Others (describe)
- 6 Reasons for using representations of a real system What are the most significant reasons for using representations of the system?
- Objects are not always (easily) perceivable or available
 - Experiments to determine the structure of reality are not always possible
 - The duration of processes is sometimes too long or too short, and
 - Using real objects can involve the risk of damage and personal safety.

If using simulations, what are the most significant reasons for using them:

- Simulations can visualize processes that would otherwise not be observable, like very small scale processes
- Simulations can enable experiments that would otherwise be too expensive
- Simulations slow processes can be accelerated and very fast processes slowed down to speeds that are comprehensible for learners
- Simulations can be used for training on systems that would otherwise be too dangerous to work with
- Simulations can provide an environment for learning independent of time and space
- Simulations can be used for training on systems in which, in real life, an inexperienced trainee could cause dangerous situations
- Simulations can be used to create ideal or abstract situations that do not occur in the real world.

7 Dimensions of representations: How would you comment the following dimensions of the used representations in the environment?

- Perspective
- Precision
- Specificity
- Complexity (granularity, generality, and scope)

8 Dynamic representations Are there any dynamic representations used in the system?
If animations are used how would you describe them?

- Time-persistent
- Time-implicit
- Time-singular

- 9 Theoretical considerations Have any of the following theories been taken into account when selecting and designing the representations?
If yes, how? If not, then could their consideration lead to a more efficient redesign?
- Computational effectiveness
 - Dual coding
 - Cognitive load theory (redundancy hypothesis & Split attention effects)
 - Multimedia design theories
 - a. *to support different ideas and processes,*
 - b. *to constrain interpretations*
 - c. *to promote deeper understanding*
- 10 Cognitive Models Have the principles and considerations emerging from the following cognitive models taken into account when selecting and designing the representations?
If yes, how? If not, then could their consideration lead to a more efficient redesign?
- A cognitive model based on dual coding
 - a. *Supporting the Selection, Organization & Integration of the information*
 - b. *Applying the design principles of Contiguity, Modality, Redundancy, Coherence and Personalization*
 - A cognitive model promoting the notion of structural mapping
 - a. *Include in the material appropriately structured images*
- 11 Purposes of using multiple representations and the resulting benefits Which of the following purposes / reasons were important for you and guided significantly the design and utilization of multiple representations?

(A)

- Expressive limitations
- Manipulation costs
- Individual differences

(B)

- Using multiple representations when one representation is insufficient for showing all aspects of the domain
- Using multiple representations when one representation should become too complex if it had to show all the information
- Different learners exhibit preferences for different representations
- Using multiple representations when the learner has multiple tasks to perform
- Using multiple representations when more than one strategy improves performance
- Using the particular properties of representations
- Using multiple representations to show the domain from different perspectives
- Using multiple representations to vary the precision of the domain
- Using multiple representations to vary the domain complexity
- Using multiple representations to constrain the interpretation of a second unfamiliar representation
- Using multiple representations to exploit the inherent properties of a representation to constrain interpretation of a second representation
- Using multiple representations to promote abstraction

- Using multiple representations to support extension
- Using multiple representations to teach the relations between representations
- Using multiple representations to make it possible to manipulate variables

(C)

(Please notice that list C is, to a certain extent, a differently organized version of most purposes/reasons presented above in list B. You may refer either to list B or C, as you like).

- Complement
 - a. Learners exhibit preferences for different representations
 - b. Learners have multiple tasks to perform
 - c. Learners have to use more than one strategy
 - d. Using just one representation would result in a complex presentation of excessive information
 - e. Employ representations which allow a certain degree of redundancy by sharing some information
- Constrain
 - a. A familiar representation can be used to constrain the interpretation of an unfamiliar one
 - b. The inherent properties of a certain representation can be used to constrain the interpretation of a more ambiguous one
- Construct
 - a. *Promote abstraction*
 - b. *Support extension (generalization)*
 - c. *Teach relations among representations*

- (D)
- The simple case
 - Multiple identical representations
 - Bridging representations
 - Heterogeneous inference
 - Useful awkwardness
- 12 Problems with multiple representations Do you expect (or have assessed somehow) the students to face the following difficulties when working with the representations?
- Understanding the syntax
 - Understanding what is represented
 - Relating the representations
 - Translating between the representations
- 13 Types of support Have any of the following possibilities been utilized to support students to cope with multiple representations?
- Automatically perform translation
 - Present the representations sequentially to discourage attempts at coordination (if translation between the representations is not necessary to learn the domain)
 - Provide at least one representational system that has features that explicitly correspond to the entities and processes that underlie the physical phenomena being taught
 - Have students use multiple, linked representations in the context of collaborative, authentic, laboratory experiments
 - Engage students in collaborative activities
- 14 Representations and collaborative learning In which of the following ways have representations been used in activities of collaborative learning? (If collaborative learning is of relevance)

- Collaboration as a tool to improve individual processing of the external representation
 - External representation as a product of collaborative processes
 - Using external representation to facilitate collaboration and collaborative learning
- 15 Degrees of freedom in interacting with the external representation How would you categorize the representations in relation to the degrees of freedom they offer?
- They just provide affordances
 - They significantly reduce the degrees of freedom

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CHAPTER 2: Representations and problem solving

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Abstract. Problem solving is an important practice in education, since it allows students to give meaning to concepts by contextualizing them. The literature reports evidence that developing problem solving abilities strongly depends on developing problem representation abilities. This, in turn, appears to be connected with students' ability to understand not only the problem's explicit information, but also the implicit one, and to connect both to their previous knowledge. Different roles in problem solving appear to be played by representations which are given with the text of problems and representations which the solvers build by themselves to support their activity during problem solution. Representations play a crucial role in problem solving in particular when abstract concepts are handled, as it is the case with mathematical problems. Here, particular attention should be paid at didactical level, since students easily assimilate abstract concepts with their representations, hence finding even more difficult than in other disciplines the use of multiple representations of a same concept. Finally, several authors address, in different ways, the issue to help problem solvers to improve their representational abilities. Despite the diversity of approaches, most of these studies highlight the need to make the students acquire critical knowledge and critical awareness of the nature and affordances of representations.

Keywords: problem solving, abstraction, interpretation of representations, construction of representations, learning.

2.1 Characterization of problem solving

Assigning to the students problems to solve is widely used in education, and has always been considered fruitful in promoting learning, since solving problems allows one to give meaning to abstract concepts by contextualizing them; moreover, it motivates the students to learn theoretical results and to apply them into practice.

The expression *problem solving*, when used in a (traditional or ICT-based) didactic environment, does not mean simply asking students to solve some problems. It refers to an approach to learning where theoretical concepts are introduced by means of the solution of problems related to situations somehow familiar to the student's experience, which allows a contextualization of this activity (Boero, 1992). Problem situations can be considered familiar with students' experience not only when they correspond to life situations, but also when they refer to fictions which are familiar to the students (De Bock et al 2003).

A problem solving approach can be fruitfully applied at any school level. This holds true for most disciplines, though often this expression is associated mostly with scientific ones, in particular with mathematics, which is the topic where students first tackle problems in elementary schools. Mathematics is, as a matter of fact, the field where most of the research on problem solving is currently carried out, but certainly not the only one. The literature reports studies related to problem solving in many school

disciplines, such as Chemistry (e.g., Sutherland, 2002), Physics (e.g., van Someren et al., 1998, pg. 67 and 263), and many others; moreover, also not curricular topics can be considered and analysed as problem-solving activities, such as design (Nelson, 2003), learning (Dettori et al., 2004) or scientific research (Cheng, 1999).

Problems which are meaningfully tackled in school can take very different forms:

- standard problems completely described and containing all necessary data;
- non-standard problems, where the solver has to take into consideration real world constraints not explicitly mentioned in the text (Nesher & Hershkoviz, 1997);
- problems without explicitly specified data (e.g., without numerical data, in mathematical problem solving), where the solvers are requested to describe the logical steps of their solutions, rather than producing a well-defined result (these problems contribute to stimulate the development of expressive abilities);
- open or semi-structured ones (Mason, 1992), which can even require the solvers to develop their own solving strategy, rather than simply apply some known processes (this type of problems, in particular, stimulates students to look deeply into tasks at hand, offers occasions to connect with each other different disciplines, and constitutes a good preparation to tackling real life problems).

What allows us to call problems all such different kinds of tasks is the fact that all of them present an initial state and a goal state, and that the solver is requested to get from the initial state to the goal state by means of series of actions that change the state. The problem is solved if such a series of actions has been found, and the goal has been reached. In general, problem-solving is a component of goal-directed action.

2.2 Use of representations in problem solving

Developing problem solving skills is strictly connected not only with acquiring solving procedures or strategies, but also with developing problem representation abilities (Abidin & Hartley, 1998). The first step to perform when tackling a problem is to interpret the given information, which is usually expressed in verbal form, and to transform it into an external or internal⁵ structured representation, which underlines and clarifies the relationship among the data and between the data and the goal of the problem. Some experimental studies by Lewis (1989) show that the majority of student's errors in problem solving arises from misrepresentations of the problem rather than from computational errors. Cifarelli (1998) suggests that the success of capable problem solvers depends in large part on their ability to construct appropriate problem representations and to use them as aids for understanding the given information and relationships among its parts. Sutherland (2002) observes that poor problem solvers tend to construct basic problem representations containing only the data and relations explicitly mentioned in the question; on the other hand, expert problem solvers produce more effective representations which include also information

⁵ Definitions of external and internal representations are given in Chapter 1

contained only implicitly in the problem's description, as well as relevant concepts from the domain, that they have already acquired.

Cheng (1999) claims that expert and successful problem solving practices are always paired with a good conceptual understanding of the knowledge of the considered domain. In particular, he argues that learners become able to tackle problem situations in a proper way only by building a complex network of concepts. As an example, he mentions the case of scientific discovery in new domains, where scientists analyse large bodies of empirical evidence (the problem's data) before they eventually build up an integration of laws for the domain which results coherent with the many different manifestations of the observed phenomena (the problem's solution).

In a didactic environment, building such conceptual network clearly does not occur simply by transmitting knowledge to the learner. Attention must be paid at least to two factors: (1) the external representations used for the domain's knowledge and (2) the solver's previous knowledge. Making use of external representations becomes essential when dealing with complex domains and big amounts of data. The solver's previous knowledge matters since learning can be viewed as an incremental process where networks of concepts are gradually constructed by assembling rules, schemas or chunks of knowledge that initially may appear rather independent of each other (Cheng, 1999).

Representations appear to be a basic component of cognitive processes involved in problem solving and conceptual understanding (Cheng, 1999). Such cognitive processes can range from simple perceptual mechanisms, at the lowest level, to high level cognitive mechanisms of central control, such as working memory, attention, interpretation, understanding, memory retrieval, learning, decision making and so on, implying increasing levels of abstraction (Zhang, 1997).

2.3 Dealing with given representations

2.3.1 Perception of representations

At simple perception level, sometimes external representations are not a source of information that can be picked up by the human mind easily, and in univocal way (Zhang, 1997). The apparently easy relation between learners and representations is, at perception level, actually a complex one, where the objects of perception (external representations) can affect the process of information selection up to determining what can be learned. This means that the representation format can determine what information is perceived and what structures can be discovered from a considered representation. According to Zhang, the information directly perceived from external representations may give rise to perceptual biases; if these biases are consistent with the task at hand, they can guide the solution steps towards the goal, while if the biases are inconsistent with the task they can even mislead action away from the goal. This implies that representations which are informationally equivalent may result not to be equivalent tools for supporting the solution of a task.

In this respect, an interesting example in the field of geometry is presented by Lobo Mesquita (1998), who refers to the *typicality theory* to point out the possibility of biases in perception, due to the format of representations. *Typicality* is defined as a property of the elements in a category and expresses the idea that some elements are used more often or more naturally than others to represent the category to which

they belong; in other words, they are more representative, or more typical, than others. The typicality of a representation results from the fact that individuals associate some external representations more easily than others to a given concept or situation. Lobo Mesquita reports an interesting study by Cordier and Cordier (1991) about the typicality of different representations of *Thales' theorem* in some European countries. These authors empirically show that the use of more or less typical representations affects problem solving performance. One of the pictures in Fig. 2.1 (a, b, c, d) was given to students with the assignment of a geometrical problem related to Thales' theorem; students who received Figure c made more errors than those who received the other ones, because this is less typical, for the theoretical situation considered, and hence makes it more difficult to evoke the theorem.

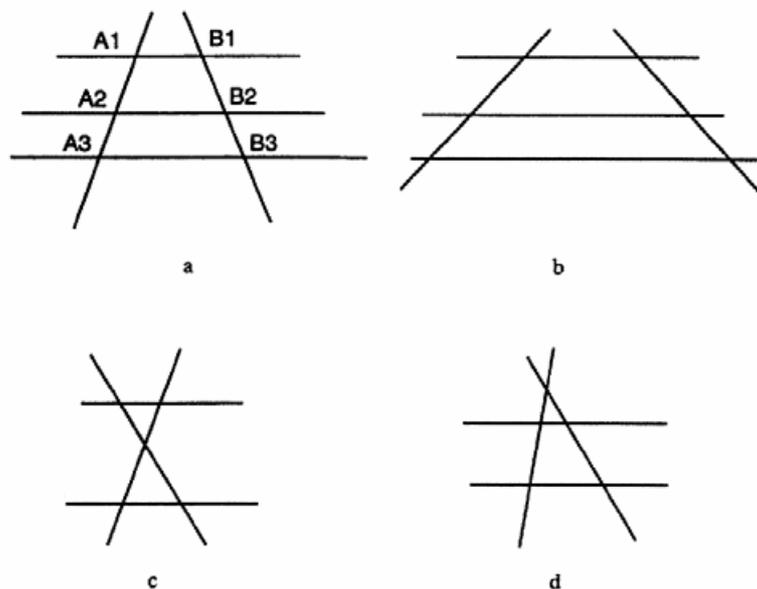


Figure 2.1. Pictures used in an experiment on typicality mentioned by Lobo Mesquita (1998).

The four pictures are informationally equivalent with respect to Thales's theorem,
but do not have the same visual biases

With multi-representational environments, solvers are provided with the possibility to observe and compare different representations, hence avoiding to be biased in their perception process; multiple representations, however, require translation and integration among representations and can therefore be sources of other difficulties, as pointed out on Chapter 1.

2.3.2 Exploiting given representations

Interpreting a representation can be a very difficult cognitive task if laws and principles governing the behaviour of the represented situation are not explicitly expressed (Cheng, 1999). In this respect, Kozma (2003), for instance, shows that it is common for novices in the field of chemistry to use only the surface features of representations to try to build an understanding of the chemical phenomena represented, disregarding the underlying principles.

A research by Cox (1999) opportunely points out that interpreting representations is not an easier task than constructing representations, as it could seem at first sight. In an experimental study, students' performance on a diagram interpretation's task (Euler's circle) are compared with performance on a task in which they had to construct their own representations of Euler's circle. The results show that only some types of interpretation errors predicted subsequent construction errors and, surprisingly, some subjects made interpretation errors but not construction errors.

Representational codes used and the function played with respect to the problem at hand, can be crucial in order to allow students to exploit given representations as a support to their problem solving activity. In this respect, several studies in the field of mathematics education (Elia and Philippou, 2004, Gagatsis and Elia, 2004) highlight how not only different representational codes affect students' problem solving performance in different ways, but also representations that use the same code but have a different function can have a different impact on the solution process. In particular, these authors show that pictures used in problem solving can have several different functions, that is, decorative, representational, organisational or informational. Decorative pictures do not give any useful information concerning the solution of the problem but just give an idea of the problem situation; representational pictures represent the whole or a part of the content of the problem, still with a descriptive purpose; organisational pictures provide directions for the solution procedure; only informational pictures provide information that is essential for the solution. Results of these studies point out that pictures that have an informational function with respect to a problem differ significantly from the other categories of pictures as concerns their impact on mathematical problem solving.

2.4 Constructing new representations

As regards constructing representations, some studies point out that often several successive representations are produced as support to the problem solving activity. This construction process is connected with the concept of visualization, that is, a cognitive process which can be defined, with Zazkis et al. (1996), as "an act in which an individual establishes a strong connection between an internal construct and something to which access is gained through the senses". It is important to note that here what is called visualization is the *connection* between external and mental made by the solver, and not simply one of the two components.

In this respect, the work of representation is seen by Cifarelli (1998) as a dynamic process, which facilitates the learner's sense-making. The solution activity is, in his opinion, characterized by successive steps of representation's construction. By generalizing across several case studies, this author argues that three increasingly abstract levels of solution activity can be inferred from the solvers' performances: recognition, re-presentation and structural abstraction. Recognition is the lowest level of abstract conceptual knowledge and occurs when the solver encounters a new situation and identifies the work done during previous tasks as relevant for solving the current one. In the process of re-presentation, the solver mentally revises the activity performed in the current solution process. In the highest level, that is, structural abstraction, the solver mentally "runs through" potential solution activity and operates on its results.

Dettori and Lemut (1994), analysing the mathematical problem solving activity of elementary school children, suggest that a solution process consists in repeatedly alternating moments of reasoning with the construction of representations, which are not necessarily pictorial, but can also be symbolic or verbal; this gives rise to a cycle where each step produces an input for, and stimulates the development of, the next step.

Arcavi (2003) models the alternation of representations and reasoning in problem solving by introducing the concept of *visually-moderated sequence*. In this case, visualization functions as a tool to find one's way in situations where one may be uncertain about how to proceed. The mechanism is composed by cyclically repeating three steps: "look, ponder, write". In other words, a visual clue V1 gives rise to a procedure P1 whose execution produces a new visual clue V2 which elicits a procedure P2 and so on.

Also Zazkis et al. (1996) suggest a model of mathematicians' behaviour where each visual step leads to a step of analysis, which, in its turn, is used to produce a new, or richer, visual image, which is then object of further analysis. Mathematicians engage in an interplay of visualization and analysis which informs their reasoning and understanding of the problem which, eventually, leads them to the final solution path. At the end of this negotiation process, the result needs to be described in formal way. This author suggests that the "structured qualitative exploration" during problem solving is typical not only of mathematicians but also of experts in all domains.

Stylianou (2002), as concerns mathematical problem solving, suggests that expert mathematicians build visual representations by steps which are clearly separated by moments when they analyse, with respect to the problem situation, the visual representations they have produced, so to get from them some input towards the solution of the problem. This analysis involves four kinds of actions: inferring additional consequences, elaborating on the new mathematical information, stating a new goal and monitoring the problem solving processes.

2.5 Handling representations to cope with abstraction

Representations become essential to support problem solving every time abstract concepts are handled. This takes place in many fields, since abstraction is a fundamental characteristic of human thinking. However, this is particularly relevant in mathematics, since this science is all about abstract concepts which can never be seen or experienced if not by means of representations. As Mitchmore and White (2004) point out, mathematics is a complex domain since it is a self-contained system separate from the physical and social world; it even uses everyday words with a different meaning (e.g. the word "root"), and contains unique objects which may be difficult to represent in intuitive manner (e.g. $\sqrt{-1}$).

As highlighted by Duval (1993), working with mathematics means working with conceptual (abstract) objects. This means that in the mathematical domain the role of external representations is crucial not only when acquiring new concepts, but also when managing concepts already known. In this respect, Duval points out that, when dealing with representations of mathematical (hence abstract) objects, there is always the risk to confuse the objects themselves with their representations, since abstraction is difficult to conceive. Hence, the educational use of representations in such cases, though mandatory, requires particular care on the didactical level.

The ambiguity between mathematical objects and their representations, which leads the students to strongly identify concepts with their representations, can make them fail to understand that two (or more) different representations may correspond to a same abstract concept. This makes the use of multiple representations in mathematical problem solving even more difficult than it usually is in the other disciplines. For this reason, often students in their problem solving activity are not able to use different representations, translating from one to the other as necessary. In this respect, Lesh et al. (1987) point out that this inability to use in a problem's solution different representations of the same concept is a serious drawback when solving realistic problems involving mathematics, since many of them are intrinsically multimodal. This means that not only can the use of different representations ease the solution process, but it can even result essential in order to correctly analyse the data or operate on them.

Even geometry involves the use and understanding of abstract objects, though it may seem more concrete, since the handled objects are intuitively representable, and hence easier to visualize. One of the main difficulties, in this case, is what Lobo Mesquita (1998) calls the *double status* of a representation, that is the fact that in geometry the same figure can represent either an abstract geometrical object or a particular concretization of it.

According to Fischbein (1993), geometrical figures are actually *figural concepts*, that is, they are endowed with all the properties of concepts (generality, essentiality, ideality, abstractness, absolute perfection, universality) and, at the same time, of all figural properties, such as shape, measures, position. A problem solver may be interested in focusing more on the first kind of attributes or on the second one, according to the characteristics of the problem at hand. Teachers should, hence, call the student's attention on this double status, when using figures in problem solving, since the figurative code, without additional information, may give rise to ambiguities.

2.6 Teaching problem solvers to work with representations

Representational ability is not innate nor trivial to acquire. On the other hand, it is essential for problem solving and learning, as pointed out in Sec. 2.2. Despite its importance, it is usually not explicitly taught in school, nor is there a well-established tradition in this respect. It is currently considered with increasing attention, though, and several authors have addressed this issue.

Lewis (1989) reports an experience on developing students' representational skills related to solving arithmetical problems. The reported approach (which proved successful) consists in training students to recognize what kind of problem they are solving so to choose what kind of representation they can most fruitfully construct for each class of problem.

Callejo (1994), based on a wide analysis of problem solving activities using graphical representations, observes that the first representation used in a solution process (either given with the text or individually produced) plays a crucial role in guiding the students toward a good solution or misleading and blocking them. For this reason, she claims that it is necessary to teach students to reflect on the choice of graphical representations and critically react to automatic choices, due to school habits, which lead them to associate representation types and solution approaches (e.g. graphs with combinatorics, etc.).

Bagni (2000) observes that many pupils in the learning of mathematics try to solve a problem by using only the representational code which is more common in the field explicitly considered (e.g. using only graphical representations when solving geometrical problems, or symbolic ones when solving algebraic problems). It is important to note that this behaviour does not necessarily affect the performance of students in simple problem solving situation, but it hinders the development of ability to co-ordinate different representational codes and of gaining representational competence. This inappropriate sectorialization of activities of deduction and construction is viewed by this author as a direct consequence of inappropriate teaching. He asserts that instruction can foster the development of representational competence through explicitly engaging students in the production of various representations and encouraging them to reflect on their meanings.

Sutherland (2002) claims that what differentiates experts' and novices' performance in problem solving is the analysis and use of information underlying their representational activity. She suggests that, in order to improve students' representational abilities, it is necessary to teach them strategic skills to analyse the information contained in problems and to combine it with the procedural and conceptual knowledge on the domain at their disposal.

Di Sessa & Sharin, (2000) use the term *meta-representational competence* to define the critical awareness and ability to reflect on representations' potentialities, affordances and good use, evaluate their quality and adequacy, exploit experiences with them, so to become both better user and better producer. Meta-representational competence includes:

- constructive resources (ideas and skills that allow students to invent new representations);
- critical knowledge (knowledge and skills that allow students to judge and compare the quality of different representations);
- knowledge about the functioning of representations (knowledge about benefits and problems using representations, as well as about affordances of different codes of representations);
- knowledge about strategies and ways to learn how to use powerful representations.

A similar concept is discussed by McKendree et al. (2002), who consider as an important component of critical thinking the ability to critically analyse why a representation is good in relation with its context of use.

Goldin (1998), on the other hand, sees the set of abilities related to meta-representational competence as an important component of one of a person's internal representational systems (verbal/syntactic systems, imagistic systems, formal notational systems of mathematics, a system of planning, monitoring and executive control and a system of affective representation). These meta-representational abilities belong, in particular, to the internal system of planning, monitoring and executive control, which is viewed as guiding the problem solving process. "This system includes competencies for 1) keeping track of the state of affairs in the other systems and in itself; 2) deciding the steps to be taken or moves to be made within all the internal representational systems, including itself and 3) modifying the other systems. Hence, this representational system seems to have a meta-cognitive role, defining the process of constructing a representation, even though the author claims that "it is not possible to firmly maintain the distinction between cognitive and meta-cognitive processes across representational systems".

Some experimental studies (Bagni, 2000, Cox & Grawemeyer, 2003a, Cox & Grawemeyer, 2003b) investigate to what extent knowledge about representations and critical reflection can affect the representational competence of learners. Cox & Grawemeyer's (2003a) experimental findings point out that expert ability to use external representations in problem solving and reasoning is associated with an accurate naming of representations and with the ability to create categories on the basis of semantic distinctions. Furthermore, knowledge about representational codes and types seems to be at the basis of a rich and articulated representational behaviour (Cox & Grawemeyer, 2003b).

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CHAPTER 3: Examples of using multiple representations

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Abstract. In literature several purposes for using multiple representations in learning environments can be found ranging from promoting abstraction, varying and reducing complexity, and teaching relations between representations to more practical purposes like when one representation is insufficient to show all aspects of a domain. This chapter gives examples of a total of fifteen purposes partly found in literature and partly based on research we did with multi-representational learning environments. Each purpose is briefly introduced and then illustrated by examples taken from SimQuest simulations.

Keywords: Multiple representations, multimedia learning, simulation-based learning environments

3.1 Introduction

Chapter 1 gave an introduction on the theoretical issues of using representations for learning. The purposes, benefits, problems, as well as types of support when using multiple representations were all discussed.

In this chapter the purposes of using multiple representations are illustrated with examples of SimQuest simulations (de Jong, van Joolingen, Veermans, & van der Meij, in press; van Joolingen & de Jong, 2003). SimQuest is a freeware authoring environment for building simulation-based learning environments (see www.simquest.nl).

3.2 Fifteen purposes of using multiple representations

There are several purposes for using multiple representations in learning environments. In this chapter we illustrate fifteen purposes with examples taken from SimQuest simulations. This overview is partly based on a classification by Ainsworth (1999b) and partly based on our research with multi-representational learning environments.

- When one representation is insufficient for showing all aspects of the domain
- When one representation should become too complex if it had to show all the information
- Different learners exhibit preferences for different representations
- When the learner has multiple tasks to perform
- When more than one strategy improves performance
- Using the particular properties of representations
- To show the domain from different perspectives
- To vary the precision of the domain
- To vary the domain complexity

- To constrain the interpretation of a second unfamiliar representation
- To exploit the inherent properties of a representation to constrain interpretation of a second representation
- To promote abstraction
- To support extension
- To teach the relations between representations
- To make it possible to manipulate variables

3.2.1 Using multiple representations when one representation is insufficient for showing all aspects of the domain

In order to understand what happens if two objects with different masses and different speeds collide, an animation of two balls colliding can be used to represent the domain. An example is shown in Figure 3.1.

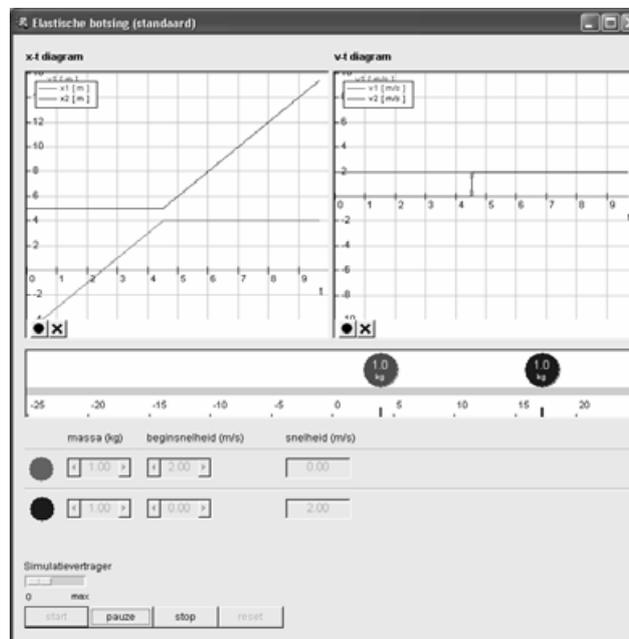


Figure 3.1. Simulation interface of SimQuest motion simulation

The animation shows the position of the balls, their begin speed and end speed, and their masses (as numbers inside the balls). The animation gives a 'real life' representation of the domain, but can not show all important aspects of the domain. An important aspect of the domain collisions is understanding the relation between mass and begin speed on the collision. The animation can give an idea of this relation, but the exact relation cannot be read off the animation. A graph is an appropriate representation to read off relations, but it cannot show the real life situation. Where the single representation cannot show all aspects of the domain, the combination of both can.

3.2.2 Using multiple representations when one representation should become too complex if it had to show all the information

In a simulation-based learning environment the simulation model is frequently divided into small pieces when exploring the complete simulation model would be too complex for learners to understand. In Figure 3.2 a simulation of a sewage plant is shown.

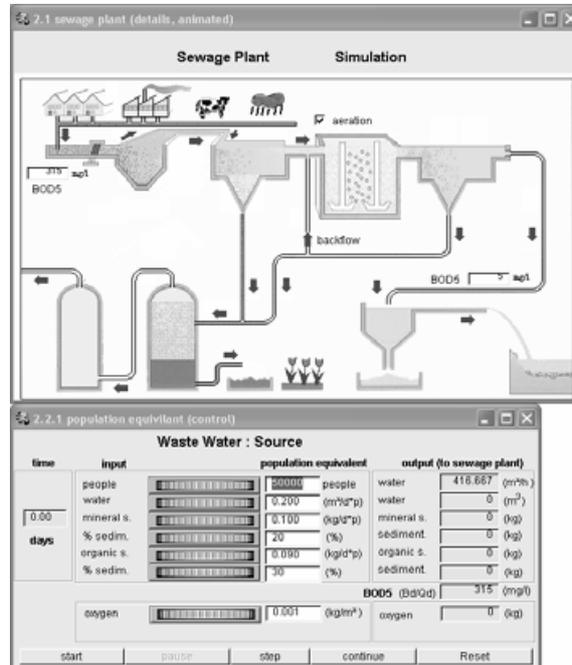


Figure 3.2. Interface showing overview of Sewage plant

The sewage plant is a complex system in which different processes are involved. In order to understand the system, the learning environment first provides an overview of the complete system and then zooms in on the separate parts. Figure 3.3 shows an example of one of the parts. With this representation students can study the behaviour of the sandtrap.

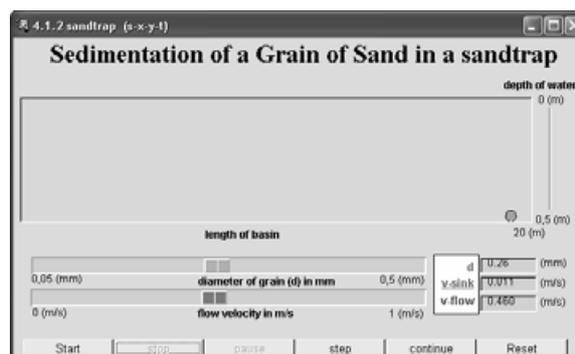


Figure 3.3. Interface showing sedimentation of grain in a sandtrap

When the behaviour of several variables in a complex process is presented by graphs, using multiple graphs showing the behaviour of different variables is often preferable over using a single graph showing all variables. With multiple graphs the student can easily study the behaviour of one variable. A drawback

is that it is harder to compare two variables that are presented in different graphs, even when these graphs are presented simultaneously.

3.2.3 Different learners exhibit preferences for different representations

Learners have different preferences for representations. For one learner a formula is the preferred representation to understand the domain, for another it is an informationally equivalent graph (see Figure 3.4 for an example). By providing multiple representations learners can explore the domain by using the representation(s) of their choice.

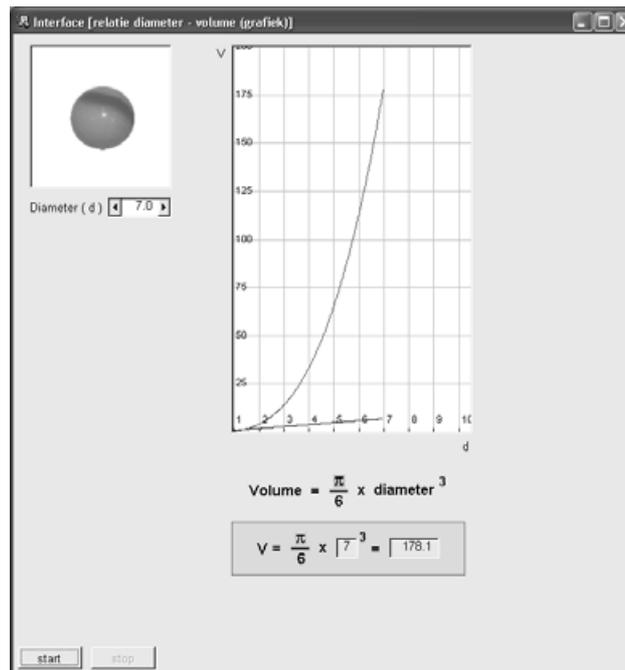


Figure 3.4. Interface showing both a formula and graph

3.2.4 Using multiple representations when the learner has multiple tasks to perform

In many learning environments learners have to perform a number of different tasks to achieve a particular goal. The goal in simulation-based learning environments often is that learners learn to understand the underlying model by exploration. Frequently the underlying model is explored by performing different tasks on multiple representations representing some aspects of the simulation model. Mostly one representation is not sufficient to support the different tasks that the learners have to perform. Particular representations facilitate performance on certain tasks.

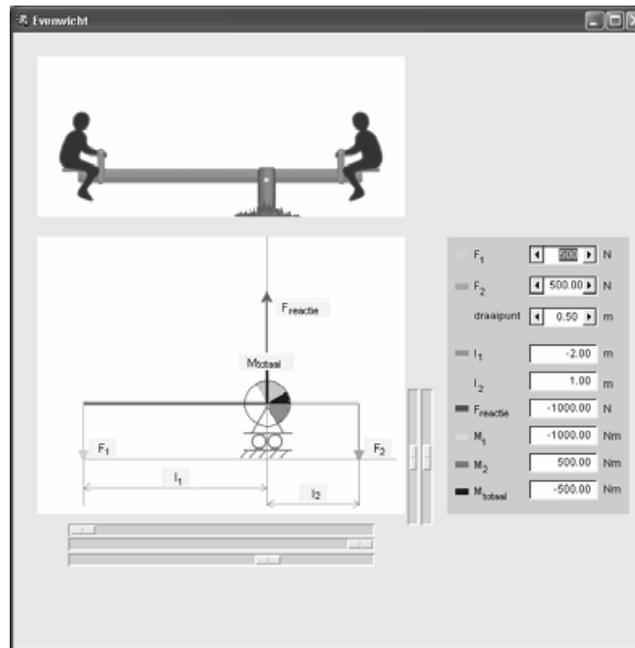


Figure 3.5. Interface of simulation on balance

When the task for the student, given the interface shown in Figure 3.5, is to position the persons on the seesaw at the same distance from the fulcrum it's easier to do that with the animation, than with the numerical representation. When the task is to find out the value of the moment in a given situation, this cannot be done by the animation. In this case students need the numerical representation to find the answer.

3.2.5 Using multiple representations when more than one strategy improves performance

To find the right solution to a given problem learners can use different strategies if they can choose between multiple representations. Learners can switch to a different strategy if the first does not work. Multiple representations may assist them in doing so (Ainsworth, 1999b). An example is shown in Figure 3.6. To find the phase shift in a given electrical circuit they can switch between the graph and the vector diagram to find the right answer.

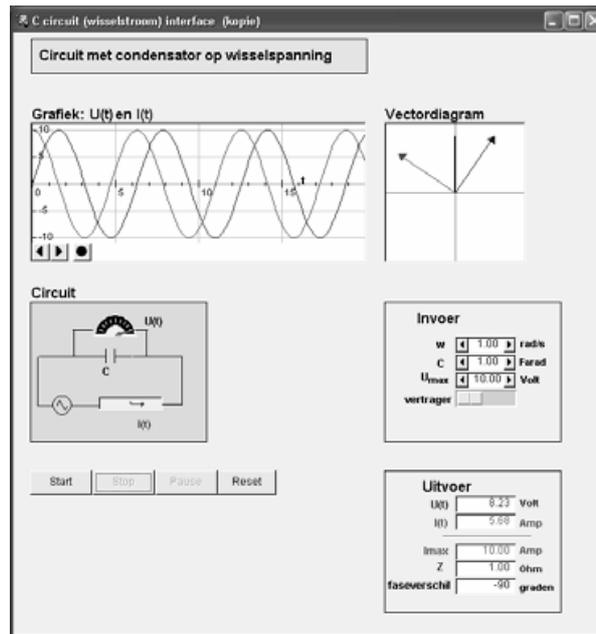


Figure 3.6. Learners are able to switch their strategy by using a different representation

3.2.6 Using the particular properties of representations

One of the most common reasons to use multiple representations in learning environments is to obtain the different computational advantages of each of the individual representations (Ainsworth, 1999a). Different types of representations may be useful for different purposes as they differ in their representational and computational efficiency (Larkin & Simon, 1987). If qualitative information has to be shown, diagrams are the best representations. Graphs, formulas, and alphanumeric representations are the best representations for showing quantitative information. Graphs are important tools in enabling learners to predict relationships between variables and to show the nature of these relationships (McKenzie & Padilla, 1984). It is expected that learners benefit from the properties of each representation and that this will lead to a deeper understanding of the subject being taught (Ainsworth, Bibby, & Wood, 1997; de Jong et al., 1998; Seufert, 2003; van Labeke & Ainsworth, 2001). If the context of a problem has to be represented the best representations to use are text or pictures. An example is given in Figure 3.7.

Figure 3.7. SimQuest assignment introducing a problem

In Figure 3.7 the text introduces the problem the learner has to solve. The context is given and also the values of variables that need to be used is the given problem. In this case the acceleration (1 m/s^2) of a scooter is given. By using the simulation the learner has to explore how long it takes the scooter to drive at its maximum speed of 10 m/s. In this experiment the learner has to adjust the acceleration to the right value, has to start the simulation and has to find the answer to the question by using the graph.

3.2.7 Using multiple representations to show the domain from different perspectives

In Figure 3.8 a lathe is shown from different perspectives. By doing this the learner is expected to have a better idea what the machine does. The left representations show the complete machine from the side and from above, the right representations zoom in on the important part of the machine. In this example the machine is literally shown from different perspectives. Multiple representations can show a domain from different perspectives. Different perspectives could also mean different functionalities of a domain, for example, showing the engine of a car from a mechanical and electrical perspective.

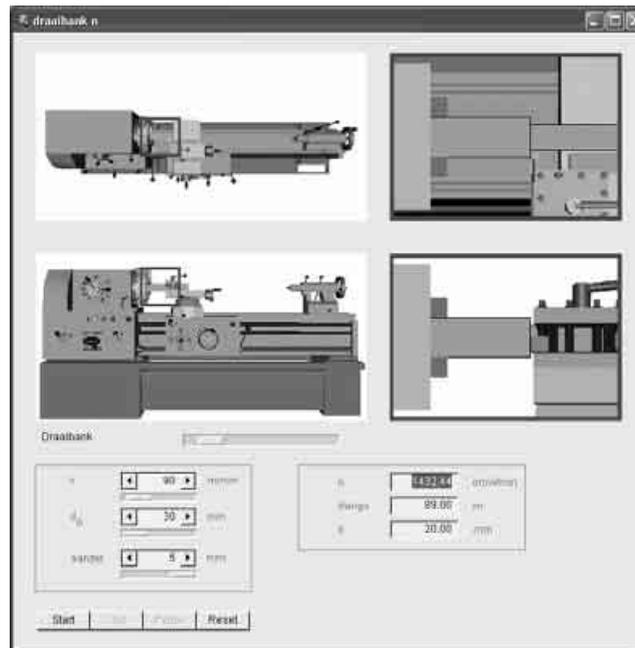


Figure 3.8. Interface showing lathe from different perspectives

3.2.8 Using multiple representations to vary the precision of the domain

When a learner explores a new domain it can be useful to first present the domain in a qualitative way before introducing the values of the variables involved. An example is given in Figure 3.9 and Figure 3.10.

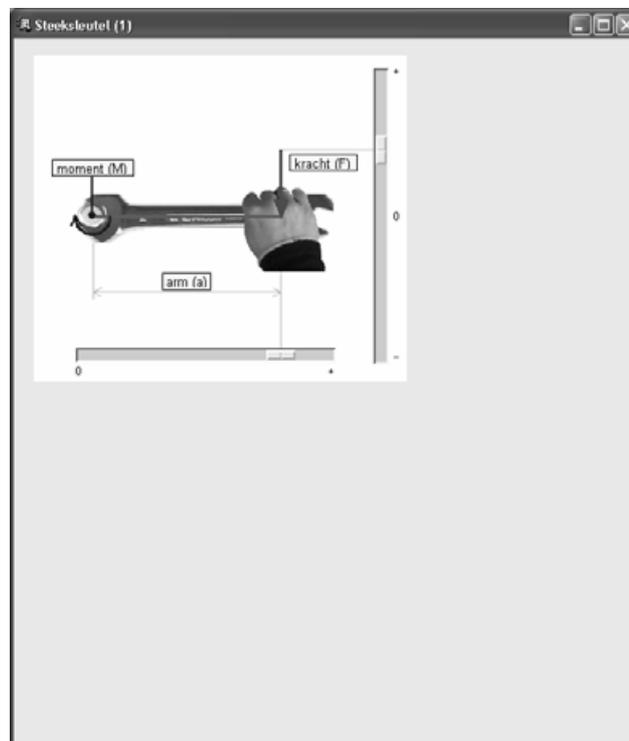


Figure 3.9. Interface showing variables qualitative

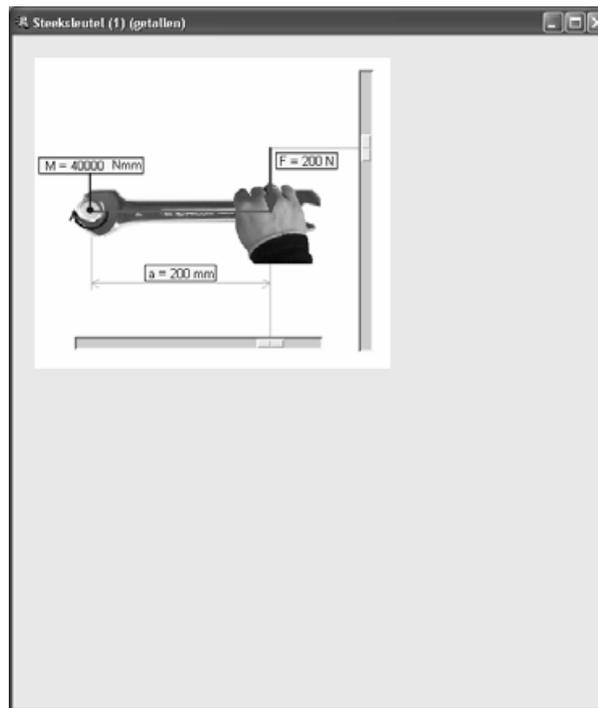


Figure 3.10. Interface showing variables quantitative

The interfaces presented belong to a simulation where the learner first explores the simulation shown in Figure 3.10 by doing several assignments encouraging the learner to explore the simulation in a qualitative way. In a second stage (Figure 3.10) the values of the variables are introduced and the learner can then explore the relation between the variables in a quantitative way.

3.2.9 Using multiple representations to vary the domain complexity

When the domain is complex, model progression could be used to sequence the learning material from simple to complex. At first the representations could show only some aspects of the domain and later on more aspects (variables) could be introduced. Also, when using multiple representations, one representation could show the whole system and other representations could zoom in on separate aspects to vary the complexity.

Figure 3.11 and Figure 3.12 show two interfaces of a simulation on transport costs. With the interface shown in Figure 3.11 learners explore the effects of permanent costs and variable costs of a truck. They can store the graphs of the situations they explore and can compare them. Figure 3.12 shows the most complex situation. Learners can now choose different locations and can for instance explore what is the cheapest combination of transport types if a cargo has to be transported from Rotterdam to Enschede via Nijmegen.

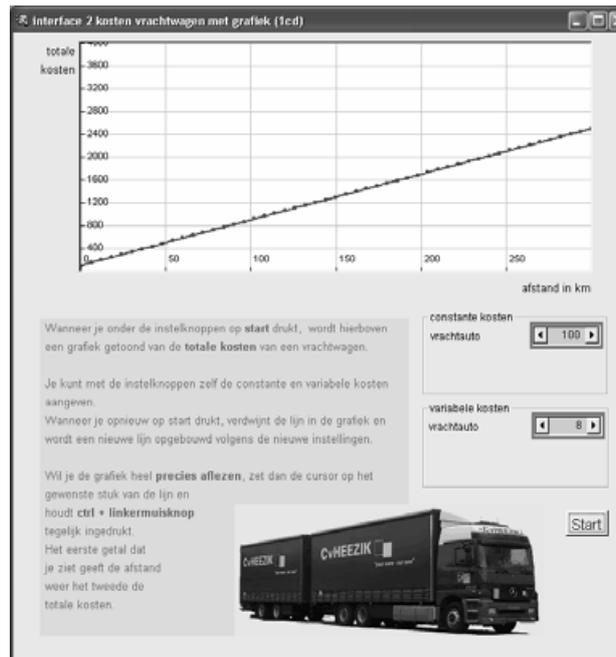


Figure 3.11. Interface showing transport costs per km

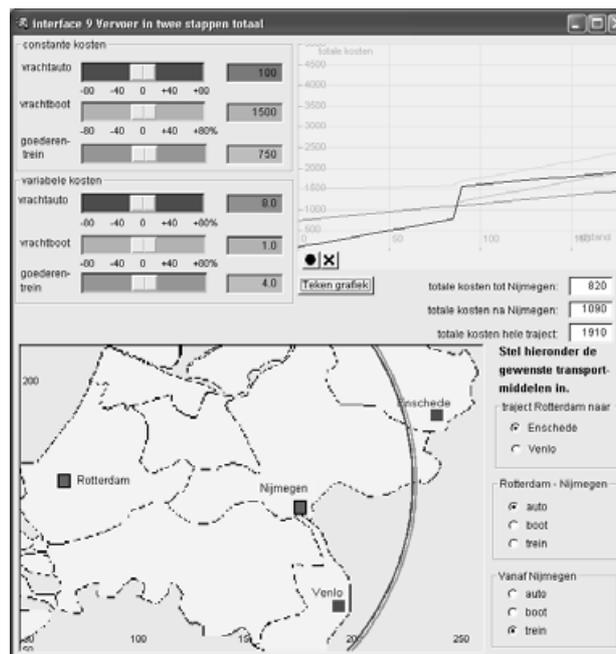


Figure 3.12. Interface showing transport costs when using different transport types

3.2.10 Using multiple representations to constrain the interpretation of a second unfamiliar representation

In a multi-representational learning environment one representation can constrain the interpretation of another representation. An animation, for example, can constrain the interpretation of a graph. There is a strong tendency among learners to view graphs as pictures rather than as symbolic representations (Kaput, 1989; Mokros & Tinker, 1987). When the animation shows a car riding up a hill with constant power, it

constrains the interpretation of the speed shown in a line graph. The animation can show learners that the line graph is not representing a valley but the speed of the car; they can see that the car slows down going up the hill and that it accelerates going down the hill. The constraining representation gives the learner support on the less familiar representation. It does not provide new information (Ainsworth, 1999a).

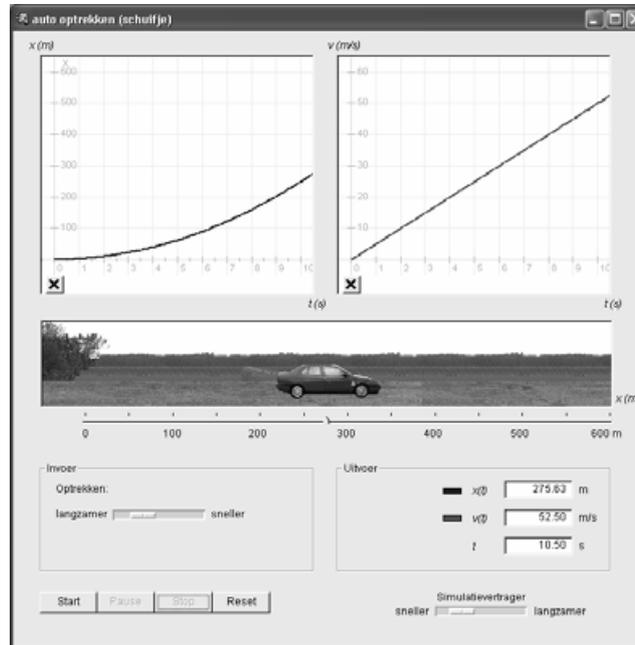


Figure 3.13. Interface showing accelerating car

Figure 3.13 shows an example of an animation of a car constraining the interpretation of the graphs above it. The animation helps the learner to understand the behaviour of the variables presented by the graphs.

3.2.11 Using multiple representations to exploit the inherent properties of a representation to constrain interpretation of a second representation

Sometimes a more abstract or unfamiliar representation can be used to constrain interpretation of a second representation. Ainsworth (1999b) gives an example that the ambiguity permitted in the propositional representation 'the knife is beside the fork' is completely permissible. However, an equivalent image would have to picture the fork either to the left or to the right of the knife. When the two representations are presented together, interpretation of the first may be constrained by the second.



Figure 3.14. Interface showing the context described by the text on the right

In Figure 3.14 the text on the right is describing the context of the situation: “A hoisting crane is carrying a load”. This description does not make clear what the horizontal and vertical position of the load is. The animation in the left window constrains the interpretation of the text by showing these positions. It makes clear that the load is located at the right side, at a fourth of the maximum length from the jib fixation, and that the load hangs at a fourth of the maximum height.

3.2.12 Using multiple representations to promote abstraction

An important motivation to use multiple representations is that they should encourage learners to construct a deeper knowledge of a domain (e.g., Ainsworth, 1999a; Petre, Blackwell, & Green, 1998). Petre et al. (1998) asserted that having to make the mental transference between representations (and possibly between paradigms) forces reflection beyond the boundaries and details of the first representation and an anticipation of correspondences in the second. The deeper level of cognitive processing can reveal glitches that might otherwise have been missed. If learners would study the simulation of the hoisting crane shown in Figure 3.14 without the graphs represented simultaneously with the other representations, it could well be the case that they would not notice the linear relation between the length and torque and between the force and torque. By simultaneously presenting multiple representations it is hoped that learners study the correspondences (and differences) between the representations and thereby get a better understanding of the domain.

3.2.13 Using multiple representations to support extension

It is expected that, by using multiple representations, subjects could transfer their knowledge of the domain presented in the learning environment to other, comparable, situations (e.g., Ainsworth, 1999a;

Petre et al., 1998). By using multiple representations it should be easier to apply knowledge to new situations because learners acquired their knowledge at a more abstract level (see section 3.1.13). When learners studied the behaviour of torque in on a hoisting crane with the simulation shown in Figure 3.14 it is expected that they are able to apply their knowledge to the simulation shown in Figure 3.15. In this simulation learners study the behaviour of torque on a bolt when operating an open-end spanner. Learner can change the position of the hand (length), and can change the value and direction of the force.

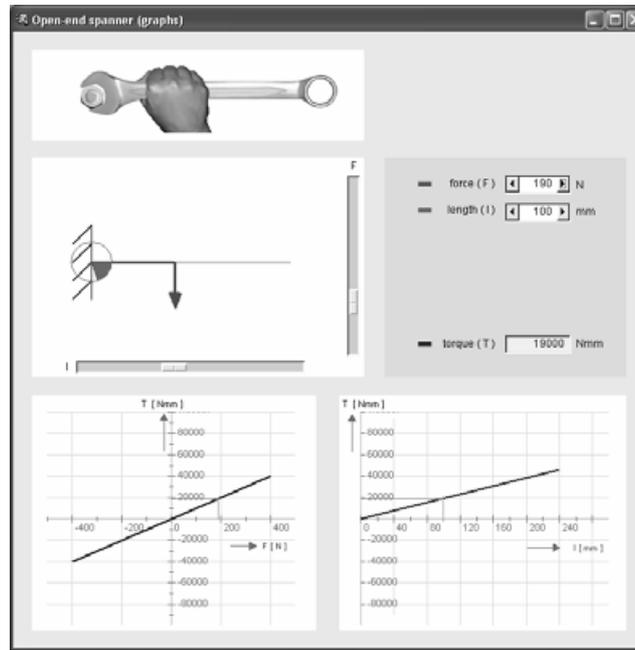


Figure 3.15. Interface showing torque on bolt

3.2.14 Using multiple representations to teach the relations between representations

When two or more representations are presented together, the relations between those representations can be taught. By using techniques as dynamic linking and colour coding relations between multiple representations can be made visible. Adding assignments can also help in teaching the relations between the representations.

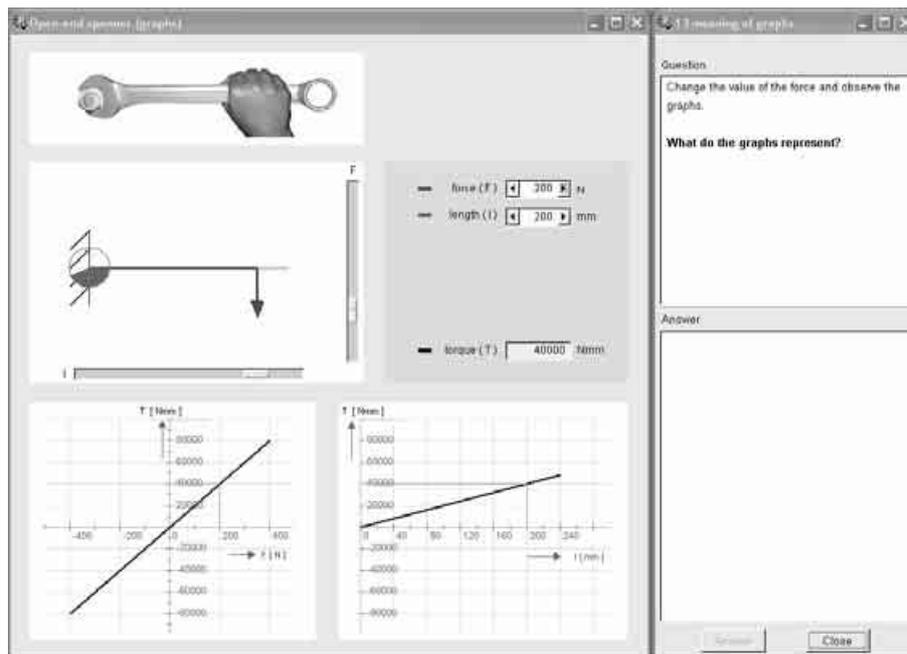


Figure 3.16. Teaching the relation between representations

Figure 3.16 shows a situation where the learner is asked to observe what happens in a second representation when a first is manipulated. In this simulation the representations are dynamically linked to each other. Actions performed on one representation are automatically shown in all other representations. If the learner changes the value of the force in the numerical representation, all other representations show the consequence of this action. In this simulation also colour coding is used in four of the representations. The force, for example, is coloured red.

3.2.15 Using multiple representations to make it possible to manipulate variables

This is a more practical use of multiple representations. Multiple representations have to be used to be able to manipulate variables for showing their effect in e.g. a graph. In the graph itself the variables cannot be manipulated. Other representation (e.g. numerical inputs and outputs) are needed for manipulation. In Figure 3.16 the values of the force and length cannot be changed in the graphs. Learners have to use the abstract or numerical representations to change these values.

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CHAPTER 4: Current Perspectives on the Pedagogical Value of Algorithm Visualization

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Abstract. The advent of computer technology offers the opportunity for developing multimodal, dynamic and interactive representations of knowledge which are expected to significantly enhance learning. This chapter presents an overview of the pedagogical effectiveness of the algorithm visualization systems, which make use of dynamic visual representations for supporting the instruction in the domain of computer algorithms. The author highlights the most important conceptual and methodological advances in the field, analyzing the properties of the representations that are usually displayed by such systems and presenting significant research results concerning their pedagogical efficiency. Available studies indicate that it is not the quality of the graphical display (“what the students see”) but students’ engagement in active learning situations with algorithm visualization systems (“what the students do”), that substantially affects the learning outcomes. Moreover, it seems that a significant level of learning is achieved when algorithm visualization systems are integrated in instructional settings which follow the constructivist paradigm. In this case students are guided not simply to view experts’ visualizations and interact with them but also to construct their own and present them to peers, thus initiating fruitful knowledge building conversations. In this way algorithm visualization systems are better conceptualized as “construction supporting” tools than simply as “knowledge conveyors”. Towards enhancing this role of the software it seems that “low-tech and fidelity” AV construction systems may be quite adequate for supporting students’ engagement in essential learning activities.

Keywords. Algorithm visualization, animation, multiple representations, multimedia learning.

4.1 Introduction

Learning, to a great extent, emerges from the interplay between external and internal representations of knowledge. An “external” representation is a symbolic structure which stands for something else. This “something else” may be a part of the perceived world (e.g. an image of a landscape is a representation of the landscape) or of the models we use to describe and understand the world (a formula, a description, a graph are all representations of the models we use to theorize about the real world). External representations employ some appropriate representational code (it may be descriptive code such as language or depictive code such as images and graphics) and a modality (audio, visual, tactile) for making explicit the quantitative and/or qualitative interdependencies between categorical elements of the world. For example, the formula “ $F=m.a$ ” represents symbolically the relationship between the magnitudes of mass, acceleration and force applied on real bodies. Examples of external representations include definitions stated in plain or technical language, tables of data, mathematical expressions, graphics, animations, audio cues, video clips. External representations may be considered either as “vehicles” for

conveying to the learner the appropriate instructional messages (a role much in accordance with the instructionist-objectivist paradigm of learning) or as an artifact for enabling students' self-expression, reflection and collaboration (following the constructivist viewpoint). Either way, they are at the heart of the instructional process and learning outcomes strongly depend on their appropriate design and utilization. Internal representations, on the other hand, are abstracted cognitive constructs (for example a schema, a propositional network or a mental model) that learners develop as a product of the learning process and on which they base their performance in problem solving activities. Learners are generally supposed to develop such internal structures when perceiving and cognitively processing information stimuli from external representations. The quality of this interaction strongly affects the quality of knowledge and students' further performance in problem solving situations.

For the construction of representations on printed material, instructors traditionally use two major representational codes: text and static visuals (images or graphics). However, computer technology offers the opportunity for developing multimodal, dynamic and interactive external representations which are expected to significantly enhance learning. In the realm of technology enhanced learning, instructors can utilize multiple representational codes and modalities (such systems are typically called "multimedia systems") in order to produce multiple representations for learning. One great challenge in the field has ever been, of course, how to combine multiple representations in a way that learning happens in the most effective and efficient way.

Dynamic representations are produced when external stimuli change somehow in time. Animated graphics, narration and video are all types of dynamic representations. Dynamic graphical representations (animations) employ the kind of visual code which changes onscreen (in a continuous or discrete way) the properties of graphical elements (such as their position, color, size). It is common thinking that animation can be appropriately used in education for representing state changes of some natural, artificial or imaginary system which evolves in time. The core idea for using animation is the expectation that the change-in-time feature of the system could be consistently represented by some respective change of the animated graphics and this mapping function would enable learners to efficiently develop an appropriate dynamic mental model of the system. Understanding, therefore, how animation can be best utilized for learning purposes is significant in the context of technology enhanced learning exactly because animation offers to instructors the starkly different possibility of presenting dynamic information to learners. This can not be accomplished in the printed medium.

One significant application of dynamic visual representations is for teaching concepts and methods in the computer algorithm domain. Learning about algorithms is considered as a difficult task (Stasko & Lawrence, 1998) not only because algorithmic processes are generally complex, but also because they are quite abstract. An algorithm is, in principal, a series of well defined steps applied on data structures and, as such, it only exists as a "creature" in the abstract world of temporal data transformations. The use of appropriate visual dynamic representations to depict algorithm behavior is, hopefully, a step towards making the abstract more concrete and the complex more understandable.

The focus in this chapter is on our current level of knowledge regarding the pedagogical efficiency of algorithm visualization software. To offer an as complete as possible overview of the subject we have reviewed many of the currently available empirical research studies and some of the most enlightening

meta-studies. In the following we are going to present (a) the basic features of algorithm visualization systems by commenting on the properties of the dynamic representations that these systems usually employ, and (b) a concise overview of currently available research evidence, discussing also the emerging implications about the educational effectiveness of these systems.

4.2 Algorithm visualization

4.2.1 What is “algorithm visualization”?

Algorithm visualization (AV) is an important sub-domain of the broader software visualization domain. As Price, Baecker and Small (1998) explain, “*visualization*” means the “power or process of forming a mental picture or vision of something not actually present to the sight”. These authors define *software visualization* as the “use of the crafts of typography, graphic design, animation, and cinematography with modern human-computer interaction and computer graphics technology to facilitate both the human understanding and effective use of computer software”. Software visualization, therefore, refers to computer based environments, where appropriate visualizations are used in order to convey to the user a deeper understanding of the data structure transformations and software operations.

Software visualization comprises two basic sub-domains: algorithm and program visualization. *Program visualization* refers to the visualizations of program code and data while *algorithm visualization* includes visualizations which deal with algorithms. (fig. 4.1). In the field of computer science, AV systems make available to learners multiple, dynamic and interactive visualizations of the changes that data sets undergo when some algorithm is applied on them.

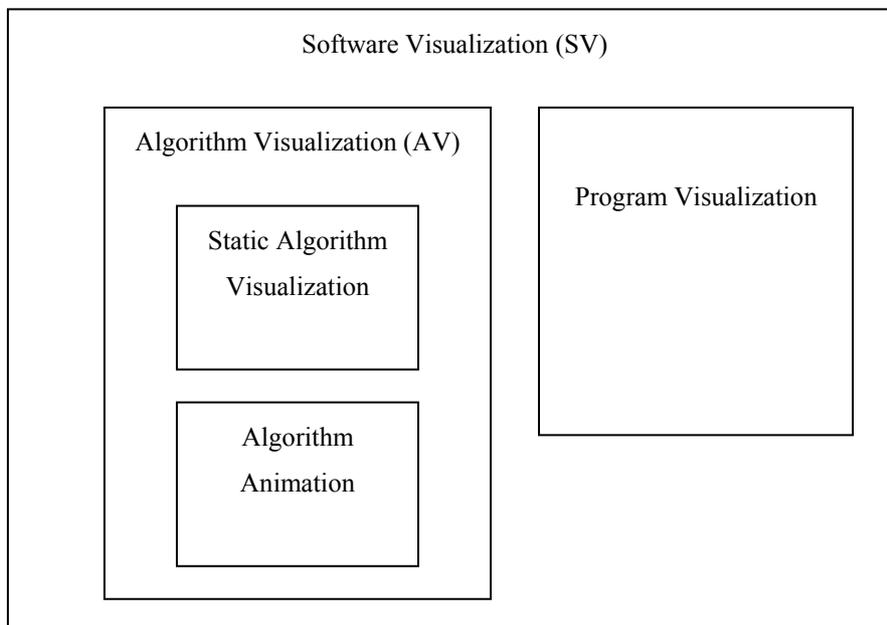


Figure 4.1. A Venn diagram presenting the SV domain (adapted from Price, Baecker & Small, 1998).

Algorithm visualization includes both the use of static visual representations (e.g. flowcharts) and dynamic (animated) ones. In the latter case the term “*algorithm animation*” is commonly used, referring

specifically to the use of dynamic visual representations for the visualization of the high-level abstractions which describe software, i.e. algorithms. An algorithm animation creates initially an abstract graphical representation of the data set, mapping the current values of the variables used in the algorithm onto appropriate graphical elements (for example dots, sticks, circles or ellipsoids). Next, these elements get animated, representing the operations between the succeeding states in the execution of the algorithm. Animating an algorithm is expected to promote students' better understanding of the structure, intricacies, shortcomings and advantages of the algorithm, even allowing for further optimization.

As common ancestor of all AV environments it is usually cited a 30-minute color film produced by Baecker (see Baecker, 1981, 1998), entitled "Sorting Out Sorting". The film presents the operation of nine different internal sorting algorithms using animation of data set coupled with explanatory narrative. It offers the possibility to visually experience the algorithm dynamics in ways which are difficult to simply describe using textual representations. Baecker (1998) emphasizes that "we can see the programs in process, running, and we therefore see the algorithms in new and unexpected ways... These views produce new understandings which are difficult to express in words" (see fig. 4.2).

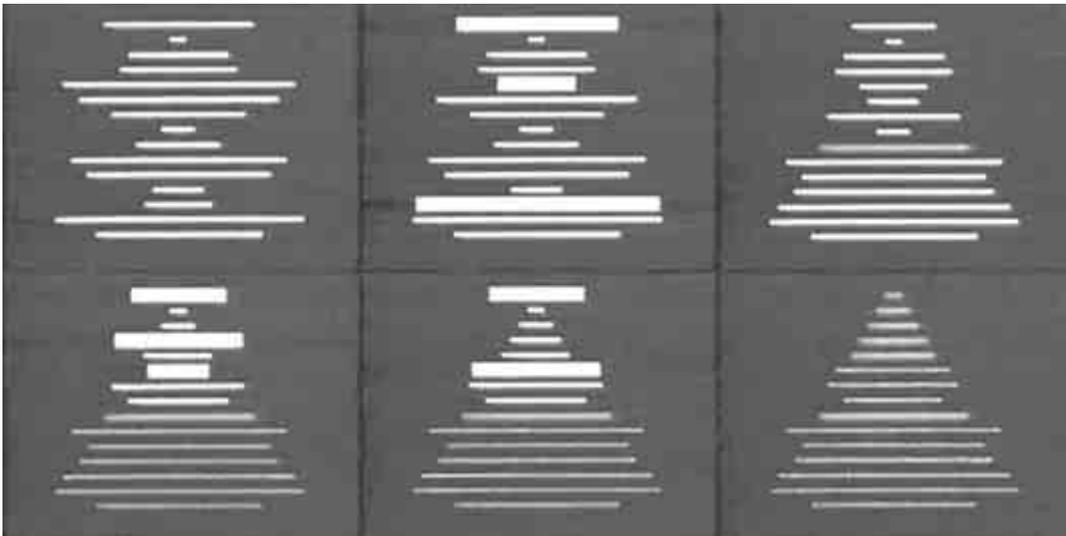
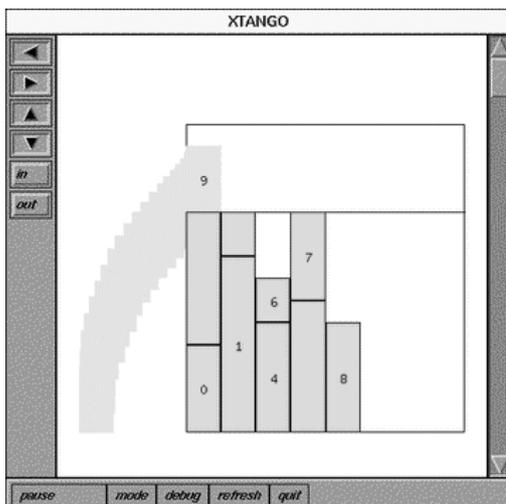


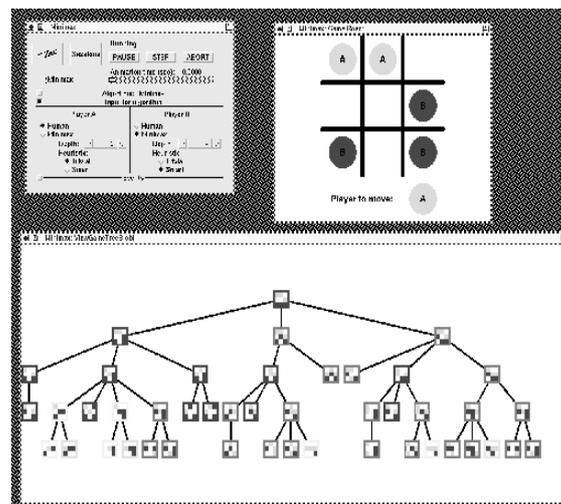
Figure 4.2. Screen dump from "Sorting Out Sorting" Film (Baecker, 1981, 1998). Data are represented as horizontal bars which progressively change their relative position as the sorting algorithm is applied on them.

Was this early non-interactive visualization a useful learning experience? Baecker (ibid, p. 378) concludes that "significant insights into algorithm behavior can be gained while only viewing the data, if the illustrations and the timing are designed carefully, and are accompanied by appropriate narration". The keyword here is "only viewing". As we shall later discuss in this chapter, several studies indicate that simply viewing algorithm visualizations does not seem to benefit students substantially. However, there is also strong support (e.g. Clark & Mayer, 2003) of the view that the quality of learning is significantly enhanced by appropriately presenting to students textual and visual information. We comment on this apparent contradiction in the last section of the chapter.

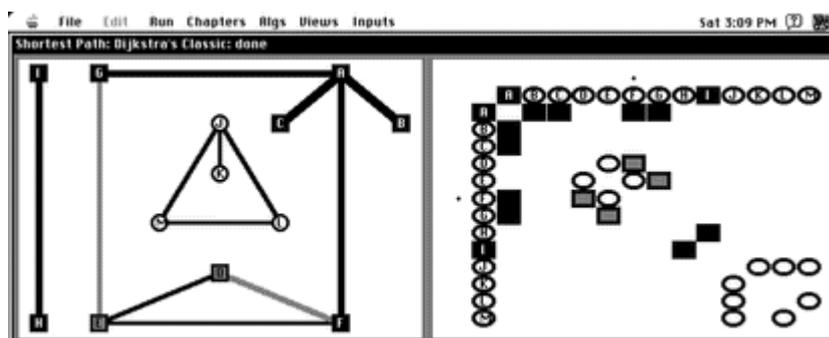
Several computer based AV systems have been developed ever since (e.g. BALSAs (Brown, 1988a), Zeus (Brown, 1991), Tango (Stasko, 1990), see fig. 4.3) and many of them have undergone significant empirical evaluation, thus offering important insights on their pedagogical efficiency. Two core design considerations in the development of these (and any other AV system) have always been (a) how to flexibly adapt the level of user-system interaction to meet the demands of various instructional activities, and (b) how to build appropriate visualizations to foster the development of efficient learner's internal representations.



XTANGO first-fit binpacking animation
(<http://www.cc.gatech.edu/gvu/softviz/algoanim/xtango.html>)



Zeus minmax algorithm animation
(<http://www.research.compaq.com/SRC/zeus/home.html>)



Dijkstra's shortest path algorithm animated in BALSAs
(<http://www.eg.bucknell.edu/~zaccone/MacBALSAs/MacBALSAs.html>)

Figure 4.3. Screen captures of AV systems. The reader can see the various forms of graphics which are used for modeling the algorithm operations.

The former means that AV systems should enable students to experiment by adapting various system functionalities depending on the situation. Consider, for example, the case of selecting initial data. The system should offer at least three distinct possibilities: random data, predefined special case data (e.g.

algorithm extreme behavior data) and user defined data. The latter refers to the problem of how to represent data structures and algorithm operations, to allow for efficient learning conditions to emerge. For example, does it make any difference if data are represented by vertical instead of horizontal bars (as in fig. 4.2)? Or, how should the various views of a complex algorithm be interconnected to avoid usability problems and enable students' translating between them?

What are the reasons for developing algorithm visualization systems?

First, because there are significant expressive limitations in the representations traditionally used for presenting algorithm operations. Students generally face serious difficulties when trying to understand the usually very complex state transformations of data sets supported only by formal textual representations (programming code) and other static visualizations (slides, images and hand-drawn figures) (Naps et al., 2003). Static visuals do not represent the dynamic characteristics of the algorithms while the use of animated representations is expected to support students to deeper understand both the conceptual and procedural knowledge of the domain.

Second, because people exhibit a variety of different learning and cognitive styles, which makes them prefer a specific representational code than another (e.g. Wu & Martin, 1997). Students certainly seem to enjoy viewing animations and this is already an important motivation for engaging in significant learning activities that should not be underestimated (Stasko & Lawrence, 1998).

Third, because instructors intuitively believe that using AV systems yields better learning outcomes (Naps et al., 2003). Although belief and reality do not necessarily coincide, an instructor who is well disposed towards the use of AV systems is one who will more probably introduce such a system in instruction and try to make the most out of it. However, it should be noticed that the manipulation costs of AV systems (for developing, supporting and maintaining them) are rather high. "The bright promise of these techniques is dimmed by the cost of their design, manufacture, integration and maintenance", (Bazik, Tamassia, Reiss & Van Dam, 1998, p. 383).

4.2.2 Properties of representations in algorithm visualization displays

Designing algorithm visualizations for instruction is not a trivial endeavor. It is important that AV systems highlight only the essential aspects of an algorithm suppressing any extraneous details and providing clear and uncluttered graphic designs (Baecker, 1998). Designers, moreover, by drawing on instructors' experience, should decide how to develop and efficiently connect visualizations to textual representations (program code) in order to make understandable even the most intricate features of the algorithm. To accomplish these tasks, designers resort to various display techniques and develop representations with specific properties and features. This section introduces the reader to these representational techniques by analytically commenting on the properties of the representations which are typically to be found in an AV system.

The represented and representing world:

The "represented world" in an AV system is the domain of data sets and algorithm operations. What is actually represented in such a system is the abstract world of logical operations which constitute the essence of algorithmic processes. This domain is traditionally represented by formal textual representations (pseudocode or code written in some programming language) which describe the steps of the algorithm. Algorithm visualizations, however, seek to exploit the power of visual representations by restoring an intuitive correspondence between data structures and displayed graphical elements. Petre, Blackwell and Green (1998) call these visualizations "information artifacts".

In AV displays there are usually two basic representational codes: text and graphics. Apart from presenting the code of the algorithm, text is also used for annotating graphics, presenting numerical data, and offering explanations. Graphics represent the data in ways that would enable students' intuitively grasping of the basic algorithm operations. For example, the height of the sticks (see fig. 4.4) is proportional to the data value and so it easier for the viewer to understand how sorting algorithms make comparisons between data and sort them accordingly.

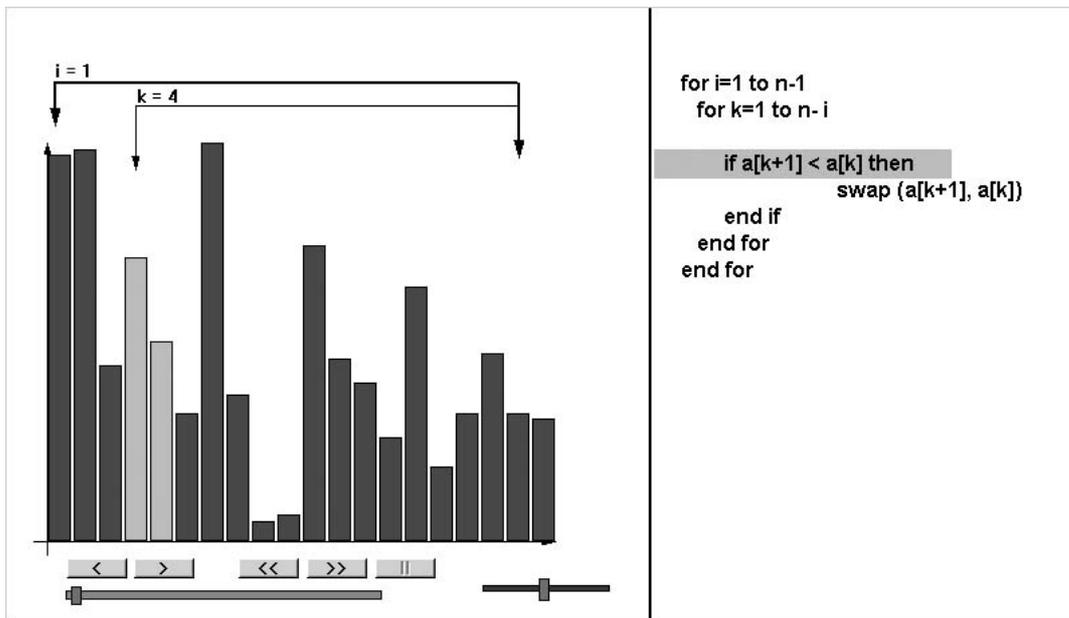


Figure 4.4. Screen dump of an early AV prototype. Two representations (code and data bars) are used to present a simple sorting algorithm (bubble sort). The height of the bars is proportional to the data value.

The buttons below the data allow the student to advance or rewind the animation either stepwise or continuously. The sliders enable speed adaptation and easy moving to points of interest. The lines and arrows above the data and the lighter grey areas (highlighted data bars and code line on the right) support students' translating between the two representations.

The aspects of the represented world being represented are those that would help students better understand how the visualized algorithm affects the data set. These aspects may vary depending on the kind of the algorithm being visualized. For example, when presenting sorting algorithms it is important to represent the values of the data in a way that the sorting operations become easily visualized. The aspects

of the representing world which do the modeling are the graphical properties such as the shape of the graphical element (e.g. circle or square), its size, color and position.

Images of real world objects can also be used especially in displays where the aim is to present some analogy between the algorithm and a real world situation. Research indicates that such analogies prime the learning experience and enhance learning outcomes (Hansen & Narayanan, 2000). It is worth noticing that there exist also systems which use sound to create aural patterns of the algorithm operations ("algorithm auralization" systems, Brown & Hershberger, 1998). More recently "concretizations" of algorithms have been proposed as instructional activities, using programmable robots to imitate the transformations of the data set (Lopez, Myller and Sutinen, 2004).

Fundamental techniques for algorithm animation displays

Brown and Hershberger (1998) emphasize that software visualization designers face significant problems in order to efficient display all available information onscreen. There is a plethora of information to be displayed on screens which are of small relative size and of lower than paper resolution. These authors present a list of techniques that AV designers employ to cope with such problems including the use of multiple views, state cues, input data selections, and color techniques for encoding the state of data structures and highlight activity.

- *Multiple views:* AV systems must encode a lot of information (especially when dealing with complex algorithms or with many algorithms simultaneously) and it is practically impossible to present all available (and desired) information in a single view. Multiple views have been employed by designers to effectively distribute information and present to the user complementary representations of the algorithm. Each view displays only a few aspects of the algorithm thus making simpler for the user to understand the presentation.
- *State cues:* Animators can show changes in the state of a data set by changing elements of their graphical representations on the screen (e.g. place, shape or color). According to Lowe (2003) the changes in animated displays may be "form" changes (transformations) which refer to changes of properties of the objects (e.g. size, shape and color), "position" changes (translations) with objects moving from one position to another, and "inclusion" changes (transitions) when objects appear or disappear from the display.
- *Input data selection:* It is also important to enable the user to choose the kind and amount of data to test the behavior of the algorithm. It is suggested to use small amount of data when first introducing an algorithm and larger amounts in later stages of work when the target of instruction is to develop elaborate and intuitive understanding of the algorithm behavior (Brown & Hershberger, 1998). The possibility for selecting special forms of data for pedagogical purposes is also important in AV systems. Users should be able to select predefined sets of data which either push the algorithm to extreme behavior (pathological data) or present special cases of behavior in order to promote student's understanding (cooked data).

- *Color techniques:* Color techniques are also widely used in AV displays to efficiently communicate significant state information. Color can be used to encode the state of data structures or to highlight activity. For example an animation may temporarily paint a small region with a contrasting color to focus attention on the painted area and highlight the exact data that the specific algorithm operation affects.
- *Smooth animation:* AV systems usually employ "smooth" animation for presenting the transition of data from one place to another. State transitions of the data set may be discrete but "animation can be useful to help smooth the transition between discrete states of a complex algorithm or process" (Stasko, 1998, p. 104). A typical example of smooth animation is when two sticks smoothly change position portraying the discrete change of position of two values in the data set.

Equivalence, affordances and dimensions of representations in AV systems

Equivalence: Comparing the representations usually appearing in AV systems one may categorize them as informationally equivalent or non-equivalent. As example of the former, consider the case of the pseudocode (or programming code) representation and the animated representation of the sorting algorithm (as depicted in fig. 4.4). These two representations represent generally the same relations (steps of the algorithm) albeit in different way (static textual vs. dynamic visual representation). In other cases the representations are not equivalent to any other. For example, a common representation concerning sorting algorithms is a two dimensional graph depicting the state of the data set as a collection of dots. Each dot represents a value in the data set, x being the array index and y the value. When running the algorithm the dots are moved to their appropriate positions depending on the data set transformation, and, consequently, the animated graph conveys the running time and the method used by each algorithm. Such kind of representation is not equivalent to any formal text based representation.

Affordances: Visualizations are expected to: (a) limit abstraction, by rendering concrete and observable what otherwise would not be easily perceivable or available for inspection, and (b) structure students' reasoning activity (by supporting a sort of "display-based" reasoning and following the notion that an effective display can ease the user's reasoning).

Perspective, Precision, Complexity: From what has been discussed so far it should be clear that the representations in AV systems vary significantly on the perspective they employ. While the traditional textual representations offer a more formal analytic perspective emphasizing the logical steps of the algorithm, the visualizations bring out the more dynamic features, enabling students to experience how fast an algorithm is operating upon data and focus also on comparing the running time and efficiency of various algorithms. One additional issue of perspective is that while textual representations allow users to focus only at a single point of code each time, visualizations try to bring the large software structures within the scope of a single view (something like "the helicopter over the landscape" (Petre, Blackwell and Green, 1998)) offering to users the opportunity of visualizing important structural characteristics of the overall software architecture.

The representations in AV systems may also vary in precision. For example, one display may present exact quantitative information about the algorithm processes (e.g. efficiency measures or the number of anticipated data comparisons) while another may present qualitatively information for depicting fundamental methods of data processing (e.g. the specific sorting method applied on data). Complexity can also be a serious problem to AV systems design and, as already mentioned, designers employ multiple views to present complementary information in order to minimize complexity. Using a single representation would be insufficient for showing all aspects of the domain and it should become too complex if it had to show all the information. Overall, algorithm visualization systems employ multiple textual and visual representations to appropriately vary the perspective, the precision and the complexity of the domain

Content, Persistence, Transformation, Versatility: Brown (1988b) discussing algorithm visualization displays proposed that animations (in general) can be described using three independent dimensions: Content, Persistence and Transformation.

- *Content*: The content of a display may be *direct* or *synthetic*. Direct representations are those that are directly produced by depicting corresponding data or code structures of the program. Thus, the display is constructed from the data structure (and vice versa) applying a simple mapping process without any other information being necessary. Synthetic representations, on the contrary, present concepts that are not originally included in (and therefore produced by) the structure of the data or any other program variable. They are usually some form of abstraction of the data or a synthesis to present how operations are causing changes to data.
- *Persistence*: this dimension refers to the property of the representation to either present information simply about the current state of data or include somehow a complete history of what has happened so far (that is the previous data states). Ainsworth and VanLabeke (2004) propose that we may distinguish between time-persistent, time-implicit and time-singular representations:
 - a. A *time-persistent* (T-P) representation includes the axis of time and enables learners to observe the way that one (or more) variable varies in time by presenting the current and all other values computed so far, of the variable.
 - b. A *time-implicit* (T-I) representation does not explicitly involve time but it presents the way that the relationship between two variables evolves in time.
 - c. A *time-singular* (T-S) representation displays the values of one (or more) variables at a given single instant of time (therefore it does not contain any historical information of the animated process).
- *Transformation*: the transformation dimension ranges from displays that show changes in the pictures discretely to those that show incremental and continuous changes. Discrete transitions simply replace on screen the old data characteristics with new ones, while incremental transformations show a smooth transition between the previous and next state. The usefulness of discrete and incremental displays depends on the amount of data depicted: discrete transformations tend to be most useful on large data sets while incremental transitions are

most effective when users are examining an algorithm running on a small set of data (Brown, 1988b).

Versatility: depending on their versatility AV displays can be described as generic or customized. A generic display is one that after initially being developed for one algorithm, it can then be easily adapted to host the representations of other related algorithms. Customized displays, however, are hard coded to display representations of a specific algorithm.

In a typical AV system there are usually available time-persistent and time-singular representations. The use of animated sticks to show how a sorting algorithm works is a time-singular representation if it does not allow the user to rewind it back and see the previous states of the data. However it is highly recommended (Ainsworth & Van Labeke, 2004) that representations should be designed as time-persistent so that students can easily move back and forward through the various states and check the points of their interest. Evidence for designing representations in time-persistent form is offered by Stasko and Lawrence (1998) who report that students identified as negative software aspects the absence of the possibility to step through the animation a frame at a time and the inability to rewind and replay (revert to the state before). Ainsworth and VanLabeke (2004, p. 9) also emphasize that "we would expect T-P representations will help learners to perform tasks that involve both current and previous values by reducing the memory requirements of holding previous states in memory to integrate with current ones". Finally, AV representations can be both of the generic and customized type depending, of course, on the type of information presented.

The functions of multiple representations in algorithm visualization systems

Ainsworth and VanLabeke (2004) stress the importance of making multiple representations available to learners in order to allow them (and instructors) to flexibly use those of the representations which best fit their learning objective. The flexibility of switching between representations is especially significant for understanding complex phenomena, a cognitive task that demands making various types of inferences based both on qualitative or quantitative information. Using multiple representations in algorithm visualization systems is expected to support all three fundamental functions (Ainsworth, 1999): (a) complementing each other, (b) constraining unfamiliar representations and (c) supporting students' constructing deeper (more abstract) understanding of the domain.

- *Complement:* Multiple representations can complement each other when they differ either in the information they contain or in the cognitive processes each one supports. In AV systems multiple representations display different views of the domain and this can be advantageous for learners regarding the tasks they have to perform (e.g. a graphical view of the changing states in the data set could more effectively support the kind of inference which is necessary for a certain task), or the strategy they follow (multiple representations may encourage learners' switching between learning strategies) or their individual preferences (students may work with their preferred representation thus engaging in learning activities more eagerly). Representations generally are expected to have different computational effectiveness depending on their appropriateness to support learner's inferential process for a specific task.

The very essence of the effort for developing AV systems is the expectation that dynamic visual representations are more appropriate for enabling learners to develop the kind of reasoning which is appropriate for the deeper understanding of such a complex domain. One representation may be more suitable for expressing the problem but less congenial to the user, and so a second representation might help the user to reason about the first. The bridging representation may assist the user to extend search and reasoning strategies appropriately. However, it is not clear yet what kind of representation may be more advantageous for the various kinds of tasks that AV systems are intended for. Petre, Blackwell and Green (1998) emphasize that "we must know more about uses, about tasks within uses, and about representations for tasks" (p. 455).

- *Constrain*: Students' prior familiarization with certain representational aspects can support them in constraining the interpretation of new representations. For example, students are expected to be familiar with the idea of a data set and therefore intuitively understand that the height of sticks on screen corresponds to the values of the represented data.
- *Construct*: Multiple representations in AV systems can be used to promote students' deeper understanding (promote abstraction). This is the case, for example, when the comparative display of multiple algorithms onscreen allows students to infer about their relative efficiency, thus gaining a deeper understanding about the overall algorithm performance, something that would not be possible just by studying isolated textual representations.

Dual Coding

Dual coding principally means that relative verbal and visual information is presented to the learner in a coordinated manner so that dual brain circuitry processes simultaneously the different external stimuli. Dual processing results in building referential connections between knowledge models based on verbal and visual information thus yielding better long term memory retention. Applying the dual coding hypothesis in AV design would mean that linguistic information (preferably in narrative form) should accompany the onscreen presentation of animated graphics, conforming to the relative presentation principles (e.g. contiguity, modality, redundancy, coherence and personalization⁶). Integrating the dual coding principles in AV systems design, seems to be a promising research area that deserves to be further explored (Hundhausen, Douglas & Stasko, 2002). Empirical evaluation of such systems has already been reported in the literature indicating improvement in the quality of the learning (e.g. Hansen, Schrimpscher & Narayanan, 1998).

Problems with multiple representations and types of support

The counterbalance in using multiple representations is that for each new representation added to the system, learners must understand its syntax (interpret its format and operators), understand what is represented and also be capable of translating between representations. To support students coping with

⁶ See chapter 1 for further information on these theoretical issues.

the translation overload, AV system designers can program their systems to automatically perform translation. This generally means that whenever an item changes in one representation (e.g. the value of a variable) the system automatically updates the respective item in any other related representation. In the case of AV systems a very common design technique for supporting translation is to simultaneously highlight the part of the code executed and the graphical entities that this execution affects (see fig. 4.4).

Another way of supporting students to rip the benefits of the AV technology is to have them use the visualizations systems in the context of collaborative activities, encouraging them to construct and present their own visualizations. In such instructional settings, AV systems should be designed in such a way that they become students' construction tools, enabling learners to collaboratively develop and present the intended visualizations, thus improving their individual processing of the external representation.

4.3 Pedagogical effectiveness of algorithm visualization

4.3.1 Is AV technology instructionally helpful?

We are going to give a straightforward answer to this question right from the beginning. Researchers seem to unanimously agree that AV systems can be of significant learning usefulness when they are used to engage students in active learning situations and not just put them in a passive viewer's position where they simply observe experts' visualizations (e.g. Hundhausen, Douglas and Stasko, 2002; Naps et al., 2003; Stasko & Lawrence, 1998). To achieve this engagement various techniques have been reported, such as having students import and study the behavior of the algorithm on their own input data sets, predicting future visualization states, programming the visualized algorithm, answering questions about the visualization and also constructing their own visualizations and presenting them to peers and instructors. In the following section we are going to analytically present and comment on the results from empirical studies which support the above stated thesis.

4.3.2 Research results from empirical studies

There are several studies in the literature, presenting empirical research results on the effectiveness and efficiency of using AV systems for learning. The majority of these studies follow the experimental research paradigm (e.g. Lawrence, Badre & Stasko, 1994), but there are also studies which apply ethnographic research methodologies focusing on results of qualitative nature (e.g. Hundhausen, 2002).

Hundhausen, Douglas and Stasko (2002) distinguish between at least four different theoretical approaches underlying the design of experimentation:

- *Epistemic Fidelity*: Epistemic Fidelity theory postulates that efficiently designed graphics can play the role of "knowledge vehicles" and transfer an expert's mental model of an algorithm to students who initially decode the available graphical representations and subsequently encode internally the conveyed knowledge.
- *Dual coding*: Emerging from Paivio's (1986) assumption that external verbal and visual information stimuli are processed in human brain by two distinct sensory channels and based on Mayer and Anderson's dual-coding hypothesis (Mayer & Anderson 1991) this line of

theorizing proposes that better learning conditions are created when both verbal and visual representations are used. In such a situation, the learner is supported to develop two mental models (one based on verbal and one on visual information) and also create referential connections between the representations. This mapping process and the integration with previous knowledge allows for better memory retention and recall.

- *Individual differences*: Theories on learners' individual differences postulate that there exist significant differences in the way that people prefer to engage in learning activities and further process the learning material. Based on this assumption researchers have identified various taxonomies for describing individual learning differences, which are usually referred in the literature as learning or cognitive styles (e.g. Kolb's learning styles (Kolb, 1994), Field Dependent / Field Independent cognitive styles). Learning environments should address various learning styles by adapting accordingly the presentation of the learning material and the learning interactions, in order to create optimum learning conditions for students independent of their learning styles.
- *Cognitive constructivism*: Constructivism asserts that knowledge can not be conveyed to the learner but that individuals rather construct their own internal knowledge representations based on their experiences in meaningful, interactive and collaborative situations. Therefore, AV systems are not to be considered (nor designed and used) as knowledge conveyors but rather as tools for enabling students to collaboratively construct their knowledge.

Experimental studies therefore can be classified according to their underlying learning theory which drives the design of the study and emphasizes specific learning benefits and reasons for their occurrence. A study, for example, classified under the "epistemic fidelity" category would be one that focuses on identifying learning benefits on the assumption that the better the mapping of algorithm structure on the animated graphical representation the better the students' learning.

The first conclusion one can draw from the majority of available studies is that the use of animation for teaching algorithms has led to lower learning benefits than was initially expected (Tversky, Morrison & Betrancourt, 2002; Narayanan & Hegarty, 2002; Kehoe, Stasko & Taylor, 2001; Stasko & Lawrence, 1998; Byrne, Catrambone & Stasko, 1999). Byrne, Catrambone & Stasko (ibid.) highlight this situation by stating that:

"The intuition of computer scientists has led them to believe that the animations must provide a learning benefit, but prior experimental studies of the influence of algorithm animation on student understanding have provided mixed results. Some studies have found benefits, but not at the levels hoped for by system developers, while others did not uncover benefits."

Tversky, Morrison & Betrancourt (2002) also caution that in several studies where animation seemed to be instructionally superior to static visuals it was due to the fact that the animation actually included additional information (either visualized or in the form of some greater interactivity). So, the idea that animated graphics per se would lead to better learning outcomes (without considering any other factors such as advanced interactivity, collaboration and social context) has proved to be too naive. These authors conclude that the many failures to find benefits of animation even in relation to change-over-time

situations calls for deeper inquiry into information processing of animation. So it seems that important questions arise in the field of algorithm animation (and animation for learning more generally): what are the conditions under which animation appears instructionally more effective? Can they be modeled? Can they be described and analyzed? We will try in the following to present the broader picture that emerges in the domain, organized into appropriate sub-sections.

Students like watching animations

First of all it should be emphasized that students like to watch animated graphics when learning in digital environments (Kann, Lindeman & Heller, 1997; Wilcocks & Sanders, 1994). Animation grabs their interest (Stasko & Lawrence, 1998) and they think they learn more from it (Demetriadis, Triantafillou, & Pombortsis, 2003). Hansen and Narayanan (2000) emphasize that students like to watch animation even if they do not really get any substantial learning benefits and so animation can be considered as "candy for the eyes". Kehoe, Stasko and Taylor (2001) present students' statements where they seem to accept that animation presents "what actually happens" in contrast to the programming code which presents "what it is supposed to happen". So, although students deal in both cases with representational codes (text and graphics) they seem to get the impression that animated visual code is somehow "closer" to reality. One could theorize that students may feel that the visual code is much closer to the actual internal representation (mental model) that they need to develop.

Novices focus on the surface features of the representation

When novices are introduced in a domain they tend to focus on the superficial features of the representations and, therefore, develop an initial understanding different from the one that characterizes experts' performance and which is based on more abstract generalized principles. Chi, Feltovich and Glaser (1981) have illustrated how novices categorize physics problems based on surface features while experts would classify the same problems according to deeper (more abstract) features. Anderson (1995) emphasizes that this change in problem representation underlie the acquisition of expertise in a number of domains including computer programming (experts think of a specific code structure, for example iteration, in terms of abstract language independent from the superficial characteristics of any specific programming languages).

Using animated maps to present weather changes to meteorological novices, Lowe (2003) reached similar conclusions, stressing that novices extract information from the animated graphics focusing on perceptual and superficial (as opposed to thematically relevant and deeper) characteristics of the display. Lowe (ibid.) concludes that the use of animation for learning should properly focus on supporting learners' extraction of domain-relevant information to be incorporated into prior knowledge structures.

Narayanan & Hegarty (2002) highlight another issue related to the difficulties that learners encounter when trying to initially comprehend the structural complexity of an animated system. They suggest that the first step toward enhancing learner' comprehension should be to employ some representational technique in order to illustrate the structural relationships between various system components (for example the use of an "exploded" diagram that shows the components separate in space).

All the above emphasize that when animation is used for learning at introductory level, substantial support should be offered in order for learners to avoid focusing on the superficial features and start comprehending the essential structural and semantically significant components of the represented system.

Integration in the classroom and instructors' attitudes

Instructors can use AV software in many different instructional scenarios the most typical being their use in lectures to present and explain aspects of the algorithms under study. AV systems can also be used in assignments, class discussions, laboratories, study, office hours and tests (Hundhausen, Douglas & Stasko, 2002). There is evidence that instructors accept the view that using AV systems can lead to better learning outcomes. Naps et al. (2003) report that when instructors were asked to indicate their level of agreement with the statement "Using visualizations can help learners learn computing concepts", the vast majority of respondents agreed or strongly agreed. This same study also acknowledges that there are serious disincentives for instructors who would like to integrate AV systems in their teaching, the most significant being the time it takes to develop visualizations. Lack of available time is reported as being a problem in other cases too: the time required to search for good examples, the time it takes to learn the new tools, the time it takes to adapt visualizations to teaching approach and/or course content. Naps et al. (2003, p. 11) conclude that "the most effective way to enable more instructors to use visualization will be to make it less time consuming and more convenient to do so."

Active learning

Several studies emphasize that learning with AV systems is much more efficient when learners are getting involved in active learning situations (Stasko & Lawrence, 1998; Hundhausen, Douglas & Stasko, 2002; Naps et al., 2003; Tversky, Morrison & Betrancourt, 2002; Kehoe, Stasko & Taylor, 2001). Active learning situations are cases where significant cognitive processing is happening, for example, activities where students make predictions (and subsequently see the results in the animation) or implement the algorithm (after viewing the animation) as part of the whole learning experience (Kann, Lindeman, & Heller, 1997) or view appropriate analogies from the real world (Hansen, Narayanan & Hegarty, 2002) or answer questions designed to stimulate critical thinking (promote reflection and self-explanation).

Lawrence, Badre and Stasko (1994) studied the use of algorithm animation in a case where the students were able to enter their own trial data to the algorithm and observe the resulting animation. These students outperformed those who viewed animations of the algorithm on predefined data (the former were in better position to understand and perform algorithm procedures and to answer conceptual questions about the algorithm). It seems that the specific interaction (entering their data) with the animation supported better cognitive processing and resulted in better performance.

One promising contribution to the group of AV systems is the HalVis system (Hansen, Schrimpscher & Narayanan, 1998, 1999; Hansen, Narayanan & Hegarty, 2002) where the use of animation is embedded in a broader hypermedia environment that utilizes multiple representations. Designers of HalVis emphasize that the use of the various representational codes should be interconnected in order to compensate for the

various cognitive demands and processes that the learner needs to be engaged into. For example, HalVis utilizes textual descriptions, audio narratives and static diagrams to provide contextual information; animations are presented in discrete chunks accompanied by explanations of the specific actions being accomplished; student participation is encouraged by allowing rich interactions with the animations and using probes or questions to stimulate critical thinking. One significant finding while evaluating the HalVis system has been that "interactive and animated analogies appear to significantly prime learning about abstract and dynamic algorithm behaviors from subsequent visualizations" (Hansen, & Narayanan, 2000). This again is a case where cognitive processing (providing appropriate contextual information and connecting to prior knowledge) significantly enhances learning outcomes from the subsequent use of animated graphics. Overall, the evaluation of HalVis has provided evidence that cognitively based design can provide students with the level of cognitive processing necessary to enhance learning significantly.

Byrne, Catrambone & Stasko (1999) report on a study where it seems that the crucial factor for better learning was not animation per se but guiding the learners to predict the algorithm behavior (learning improvement was found both in the group that used animation and in the group that used static diagrams). Narayanan & Hegarty (2002) also report having confirmed in a series of experiments the hypothesis that people generally learn better when attempting to predict the function of the system before watching the actual dynamic behavior of the system. However, Byrne, Catrambone & Stasko (1999) stress that the learning benefit from prediction has been observed only in the case of learning a simpler algorithm and not a complex one.

Naps et al. (2003) highlight in their "engagement taxonomy", the various levels of educationally fruitful interactions that AV systems could engage students into. From the basic level of "viewing" (not otherwise interacting with the AV system) to the advanced level of "presenting" (within a constructivist framework of learning) these levels are:

- *Viewing*: The state of simply viewing the visualizations or have available a basic level of control over its execution (e.g., controlling the direction and pace of the animation)
- *Responding*: Students are challenged to answer appropriate questions concerning the visualized algorithm.
- *Changing*: Student can modify the visualization. A typical example of such modification is when the students can change the input of the algorithm under study in order to explore the algorithm's behavior in various cases.
- *Constructing*: Students construct their own visualizations of the algorithm (this can be done either by "direct generation" or by hand construction).
- *Presenting*: Students build and present their own visualization to an audience for feedback and discussion.

There are still other factors reported in the literature which could be related to the level and quality of learners' cognitive processing. For example, drawing attention to appropriate features of the presentation might be a significant design factor for animation to increase effectiveness (Faraday & Sutcliffe, 1997). This fits well with the first step of "selection" in the cognitive model for multimedia learning based on dual coding hypothesis (Mayer, 2003): designers of e-learning environments should support learners to

focus their attention on the most significant elements of information thus promoting the selection process which is the first step for the development of mental models for dual coding.

Some other studies also promote the idea of "cognitive media", suggesting that "physical media" (representational codes) such as text, pictures, animations, etc. should be used to create appropriate forms of information (such as descriptions, examples, case studies, constructive visualizations) which are in accord with human inferential processes (Recker et al., 1995). Instructors should develop an understanding about the appropriateness and specific use that different representational codes may have; that text, for example, is important for precision, pseudocode is useful for conveying steps of the algorithm and animations are good for depicting operational behavior (Kehoe & Statsko, 1996).

Kann, Lindeman, & Heller (1997) provide evidence on the issue of knowledge transfer reporting a case where the use of algorithm animation had significant transfer effects: students who viewed animation enhanced their ability to recognize recursive problems. Narayanan & Hegarty (2002) having developed a six-step cognitive model for comprehension of dynamic information, present data supporting the view that the design of multimedia presentations which follow principles of this cognitively informed model may lead to better learning outcomes than conventional learning material design (either in paper based or computer based material). Their model suggests that design should provide support for learners to decompose symbolic representations, construct a static mental model, make referential connections, hypothesize causal or logical lines of the systems, construct a dynamic mental model and, finally, understand basic principles. Authors support the view that "it is the content and structure which is important and not the media and the modality for technology enhanced learning".

Finally, Douglas, Hundhausen and McKeown (1996) report that the visual depictions commonly used in algorithm visualizations may not accord well with student-generated conceptualizations of the algorithms). This noncongruence may help to explain some of the mixed results in the earlier empirical studies.

Designing the user interface

Ausserhoffer (2000) stresses that the successful use of animation depends also on the "transparency" of the environment in relation to the demands of the learner, which means that the user interface of the AV system should not intervene with the "language" (e.g. syntax) that the learners are accustomed to express the algorithm with. The user should be set free from all questions on how to build the animation sequence out of his input data. This study suggests that animation user interface should lower as much as possible the additional cognitive overload arising from the learners' need to successfully input their problem situation to the software tool. Gurka & Citrin (1996) also include animation system usability in the set of seven factors which they identified as significant in order for the animation to be fruitfully used.

Gloor (1998) discussing also the issues of user interface design presents "ten commandments" for building algorithm visualization user interface. Among other guidelines (which are also relevant in the general case of designing a user interface) Gloor suggests that design should (a) emphasize the visual component by rendering visualizations as self-explanatory as possible, (b) incorporate both symbolic and

iconic representations (in accordance with the dual coding principle) and (c) include analysis of algorithm behavior and execution history.

The kind of knowledge, task characteristics and individual differences

There is evidence that the use of animated graphics may affect learning in different degree, depending on the kind of knowledge under consideration (conceptual vs. procedural) and the learners' characteristics (gender and/or spatial skills). Jarc (1999) emphasizes this view stating that "it appears that algorithm animation may influence learning certain kinds of knowledge more than learning other kinds or may help certain kinds of students more than others."

Kehoe, Stasko and Taylor (2001) present evidence which supports the hypothesis that algorithm animation can best facilitate learning of the procedural operations of algorithms. According to these researchers "algorithm animations seem best suited to helping to convey the procedural step-by-step operations of an algorithm. They provide an explicit visual representation of an otherwise abstract process", (ibid., p. 282). Gurka and Citrin (1996) based on a review of empirical studies emphasize the importance of individual differences among learners in relation to animation generated learning benefits. Chan Lin (2001) reports on a study which focuses on the effectiveness of visual (animation and graphics) and textual presentation format in relation to the gender of the students and the kind of information presented. The results suggest that visual format may be more beneficial for procedural than declarative knowledge and especially for girls who benefited significantly more from visuals in relation to both these kinds of knowledge. Overall this study suggests that the benefits of visual formats may strongly depend on the kind of knowledge and the gender of the learner. Chan Lin (ibid.) stresses that the use of the visual format should not be assumed superior to other formats before gender and other individual and task characteristics of the learners are taken into account.

Park and Gittelman (1992) compared animated versus static visual displays in helping students troubleshoot electronic circuits. They did find a significant benefit of animated visuals, which means that the animated visuals group students were able to repair circuits with fewer trials. The researchers argue that a key factor in learning from animation is an appropriate match to the specific learning requirements of the particular tasks being examined. This observation fits well with the more general view that different representations are of different computational efficiency depending on the task at hand, thus demanding that designers should align representations with tasks.

Research Methodology

The failure of many studies to clearly identify the learning benefits emerging from animation has led some researchers to hypothesize that another research approach might be more useful for getting a deeper insight to the issue of the subtle yet significant benefits of animated graphics for learning.

Following this idea Kehoe, Stasko and Taylor (2001, p. 269) point out that (possibly) "something in the design of the experiment is preventing participants from receiving the benefits or in other words, the theory of how animations could help needs to be re-examined". So they set up a research case where a more realistic, homework-style learning situation was created. This may be characterized as a "study-

type" learning situation (animations were available while students were answering questions, unlimited time of using learning material was permitted, students knew the learning issues in advance) as opposed to more restricted "examination-type" situations (students are not aware of the questions they have to answer, learning material (animations) are removed after a certain period of time) which are typically employed in several formal experiments. The researchers speculate that in this study-type situation students could better benefit from available media and their combinations exactly because they knew how to better exploit their strengths in relation to the already known learning objectives.

AV systems as construction tools

Hundhausen (2002) strongly emphasizes that studies on AV efficiency have consistently yielded significant results when studying how the level of learners' active involvement affected learning (for example by asking students to construct their own data sets, answer strategically chosen questions, make predictions about the behavior of the algorithm or program the algorithm) and not when focusing on the representational characteristics (e.g. when studying the effect that changes in the attributes of displayed graphics might have on learning). Exploring further the idea that AV systems could be much more effective in the context of constructivist educational approaches, Hundhausen (ibid.) proposes that it is rather the "low tech" AV technology that efficiently supports students' focusing on relevant activities and concepts when constructing their visualizations, while "high tech" conventional AV systems may even distract them from doing so. From a constructivist point of view, therefore, an AV system is evaluated by taking into account its ability to evoke significant peer-to-peer and student-to-instructor learning interactions (becoming thus a "construction tool") and not so much as a tool which conveys to the students the visualization of the expert ("knowledge conveyor").

4.3.3 Representational density

From what has been presented so far, it is clear that the simple presentation of algorithm visualizations can not be expected to essentially advance learning as compared to the learner's engagement in active learning. However, other studies support the view that learning is significantly enhanced when visual and linguistic (verbal) elements of information are successfully dual coded in learner's brain. There are several experiments reported (e.g. Mayer, 2003) where the appropriately organized presentation of verbal and visual material resulted in significant better learning outcomes as compared to learning based only on textual learning material. Why does the simple presentation of visuals affect in so different way the learning situation? Do the above two lines of research lead to contradictory results?

We believe that answering these questions would make clearer that the cognitive processing of external representations can not be equally efficient in all situations. To better understand this let us take a closer look at what in the literature is usually termed as "active" learning. The term "active" is misleading to the extent that it allows one to assume that there is also "passive" learning. However, all learning is active. For learning to take place there is always some cognitive activity which is the reason for the development of mental representations in learners' long term memory. Obviously, we can learn even by simply viewing an external visual representation, provided of course that it can be efficiently processed.

However our cognitive system exhibits specific limitations one significant being the limited capacity of the working memory (see, for example, Clark and Mayer, 2003). When a complex and demanding external visual representation is presented to the learners for the first time then their cognitive system is overloaded.

To better describe this situation we find it useful to introduce the concept of "*representational density*". A representation is dense for a learner if, for some reason, the learner experiences a high cognitive overload when trying to process the information conveyed by the representation. These reasons may include:

- Abstraction (learner lacks prior knowledge on which to "anchor" the abstract representation).
- Complexity (too many interrelated pieces of information are presented overloading learner's working memory).
- Translation (information of the domain is shared between multiple representations and translating between them is demanding, thus overloading also learner's working memory)

When simply viewing a dense representation the cognitive processing of information is difficult if not impossible for the learners. Their internal cognitive functions are hindered; for example, the development of a mental model based on visual information and further referential mapping is retarded because it is difficult for the learner to rehearse the information in working memory and efficiently engage in the selection, organization, and integration cognitive processes⁷. In such a case the learners need additional learning experiences to appropriately analyze and process the complex information and construct the kind of internal representations adequate for understanding the dense representation (thus turning it to a "thinner" one, a more transparent one). Conversely, when the learners observe a representation of "low density" (the representation is simple or learners are already familiar with it or the class of similar representations) then the cognitive operations are facilitated and learning happens by mentally processing all available information (referential mapping is efficiently done and dual coding supports better memorization and recall). This is active learning too, with the difference that there is no demand for additional supporting learning activities.

Since the density of a representation varies depending on learner's expertise and prior knowledge then it is natural to expect that a simple iconic representation of everyday gadgets (such as those that has been used in the experiments attesting the superiority of combined textual and visual presentation) is transparent for the subjects of the experiments while the advanced complex visualizations in algorithm animation material are significantly dense for students who use them for the first time. Moreover, the fact that representational density can be minimized when the learner gets familiar with its syntax, leads us to hypothesize that even in the domain of algorithm animation the extensive learner's familiarization with the representation format will inevitably make the representations transparent enough so that their simple presentation and use will lead to efficient dual coding and therefore better learning. This is a hypothesis that can be experimentally tested.

⁷ These specific cognitive functions refer to the model for multimedia learning based on the dual coding hypothesis (see chapter 1 for details).

4.4 Conclusions

Algorithm visualization systems use multiple dynamic visual representations to support learning and instruction in the computer algorithm domain. Current research indicates that these systems can efficiently lead to better learning outcomes provided that they are used in ways that promote students' active engagement in deeper processing learning situations. The designers' and instructors' mission would be, therefore, to support students' efficient learning by (a) designing the user interface and the available multiple representations in a way that translation overload is kept to a minimum, (b) designing the AV system in a way that promotes the students' engagement in active learning situations, and (c) integrating AV tools in constructivist learning experiences to help students construct, share and negotiate their own meaningful visualizations.

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CHAPTER 5: The Interaction Between Internal and External Collaboration Scripts in Computer-Supported Collaborative Learning

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Abstract. In this chapter, scripts are discussed as instances for both internal and external representations that interact in computer-supported collaborative learning. The main purpose of most external collaboration script approaches is to facilitate collaborative processes and individual learning of the subject matter. Collaboration scripts often include a variety of mainly textual and graphical representations. However, it has to be conceded that the selection of such representations is rarely guided by psychological considerations. Rather, most approaches have their roots in theoretical accounts on collaborative learning or on computer-supported collaborative work. With internal scripts we mean the procedural knowledge individuals possess that guides them in collaborative learning situations. It is reasonable to assume that external collaboration scripts and the learners' internal scripts on collaboration interact with each other. First results from our research concerning this question are reported. Although not always possible, we used the criteria developed in chapter 1 to assess our own approach, namely a collaboration script for facilitating argumentative processes between two learners in a computer-supported collaborative inquiry learning environment. In the final part of this chapter, we try to sketch the main ideas for the development of a theoretical framework that can account for internalization processes during the interaction with an external script, which is based on considerations from distributed cognition.

5.1 Introduction

External representations play a crucial role in computer-supported collaborative learning. There are several reasons for why it is useful to bring together theory and research on individual learning with external representations on the one hand and theories of collaborative learning on the other. *Firstly*, collaboration can be used as a tool to improve individual processing of an external representation. By making predictions and observations as well as by interpreting the results of collaboratively manipulating a simulation of a water-flow model, for example, each learners' contributions can stimulate elaborative processes on behalf of the learning partner. *Secondly*, scenarios can be developed in which external representations are the product of collaborative processes. For example, learners might have the task to collaboratively develop a model with a simulation tool. *Thirdly*, external representations can be used to facilitate collaboration and collaborative learning. An external representation like a tangible physical object or a representation of arguments on a computer screen might direct learners' attention to specific parameters on the screen, thereby promoting specific discourse moves and in the end partially shaping their interactions (Roschelle & Teasley, 1995).

In this paper, we concentrate on the third point: using external representations to facilitate collaboration and collaborative learning, thereby focusing on a specific form of external representations of collaborative processes, namely "scripts". Today, in research on computer-supported collaborative learning, scripts are becoming more and more acknowledged as a means to effectively structure collaborative learning in a way that learners engage in more sophisticated activities, which in turn often leads to a deeper understanding of the problem at hand.

In instructional psychology, collaboration scripts are used and studied now for twenty years, at first in traditional face-to-face settings (e.g., O'Donnell, Dansereau, Rocklin, Hythecker, Lambiotte, Larson, & Young, 1985; King, 1998), but with the advent of the new communication and information technologies, collaboration scripts were increasingly developed to improve the effectiveness of computer-supported collaborative learning environments as well (e.g., Weinberger, Reiserer, Ertl, Fischer, & Mandl, in press; Rummel, Spada, Caspar, Ophoff, & Schornstein, 2003). Kollar, Fischer, & Hesse (2003) have provided a framework for a description of different collaboration script approaches from both traditional research on collaborative learning and computer-supported collaborative learning, that included six conceptual components.

Firstly, collaboration scripts are always designed to achieve a certain *objective*. Such an objective might be to get learners to acquire problem-solving strategies or to increase metacognitive awareness. Choosing a specific objective that is worth being supported should be the first step in developing a collaboration script. Only then a designer can approach the question how exactly the particular learning objectives should be reached.

Secondly, scripts should always induce *activities* that contribute to reach these objectives. For example, activities for reaching the objective to increase metacognitive awareness might be "monitoring" or "question asking". It is logical that there should always be a fit between the induced activities and the learning objectives that are tried to be reached by a collaboration script. However, assessing different collaboration script approaches revealed that this is not a trivial question. Especially in approaches from CSCL, it could be observed that the specific scripts are often designed in order to reach some "higher-level" objective like acquiring problem-solving competences, but that the activities that were supported were on a rather coordinative level like "ask for your partner's agreement before you edit the diagram".

Thirdly, the particular activities that are induced by a collaboration script are often supposed to be shown in a certain *sequence*. For example, in the guided reciprocal peer questioning approach (King, 1998), learners are at first supposed to ask review questions, then thinking questions, and then probing questions. Following that, if the questioner experiences problems with the learning partner giving adequate answers to these questions, he or she is supposed to ask hint questions, followed by metacognitive ("thinking-about-thinking") questions.

Fourthly, the induced activities often imply a specific sort of *collaborative role* to be taken on by each learner, and these roles are often switched over the course of collaboration. For example, in reciprocal teaching (Palincsar & Brown, 1984), learners are supposed to rotate a kind of "discussion-leader" role several times during the learning experience. There are remarkable differences between different

collaboration script approaches with respect to (a) what collaborative roles are induced, (b) how they are induced, and (c) if there are role switches and if yes, how they are achieved.

Fifthly, collaboration scripts can be analyzed in terms of the *type(s) of representation(s)* they are using. For example, script instructions can be provided in a textual manner or in a graphical way. Sometimes, learners receive instructions orally. As we will show later, questions like which representation format should be used in order to support learners most effectively to perform a certain task have hardly been subject to research on collaboration scripts.

Finally, scripts can be assessed in terms of their *locus of representation*. This concerns the question, where the script that is guiding the individuals' actions in a collaborative learning situation is represented – is it represented “in the learners' heads” (internal locus of representation) or is it represented in the external environment of the learners? For example, in some script approaches learners are supposed to internalize the instructions that are provided by the external collaboration script prior to the actual collaboration phase in a specific training. In other cases, however, the collaboration script stays accessible in the learning environment (for example on a computer screen) throughout the whole interaction phase. In yet other approaches, a gradual internalization of (external) script instructions can be assumed, that actually should be reflected in some sort of fading of these external instructions (Pea, 2004). However, this is an aspect that has hardly been subject to research on collaboration scripts. Therefore, in this chapter we will describe our own research approach, by which we were explicitly addressing the interplay of internal and external script components or “scriptlets” (Schank, 2002) in computer-supported collaborative learning. Referring to Schank and Abelson (1977), we assume that learners are holding individual prior knowledge on collaboration even before they enter a collaborative learning situation, which we will call the learners' “internal scripts” on collaboration. These internal scripts guide learners in understanding of and acting in particular everyday situations. For some activities, internal scripts are rather well-shared among the proponents of a certain culture (e.g., having dinner in a restaurant), whereas for others, internal scripts might be more unique to the individual holding this internal script (e.g., collaborating in an online learning environment). Therefore, we regard it as an important question to ask how externally induced collaboration scripts and the learners' internal scripts on collaboration play together and how they can be orchestrated in order to support collaborative learning processes as well as the individuals' knowledge acquisition about the problem at hand.

5.2 Scripts in computer-supported collaborative inquiry learning

In this chapter, we will describe an approach taken by ourselves (see Kollar, Fischer, Slotta, Koschwitz, & Kobbe, 2004), in which we developed an external collaboration script that was aimed at facilitating learners' collaborative argumentative knowledge construction while learning in dyads in front of one screen with a web-based collaborative inquiry learning environment (WISE; Slotta & Linn, 2000). Over the last years, great efforts have been undertaken in order to develop computer-supported inquiry learning environments like CoLAB (Savelsbergh, van Joolingen, Sins, de Jong & Lazonder, 2004), and BGuILE (Reiser, Tabak, Sandoval, Smith, Steinmuller & Leone, 2001), in which learners are enabled to explore scientific phenomena like “evolution” or “water flow” in a rather scientific manner. Arguing is a core

activity learners have to engage in when working in a collaborative inquiry learning environment. For example, arguments have to be built to explain and set up hypotheses, to plan an experiment, to interpret results, etc. WISE contains several curriculum projects for science learning, in which learners get information about specific science phenomena (e.g., “How far does light go?”), get access to online materials related to the issue (e.g., online newspaper articles, photographs, etc.), and are asked to discuss the validity of different hypotheses that might account for the problem at hand. For our purposes, we chose a curriculum project called “The Deformed Frogs Mystery”, in which students learned that huge numbers of frogs with physical limb and eye deformities were found in the late nineties. They were then provided with two hypotheses, which are subject to controversy with respect to explaining what causes these deformities. One hypothesis stated that the deformities were caused by a parasite that burrowed into the tadpoles, whereas the other hypothesis stated that the deformities were due to an environmental-chemical substance in the water of the dumps the frogs live in. The external collaboration script we developed (see below) was designed to support learners in discussing the information contained in the curriculum project (e.g., research reports, maps on the distribution of the deformities, photographs etc.) to finally decide which hypothesis was more valid. We were interested in whether this rather high structured external script would lead to better results in terms of learners’ acquisition of both domain-specific (knowledge about the contents of the curriculum project) and domain-general knowledge (knowledge about argumentation strategies) compared to a rather low structured external script. Further, we measured the learners’ internal scripts on argumentative knowledge construction and identified them as well as either being low or high structured, so that we were able to investigate what kind of external script would fit for what types of learners.

In the description of our approach, we will at first focus on the high structured external script, because it is our aim to analyze this collaboration script in terms of the dimensions proposed in chapter 1. However, following this we will also discuss the question of the interplay between internally and externally represented scripts, thereby shortly sketching some of the results that emerged from our study.

5.2.1 An external collaboration script for collaborative argumentative knowledge construction

The collaboration script we implemented into the WISE curriculum unit was designed to support learners in collaborative argumentative knowledge construction. By collaborative argumentative knowledge construction we mean the individual acquisition of both domain-specific and domain-general knowledge through engaging in argumentation. Yet, research on argumentation appears to be scattered, so it is not easy to determine what kinds of argumentative moves should be supported and how this support should be provided. We decided to merge two approaches in order to facilitate learners’ argumentative processes: On the one hand, we decided it was worthwhile to support learners in giving “complete” arguments. In order to define what a “complete” argument is, we referred to the well-known structural argument scheme by Toulmin (1958). According to the Toulmin model, arguments can include six structural components, namely data, claims, warrants, backings, rebuttals and qualifiers. In our work, we concentrate on enabling students to use *data*, on which an argument is based on, *claims* that are made on the basis of these data, and *warrants* that specify the relationship between data and claim, since these three components might be viewed as the most basic ones that constitute a scientific argument. On the other hand, there is a dynamic

perspective dealing with how argumentation develops in discourse. In such a view, argumentative sequences like “argument – counterargument – integrative reply” are important. Generating these argumentative sequences should result in higher learning gains concerning the contents of the subject matter (Leitão , 2000). Yet, there are few studies that have considered both perspectives, a research gap that is accounted for in our work.

The collaboration script we developed aimed at supporting learners in giving complete arguments (data, claim, warrant) as well as in generating complete argumentative sequences (argument, counterargument, integrative argument). The script was implemented into the WISE curriculum project “The Deformed Frogs Mystery” at several points of the project, namely always at the end of a content-specific chapter when it was the learners’ task to discuss the consequences of the presented evidence for the parasite and the environmental-chemical hypothesis (by clicking on buttons named “Discuss the parasite hypothesis” or “Discuss the environmental-chemical hypothesis” respectively). The design of the collaboration script can be viewed in figure 5.1.

The screenshot displays a web browser window with the URL <http://wise.berkeley.edu/student/toolbar.php?projectID=7627>. The main content area is titled "Hinweise zum Argumentieren" (Hints for Argumentation). It provides instructions on how to structure a discussion into three parts: 1. Argument, 2. Gegenargument (Counterargument), and 3. Integratives Argument (Integrative Argument). Each part is defined by its components: Observation (Beobachtung), Claim (Behauptung), and Justification (Begründung). A flow diagram at the bottom illustrates the sequence: 1. Argument (with sub-components: Beobachtung, Behauptung, Begründung) → 2. Gegenargument (with sub-components: Beobachtung, Behauptung, Begründung) → 3. Integratives Argument (with sub-components: Beobachtung, Behauptung, Begründung). A sidebar on the left contains navigation buttons and a progress indicator for "Abschnitt 1 VON 5" (Section 1 of 5).

Figure 5.1: Screenshot of the collaboration script (upper part of the screen, including the instructional text and the graphical representation of the argumentation flow).

This screen depicts the first part of the collaboration script at the time of its first appearance, i.e. when it was the first time that learners had to discuss the two hypotheses at the end of the first chapter of the project. In this frame, learners received textual information concerning how they should proceed in order to discuss the two hypotheses. In this text, they were told that they were ought to give an argument, a

counterargument, and an integrative argument, and that each of these three arguments had to include data, a claim, and a warrant. This structure was also displayed in a graphical manner, which can be viewed in the lower part of the screen. Further, if learners had trouble to understand these instructions, they had the opportunity to click on a link that led them to an example of a complete argumentative sequence including complete single arguments. Finally, the text on this screen informed learners that they had to take on different roles during the discussion. For the first discussion, it was specified that learning partner A had to advocate the parasite hypothesis (i.e., give an argument in favour of it), and learning partner B to attack the parasite hypothesis (i.e., give a counterargument). These roles were switched several times over the course the project in order to avoid biased information processing.

When learners scrolled further down, a number of empty text boxes appeared (figure 5.2). Above each text box, it was specified (in a textual manner) who of the two learning partners was supposed to fill it in and with what argument component. For example, for the first text box, it was specified that learning partner A was supposed to name an observation (data) he wanted to build his argument on. Next, he had to type a claim into the second text box, and a warrant that specified why the data supported the claim into the third text box. In order to make it more easy, the script provided sentence starters (e.g., "So it can be claimed..." for the claim) for each argument component, so that learners only had to complete the particular sentence with their observation, claim or warrant. For the time during which learning partner A was creating his argument, it was further specified that learning partner B had to monitor the completeness of A's argument. For the next three text boxes, these tasks changed, since B had to type a counterargument on A's argument (again with the three components "data", "claim", and "warrant"), and A had to monitor the completeness of B's counterargument. In the last three text boxes, both partners were supposed to jointly compose an integrative argument and to jointly monitor its completeness.

For discussing the environmental-chemical hypothesis, which was the next step in the curriculum project, learner B had to give an argument, followed by A's counterargument and a jointly composed integrative argument. As already mentioned, for the next times learners were supposed to discuss the two hypotheses, the roles of advocates for one of the two hypotheses were switched several times.

Since prior research has shown that collaboration scripts that are too restrictive can significantly reduce learning motivation of the learners (Kollar, 2001), the collaboration script used here was continuously faded out over the course of the curriculum project, i.e., at the end of the second chapter of the project, learners did not again receive the complete instructional text, and they only had to fill in three text boxes (one for the argument, the counterargument, and the integrative argument each). Further, the sentence starters were removed. Reducing the amount of instruction kept on until the end of the curriculum project. However, what was always present were (a) an instructional text (which got shorter over time), (b) a number of text boxes (nine at the beginning, then three, then one), (c) the graphical representation of the argumentation flow, (d) the link to the example, and (e) a specification of who had to fill in which text box.

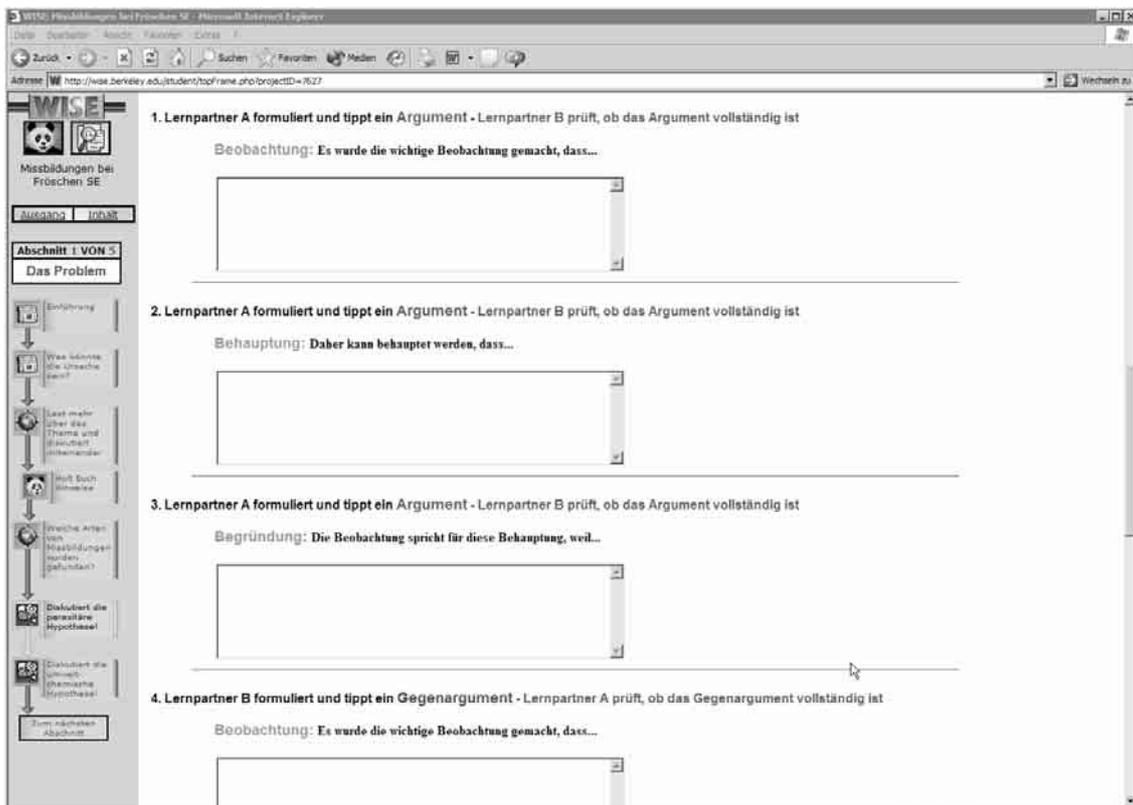


Figure 5.2: Screenshot of the collaboration script (lower part of the screen, including text boxes and sentence starters to be filled in by one of the two learning partners).

5.2.2 Analysis of the collaboration script with respect to characteristics of the used representations

We will now try to assess the collaborative argumentation script we used in our research in terms of the dimensions proposed in chapter 1. Note that in contrast to the widespread use of external representations as a means to represent *domain knowledge*, collaboration scripts rather represent *processes* of learning and collaboration. Therefore, not all dimensions seem to be useful for assessing our approach. Hence, we will focus on the dimensions we perceive as adequate for our particular collaboration script, mainly centering around aspects of *what* is represented, *how* it is represented, and *what problems* might occur in using multiple representations in a collaboration script. One of the most challenging problems, however, we regard as lying in the development of a theoretical framework on collaboration scripts, with a special focus on the interplay of internal and external scripts. Therefore, the discussion of theoretical considerations underlying our approach will follow the discussion of representational aspects in a special paragraph.

Multiple representations. As can be seen from the description, the collaboration script included both textual and graphical representations of the script instructions. Textual representations were the introductory text (the amount of which was reduced the more often the script appeared), the sentence starters (which disappeared after the second time learners had to discuss the hypotheses), and the example of a complete argumentative sequence that learners could click on voluntarily. The graphical representation of the argumentative flow was used whenever learners were asked to discuss the two

hypotheses. What is common to the two types of representations is that they both are static rather than dynamic representations. However, the representations provided in the external script were not the only ones, which had the potential to influence collaborative learning processes. Also the learners' internal representations of how to engage in collaborative argumentative knowledge construction were present in the collaborative learning situation, and each learner potentially could use the learning partner's internal representation as well, for example by asking "Does a counterargument also have to include data, claim and warrant?".

The representing world, representational codes, and modality. At a first glance, the collaboration script relied on textual and graphical codes, the contents of which were perceived by the learners through the visual channel. However, it might have been the case that one learning partner would orally repeat or paraphrase specific script instructions (e.g., "You did not give a warrant yet"), thereby representing a further "source of representations". Then, auditory channels of perception would also have been used.

Affordances of the representations. The main affordance provided by the collaboration script was that it structured the collaborative reasoning activity. The text boxes along with the introductory text, the example, and the graphical representation included "Aufforderungscharakteristika" with respect to get learners engaged in using evidence, come to conclusions, warrant these conclusions, consider counterevidence etc. The fact that there were empty text boxes for each of which learners received explanations for how they should be filled, should have led them to follow the script instructions in an intended way. Inducing an advocacy for one of the two hypotheses further was expected to lead to a higher rate of socio-cognitive conflicts (Doise & Mugny, 1984), which was supposed to encourage individual elaborative processes. Consequently, getting learners engaged in these activities was expected to result in an acquisition of both domain-specific knowledge about the problem at hand and domain-general knowledge about argumentation. It was hypothesized that learners having collaborated by aid of this collaboration script compared to a script that was low structured would result in a qualitatively better (written and oral) discourse and in better performance in subsequent knowledge tests. Preliminary results indicate that the script was able to get learners engaged in a qualitatively better written discourse and that learners acquired more domain-general knowledge on argumentation.

Reasons for using representations. The main reason for using representations was that the objects being represented (the particular parts of the argumentation strategy) are an abstract entity, which might not be perceivable or available for students if the strategy would not be represented in their surround (Perkins, 1993). The reasons for using textual and graphical representations of the script instructions were rather pragmatical. Considering the fact that participants in our study were students who accessed the web-based learning environment through their school's computer network, the used representations had to be rather low-level from a technological point of view. Further, inducing an argumentation strategy via text and graphical representations can be considered as fitting nicely with the learners' prior experiences since instruction at school is often provided in a textual and/or graphical manner. So, it was likely that students would understand what the script demanded them to do and internalize the strategies that were implied by the external script. However, "doubling" the same instruction in the introductory text and in the graphical representation was included in order to account for different needs of the students with respect to their preferences of how to get instructional information.

Precision and complexity of representations. Over the course of collaboration, the collaboration script's precision wanes. At the first appearance of the script, the instructions are very precise and tell the learners in a very explicit manner how they are supposed to fill in the text boxes. However, the more often learners discuss the parasite and the environmental-chemical hypothesis, the preciseness of the script instructions diminishes, which can be seen in that (a) the sentence starters disappear, and (b) the number of text boxes becomes lower. However, of course it was hoped that an internalization process with respect to the induced activities would emerge, which would make learners engage in the induced activities even without explicitly (or precisely) being told to do so. Hence, complexity of the (external) collaboration script was reduced as a function of time. However, a reduction of complexity in the external script might go along with an expansion of complexity in the learners' internal scripts as a function of how strongly they have internalized scriptlets from the external script. From a systemic perspective, then, complexity of the task itself would stay the same – the only thing that would change would be the complexity of the external and the internal representations. This aspect will be further discussed in the theory section of this chapter.

Purposes of using multiple representations and the resulting benefits. Chapter 1 provided a list of three main purposes for using multiple representations: First, multiple representations can *complement* each other. Second, multiple representations can be used because the inherent properties of one representation can *constrain* the interpretation of another representations. And third, multiple representations can be used in order to *facilitate* a construction of deeper knowledge structures in the internal representational systems of the learners. We think that the different representations used in our collaboration script can be regarded in terms of all three purposes. First, we included different representations of the instructions in order to account for possible preferences learners might exhibit. It might be that some learners understood the instructional text very well, whereas for others it might have been fruitful to have the opportunity to look at the graphical depiction of the argumentation flow or have an example showing a complete argumentative sequence. Further, since learners had to perform a variety of complex activities, it might be a good thing to have them at first read the whole instruction, and then provide the opportunity to glance at a compressed graphical depiction of the argumentation flow. Using just one representation (text, for example) might hence result in a complex presentation of excessive information, which would be likely to cause cognitive overload on behalf of the learners. Second, some learners might have difficulties when they would only be provided with a "condensed" graphically representation of the induced strategy. In this case, it is useful to provide learners with some more specific instructional text, which helps to interpret the graphical representation of the collaboration script. That way, the text can help learners to understand the graphical representation of the script in that it constrains its interpretation. Third, using a textual and a graphical representation can be viewed as promoting abstraction (Schwartz, 1995) of the induced activities in a better way than would be possible when using only one kind of these activities. In this vein, especially the clickable example of a complete argumentative sequence should be considered: there, learners could see an authentic application of the strategy that was textually and graphically represented before, which should have led to a light-bulb moment in a sense that some learners might have not understood the script instructions before not having seen a real application of this formal

strategy. The example in combination with the abstract and formal instruction might then be useful to abstract and generalize from the example to an argumentative discourse about the contents at hand.

Problems with multiple representations. Since we are still in assessing the students' collaborative artifacts (i.e. what they typed into the text boxes), we cannot yet say if there were substantial problems with respect to understanding what was represented. However, it might be that single students could have had problems with understanding terms like "integrative argument". Yet as already mentioned, we tried to minimize this danger by offering students multiple representations of the collaboration script, namely a textual version along with a graphical representation plus an example, in which a complete argumentative sequence was represented. Since the different representations were rather isomorphic, we did not expect students to have problems in relating them or translating between them.

Types of support. Beyond the support students gained by reading the textual and looking at the graphical representations of the collaboration script, they also were supported in processing the external representations simply because they found themselves in a collaborative learning situation. Hence, if one of the learning partners would not understand the contents of the collaboration script, this lacking information could be asked from the learning partner. However, it has to be conceded that it is likely the case that students show a "illusion of consensus" (Miyake, 1986) assuming that both learning partners have understood the instruction in the same way, and that differences in understanding only appear later during the individual application of the strategy. However, still, the fact that there was a collaborative learning situation made it more likely to reveal misunderstandings in that respect than would be possible in a single-learner scenario. Realizing a collaborative learning scenario increased the likelihood of mutual corrections. Abstracting from the mere understanding of the instructions learners were faced with, the collaboration script was designed to promote collaborative learning processes, which probably would not appear if learners were not provided with such a script. The collaborative learning processes that were invoked by following the script instructions were assumed to result in a deeper processing of the learning materials and should in the end lead to a better understanding of both domain-specific and domain-general knowledge.

Degrees of freedom in interacting with the external representations. Concerning the question how many degrees of freedom learners experienced during working with the argumentation script, we suggest to make a difference between *how* to discuss evidence and *what* evidence to discuss. With respect to *how* learners were supposed to discuss evidence, the script – at least in the beginning – restricted their degrees of freedom rather extensively. However, the longer the learning session and the more often learners had performed the task of discussing the two hypotheses, we assumed an internalization process with respect to the external instructions would take place, which allowed for a smooth reduction of the script instructions. This, in turn would make it possible to give some of the degrees of freedom back to the learners by reducing the amount of instruction inherent in the external collaboration script. Consequently, the last instances in which the collaboration script appears can be regarded as rather providing rough margins to apply the learned strategy without too much coercion (no sentence starters, less text boxes). With respect to *what* evidence learners discussed, there were rather many degrees of freedom, since the collaboration script did only specify what strategy should be used to discuss, but not what contents were supposed to be discussed. In fact, we observed many students who often referred to their personal prior

knowledge on the effects of the hole in the ozone layer on physical deformities, without this topic being a part of the curriculum unit.

5.2.3 Theories guiding the design of the collaboration script

In the dimensions proposed in chapter 1, four theoretical approaches, which are dominant in research on external representations, have been introduced: (a) theories of computational effectiveness (e.g., Larkin & Simon, 1987), (b) dual coding (Paivio, 1990), (c) cognitive load theory (Yeung, Jin, & Sweller, 1998), and (d) multimedia design theories (e.g., Ainsworth, 1999; Mayer, 2003; Schnotz & Bannert, 2003). For the design and implementation of our collaboration script, none of these theories were constitutive. Rather, we designed the collaboration script against the background of a cognitive-elaborative perspective on collaborative learning (see Webb, 1989) dealing with the question how collaborative processes can be stimulated that serve as a motor for individual learning. Main mechanisms and processes are socio-cognitive conflicts (Doise & Mugny, 1984), giving and receiving explanations (Webb, 1989), asking questions (King, 1998), and engaging in argumentation (Leitão, 2000). For example, distributing collaborative roles among the learning partners was considered as a means to invoke socio-cognitive conflicts between the learning partners. In a socio-cognitive conflict, learner A is confronted with the (externalized) internal representations of learner B, which probably will deviate from his own representation (since he has to advocate the opposite hypothesis). Likewise, giving explanations can be regarded as being a source for representations from the learning partner that can be compared to one's own representations and be subject to further discussion, leading to restructuring processes in the individual's cognitive system.

However, for future research on collaboration scripts, we do see a potential for using theories as the proposed ones. For example, dual coding (Mayer, 2003) as well as structure mapping (Schnotz & Bannert, 2003) might be useful with respect to design issues like using rather text or graphical representations or both in order to get learners engaged in higher-order collaborative processes. Also, cognitive load theory might provide a useful interpretative background especially when developing collaboration scripts, in which the induced activities are complex and new to the learners. Up to now, however, we perceive research on collaboration scripts as being stimulated by either cognitive models on collaborative learning (see above) or – in case of many computer-based collaboration script approaches – as having its background in research on computer-supported collaborative work rather than in the proposed theoretical accounts, which focus more likely on individual learning with external representations.

Elsewhere, we have developed a framework for describing scripts for collaborative learning from a distributed cognition perspective (Kollar et al., 2003; Carmien, Kollar, Fischer, & Fischer, in prep.). One main claim of approaches from the tradition of distributed cognition (e.g., Salomon, 1993) is that cognitive processes do not only occur within an individual's mind. Rather, they can also be regarded as partially being distributed over the technological and social environment of the individual, although this conception is not without criticism (see Newell, 1990). Consequently, the unit of analysis shifts from the single learner's cognitive system to the cognitive system that is established by the learner plus his

surround, together forming an "activity system" (Cole & Engeström, 1993). Perkins (1993) provides an account to describe this instance, distinguishing between the "person-solo" and the "person-plus". Theory and research on distributed cognition claims that an adequate examination of cognitive processes occurring during a learning session requires a consideration of both, the cognitive processes within the "person-solo" as well as the ones occurring in the "person-plus".

Transferring these considerations to learning with collaboration scripts, one can ask the following questions: What are the components of the "activity system" (Cole & Engeström, 1993) that is acting in the learning situation? How do these components interrelate? Which parts or components of "cognition" or "intelligence" (Pea, 1993), or "scripts" should be *distributed* among the components of the activity system, and which ones should rather be *shared* or *kept* by the individual?

Imagine two people learning collaboratively by aid of a collaboration script. Let us take learner A as the "person-solo", including his or her individual cognitions, motives, beliefs, in short his or her internal script. The immediate surround consists of (a) learning partner B and (b) the learning environment of which the collaboration script is an integral part. The "person-solo" might be supposed to acquire a certain kind of knowledge during the learning phase. This goal could have been set by the teacher or by the designer of the particular learning environment. The collaboration script, representing an intentional attempt by the designer to get the "person-solo" engaged in activities correlated to reaching the particular learning objectives, can be thought of as carrying "intelligence" concerning how to act in this learning situation. It enriches the learning situation by providing affordances (concerning the activities the "person-solo" is supposed to accomplish) and constraints (concerning the activities the "person-solo" is not supposed to accomplish). Similarly, learning partner B owns intelligence as represented in cognitions, beliefs, motives etc. For partner A, partner B's script can be a source of knowledge with respect to how to act in the learning situation, as well as the script instructions and his or her own cognitions. In short, the script is distributed among learner A, learner B, and the learning environment.

The designer of the learning environment must determine what knowledge can be assumed to be existent either within learner A's or learner B's cognitions – or in both. That determination should guide the consideration about what knowledge or intelligence should be integrated into the collaboration script. The assumption that the learners (or at least one of them) possess adequate internal scripts on how to collaborate effectively should lead to a reduction of devices in the externally imposed collaboration script that are aimed towards supporting the learning partners' collaboration process. If there are already adequate internal scripts, a provision of external scripts may be detrimental or at least dispensable; if there are no adequate internal scripts, it is necessary to provide one externally.

However, as collaborative learning situations evolve over time, it is conceivable that learners might gradually internalize the learning activities specified by an external collaboration script. In this case, gradually fading (Pea, 2004) the external script instructions out during the learning process can be helpful, since some of the imposed activities become part of the learners' script repertoires and therefore do not need to be scaffolded any longer. McNeill, Lizotte, Krajcik, and Marx (2004) could even demonstrate that faded instruction concerning writing explanations can lead to better performance in analogous post-tests when compared with continuous scaffolding. In other words, the script designer has to decide what the *effects with* and the *effects of* the script should be. According to Salomon (1993),

effects with technology comprise effects that occur during interaction with that technology, or in this case the externally imposed collaboration script. These effects help learners to move toward a solution of the task. *Effects of* the script, in contrast, are those that appear when learners acquire some kind of knowledge or skills that can be transferred to other contexts. For example, a goal of an externally imposed collaboration script could be to help learners in finding a solution for a particular problem at hand (effects with), but also to develop heuristics that can be transferred to problem solving processes, which are different from the ones at hand (effects of). Building on this distinction, the designer of an externally imposed collaboration script also has to make a decision concerning which activities the learners should internalize and which "scriptlets" (Schank, 2002) can be "left" within the external collaboration script. For example, internalizing script features aiming at supporting coordination within a videoconference setting is probably less worthwhile than internalizing script features that support learners to engage in argumentative discourse.

We believe that viewing collaborative learning with collaboration scripts from a distributed cognition perspective might be fruitful both for future theory building and for the development of collaboration scripts that facilitate both: group learning and individual learning.

5.3 First results concerning the interplay of internal and external scripts

In the beginning of this chapter, we shortly outlined that we were particularly interested in how specific types of externally provided collaboration scripts would interact with the learners' internal scripts on argumentative knowledge construction. To answer this questions, two steps had to be undertaken (see also Kollar, et al., 2004; Kollar & Fischer, 2004): First, we developed a second external collaboration script to be compared with the high structured external script we have just assessed. This low structured external script appeared at the same points in the WISE curriculum project, and it demanded learners to discuss the parasite and the environmental-chemical hypothesis on the basis of the evidence they could explore in each chapter of the environment. The interaction of the two collaborators was not further structured. Second, the learners' internal scripts on argumentative knowledge had to be measured. Learners were identified as holding a high or a low structured internal script by assessing their performance in a test, in which they were asked to evaluate a fictitious discourse between two students about a science topic. This discourse included "good" and "bad" arguments and argumentative sequences in the sense of the models proposed by Toulmin (1958) and Leitão (2000), i.e., some utterances contained complete arguments, whereas others did not, and sometimes, argumentative sequences had the "argument – counterargument – integrative argument"-structure proposed by Leitão (2000), whereas in other cases, they had not. The students' task then was to individually identify these "good" and "bad" arguments or argumentative sequences and specify why they were good or bad. The individual point scores on this measure were then used for a median split procedure, resulting in half of the learners holding low structured internal scripts and half of the learners holding high structured internal scripts on argumentative knowledge construction. Next, dyads were established, which were homogeneous with respect to the individuals' internal scripts and gender and were randomly assigned to one of the two external script-conditions.

The main results of our study were the following (taken from Kollar & Fischer, 2004): With respect to the acquisition of domain-general knowledge about argumentation, it appeared that the high structured external script was effective. Learners having collaborated by aid of the high structured external script achieved higher scores in the particular posttest than did learners who learned on the basis of the low structured external script. When controlling for argumentation-specific prior knowledge, it did not matter if the learners' internal scripts were high or low structured. Also, the interaction between internal and external script did not turn out to be significant (see figure 5.3).

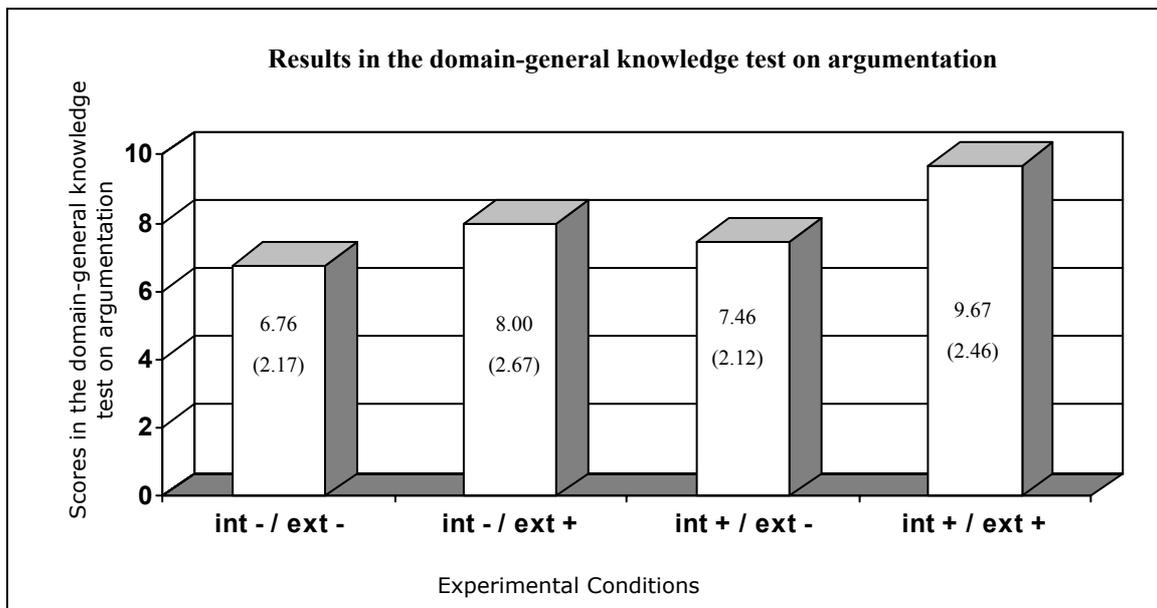


Figure 5.3: Average scores (standard deviations in brackets) in the test on domain-general knowledge on argumentation across the four experimental conditions ("int" = internal script; "ext" = external script; "-" = low structured; "+" = high structured; taken from Kollar & Fischer, 2004).

However, the high structured external script did not manage to boost learners' individual acquisition of domain-specific content knowledge: there, it appeared that the learners' internal scripts on argumentative knowledge construction were more influential (see table 5.1).

Table 5.1: Average scores (standard deviations in brackets) in the domain-specific knowledge test (pre- and posttest) in the four experimental conditions (taken from Kollar & Fischer, 2004).

	Low structured internal script				High structured internal script			
	Low structured external script		High structured external script		Low structured external script		High structured external script	
	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest
	M	M	M	M	M	M	M	M
	(SD)	(SD)	(SD)	(SD)	(SD)	(SD)	(SD)	(SD)
Domain-specific content knowledge	2.58	4.69	2.32	4.91	2.50	6.00	2.50	6.12
	(1.33)	(2.05)	(1.32)	(2.02)	(1.48)	(1.65)	(1.32)	(2.03)

Learners holding high structured internal scripts outperformed those holding low structured internal scripts. Thus, it can be said that if students do already possess well-defined knowledge about how to engage in argumentation, they can use this knowledge in order to elaborate content knowledge more deeply and thus to acquire more domain-specific content knowledge. However, we are currently trying to find further support for this interpretation by analyzing students' discourse (both written and oral). More specifically, we are interested in whether and how the interplay of internal and external scripts evolves over time, assuming that the more often and the more deeply learners interact with the external collaboration script, the more they will internalize the strategies that are induced by it. This would also lead to theoretical considerations and offer a dynamic perspective on how to orchestrate internal and external scripts in order to let effective learning take place. We suggest that for this, a distributed cognition perspective might be useful in order to reconceptualize this relationship.

5.4 Conclusion

In this chapter, we conceptualized collaboration scripts as a specific form of external representation in that they provide learners with procedural information how to proceed in a collaborative learning situation. We then tried to apply the dimensions that were introduced in chapter 1 for an assessment of our collaboration script approach, which aimed at inducing a collaborative argumentative knowledge construction strategy learners were supposed to apply in discussing the contents of a collaborative inquiry learning environment.

Some of the dimensions of the catalogue developed in chapter 1 were easily applicable to our approach, e.g. questions for the types of the multiple representations being used, what modality they were referring to, or how precise and specific the script instructions were. On a theoretical level, however, we added ideas coming from research on collaborative learning as well as from distributed cognition to the theoretical models that were proposed in chapter 1. We noticed that these rather classically cognitively oriented models up to now were not strongly accepted by research on collaboration scripts. Rather, it seems to be the case that there are whole different theoretical backgrounds for research on (individual) learning with external representations like simulations and animations, and for collaborative learning with collaboration scripts. Of course, describing a collaborative learning scenario and the instructional means that are developed in order to facilitate collaborative processes necessarily have to be based on theoretical accounts for collaborative learning. However, we do see a great potential in introducing theoretical models of multimedia design into research on learning with collaboration scripts. By aid of these theories, it should be possible to develop collaboration scripts, whose roots are not only located in instructional psychology research on collaborative learning but which also make use of insights gathered in media psychology. For example, the dual coding approach might lead a designer to include script instructions, which are represented both textually and orally (e.g., by including a sound file into a computer-supported learning environment. Indeed, here seems to be a gap in theory and research on collaboration scripts.

Another aspect that deserves more both theoretical and empirical work is the question of how internal and external representations play together in learning with collaboration scripts. Referencing to Schank and Abelson (1977), we claimed it to be useful to conceptualize learners as entering collaborative learning

situations with more or less well-developed procedural knowledge that guides their interactive behaviour, calling this knowledge "internal scripts". It is likely that internal and external scripts interact in many ways, although our study did not demonstrate any negative interaction between internal and external scripts. Further, it was shown that internal scripts might be more powerful with respect to the acquisition of domain-specific content knowledge and that external scripts can be designed in order to facilitate the acquisition of domain-general knowledge on argumentation. However, a lot needs to be done to better understand this interplay.

In the end of this chapter, we tried to outline some thoughts towards a theoretical framework for how to conceptualize this complex interplay – based on distributed cognition – thereby also taking into account internalization processes that might appear during collaboration and that might make it necessary to think about a gradual reduction of the instructions inherent in the external collaboration script representation. One of the main questions for future research on collaboration scripts therefore should be: How can the different scriptlets represented in a collaborative learning scenario (internal scripts of the learners, external script of a computer environment and/or of a teacher) be orchestrated in order to improve collaborative processes and individual learning outcomes? Both empirical and theoretical accounts are needed to answer this question.

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CHAPTER 6: Representation, note-taking and memorisation

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Abstract: Multimedia learning materials contain different modalities and representations of concepts to be learned. Question is: during the learning process how can students effectively take notes in form of a summary, which would aid memorisation of the material as a whole including interconnections. For this purpose we would examine the use of hypermedia mind maps as a tool for taking notes/making summaries and the issues of their use in aiding memorisation for students with different learning styles and cognitive approaches.

6.1 Mind mapping

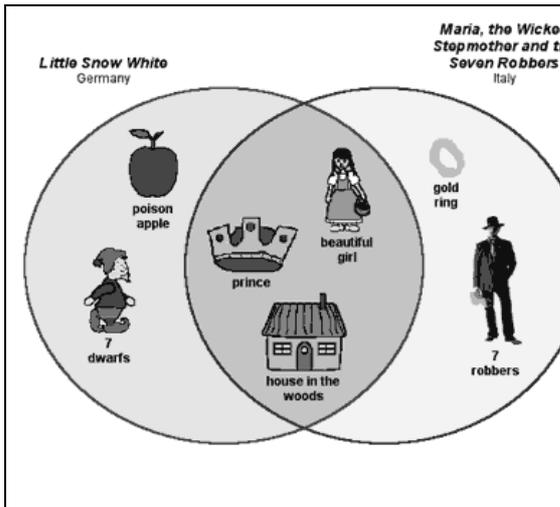
Jonassen et al. (Jonassen, et al, 1993) defined concept maps as “representations of concepts and their interrelationship that are intended to represent the knowledge structures that humans stored in their minds.” While concept maps are formed by nodes (represented as lexical labels) and links (represented as lines) having individual labels between nodes, mind maps can be more freestyle, visual and do not necessarily have particular meanings imposed on relationships (Buzan, 1995).

The main characteristics of concept mapping and mind maps as learning tool:

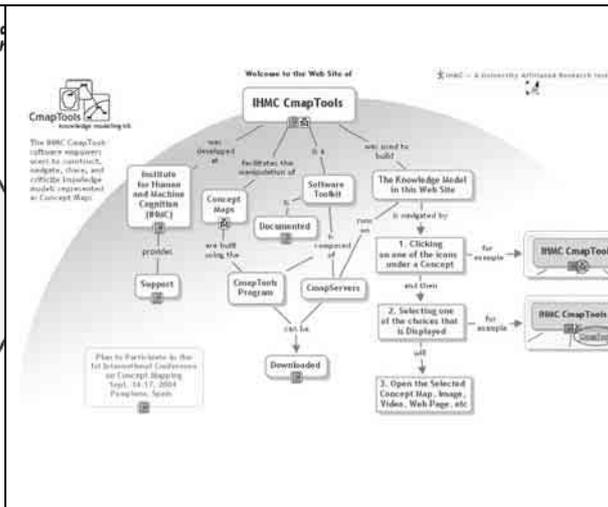
- They help to access representation as a given state in learning, especially if involving drawing and writing processes.
- They are communicational tools to share content and ideas in their complexity.
- They are useful for collaborative activities, where existing representations can be easily modified if created using computer tools.
- Creating them is an effective constructive learning process since it requires explication, reflection and enhances critical thinking.
- Using them in context of hypertext is suitable as navigation tool within educational materials and in assisting reading comprehension within complex text.

6.1.1 Some software that supports mapping of the mind:

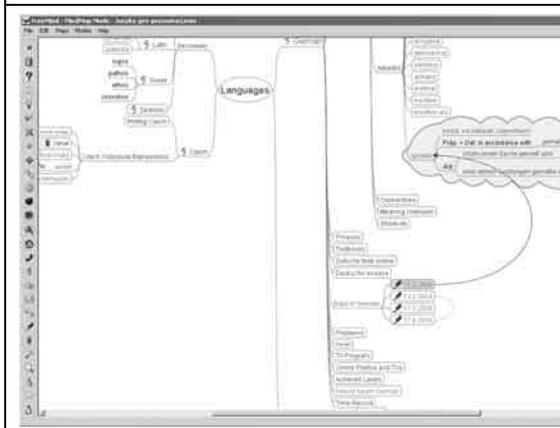
Axon Idea Processor	http://web.singnet.com.sg/~axon2000/
BrainMine	http://www.neuralmatter.com/
ConceptDraw	http://www.conceptdraw.com/en/products/mind map/main.php
FreeMind	http://freemind.sourceforge.net/
IHMC CmapTools	http://cmap.ihmc.us/
Inspiration	http://www.inspiration.com/productinfo/inspiration/index.cfm
NovaMind	http://www.nova-mind.com/
The Creative Thinker	http://www.idonresources.com/ct/creativethinker.html



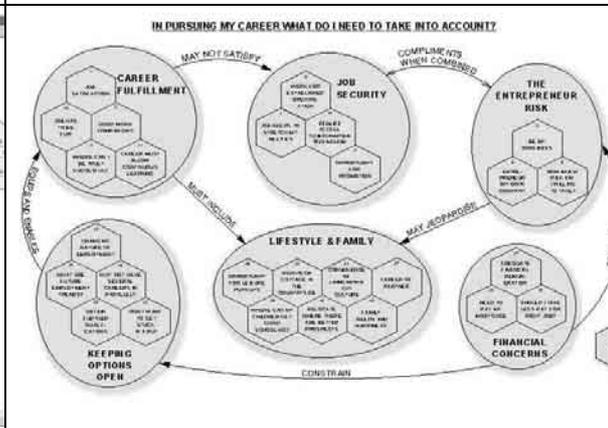
by Kidspiration (Inspiration for kids)



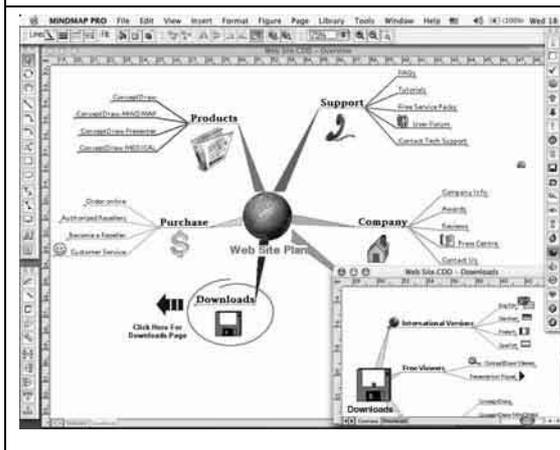
by IHMC Cmap



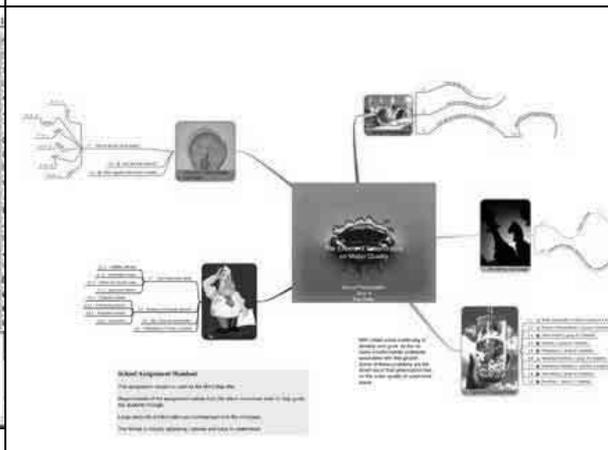
by Freemind freeware



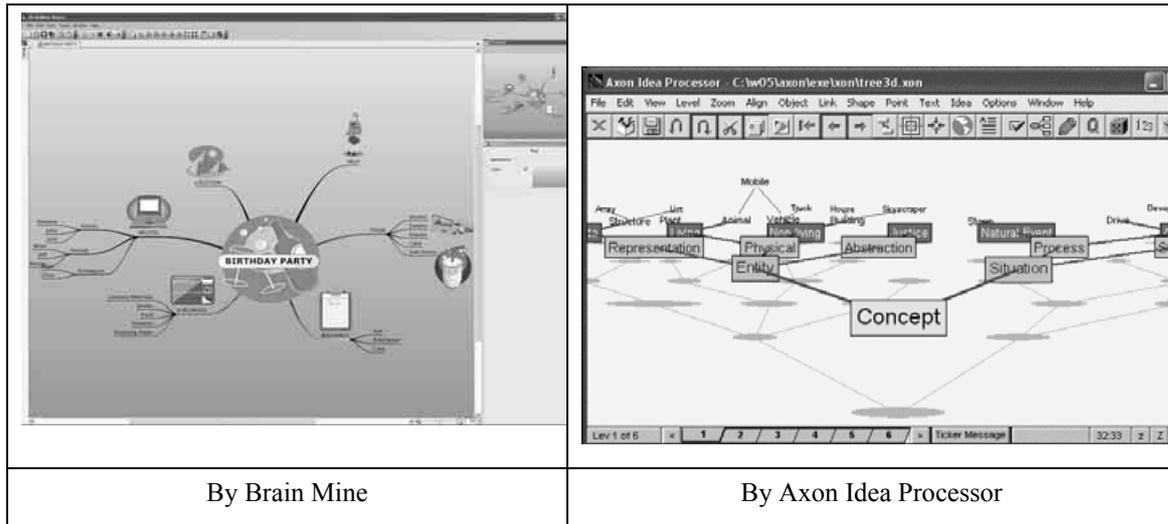
by Creative Thinker



By Concept Draw



By Nova Mind



Carefully used, the Web can serve both as a way to represent maps of content, and also as tools to assess what students know about something, using tools described. Mind mapping tools should be designed in order to provide maximum freedom for the learners to use it as flexible as possible.

6.1.2 Information mapping techniques

Note taking is considered (among others) an organizational coding strategy. Note taking may be a highly generative activity; however, quality of notes, type of elaborations, and opportunity for review can affect what, how much, and for how long information is learned.

Organizational tasks require learners to relate ideas from a passage together by using a variety of symbolic representations. Integration Strategies examines the effects of activities that require a student to relate information to prior knowledge, where learners are integrating information through imaging, elaborations, and analogies.

Some mapping techniques are radial, with the key concept in the centre of the diagram and related concepts on arms reaching out from the centre (Hughes, 1989). Other schemes are more hierarchical with concepts placed on branches of a tree (Johnson, Pittelman, & Heimlich, 1986). Still others maintain the roughly linear format of sentences but use special symbols to encode interconcept relations, like equals signs or different kinds of boxes (Armbruster & Anderson, 1984). Some computer-based systems provide more flexibility by allowing zooming in or out on concepts to reveal subconcepts within them and by allowing users to introduce pictures and graphics from other sources (Fisher, Faletti, Patterson, Thornton, Lipson, & Spring, 1990).

Research suggests that a number of concepts can be explored by using hypermedia's cognitive flexibility. This technology parallels mental models by permitting associations or links among various ideas to be formed, then constructing meaning among these relationships (Kozma, 1991). Hypertext cannot help cram facts into students' heads any more effectively than most texts. It is most effective for helping students to integrate concepts, engage in problem-solving activities, and develop multifaceted mental representations and understanding.

6.1.3 Some mapping strategies (Fisher, 2000a):

A. Cluster Maps and Webs: Clustering and webbing are techniques that capture associations between ideas. Cluster mapping was developed as a creative writing technique by Rico (1983). The idea is that clusters are produced by "first gaining access to the natural functions of the right brain and its predilection for wholeness, images, and metaphors, followed by a conscious collaboration with the syntactical, logical left brain" (Ambron, 1988, p. 122).

B. Mind maps: Mind maps® are similar to cluster maps and webs, but have been developed and promoted independently by Tony Buzan, saying: „The Mind Map is your external mirror of your own Radiant Thinking and allows you access into this vast thinking powerhouse" (Buzan 1995).

C. Computer-Generated Associative Networks: Cluster maps, webs, and Mind Maps are strategies for people to use to help them think about and learn a topic. When used as learning tools they can be considered input devices. Mapping can also be used to see what is already inside a person's mind. In this case, mapping becomes an output device. Schvaneveldt (1990) developed the Pathfinder software to do this.

D. Concept Circle Diagrams: As noted above, concept circle diagrams (CDs) were developed by Wandersee (1987). These diagrams help students to understand inclusive/exclusive relations among elements and categories.

E. Concept Maps: Concept mapping was invented by Joseph Novak and several of his graduate students and has since been enthusiastically promoted by Novak (e.g., Novak & Gowin, 1984).

F. Semantic Networks: The SemNet® software for the Macintosh was initially designed as a learning tool for use by students, especially those in college biology classrooms (Fisher, Faletti, Patterson, Thornton, Lipson & Spring, 1990), although it now enjoys much wider use. SemNet® [<http://www.biologylessons.sdsu.edu/about/semnetdown.html>] provides a model for the way in which denotative factual information is organized and functions in long-term memory. The software allows individuals to construct large networks of ideas containing dozens or hundreds or thousands of concepts. Bidirectional links are formed between pairs of related concepts.

G. Conceptual Graphs: So far we have discussed knowledge mapping as a learning tool and assessment tool. The conceptual graphs introduced here have been used primarily as a research tool. Conceptual graphs differ from concept maps and semantic networks in that concept nodes may contain concepts, events, states, goals, and other elements, and these can be described by simple names or complex propositions. The nodes are connected by named unidirectional or bidirectional relations. Overall, complexity rises to a higher level. Conceptual graphs are usually laid out on large paper maps but have sometimes been created with a special version of the SemNet® software that does not limit the number of characters in a concept node

H. Visual Thinking Networking (VTN): The Visual Thinking Network (VTN) is a new technique being developed by Palma J. Longo (1999). It incorporates many of the features of Mind Mapping, including color, shapes, graphics, and "playfulness" in representations, but also adds named unidirectional and bidirectional names to the links between ideas.

However, it is important to realize that mapping is a flexible, adaptable tool, and nearly all forms of knowledge mapping have been adapted in many different ways and for many different purposes.

Knowledge mapping is a very new field, barely 50 years old in its modern incarnation. It is a field that is still in search of the right metaphors, algorithms, and conventions. The need for good effective mapping strategies grows with each new day of the knowledge explosion.

6.2 Affordances (roles) of the representations

6.2.1 Information equivalence

Mind maps should be informationally equivalent to the learning material it summarises. It would be good if note-taking/summary making tools could also use different modalities and allow any choice of representation to be integrated within in order to aid summary memorisation.

Strategies exploiting the structural isomorphism of graphics and knowledge schemata have also formed the basis for a variety of text and information-mapping schemes aimed at improving comprehension (Armbruster & Anderson, 1982, 1984; Novak, 1998) and study skills (Dansereau et al., 1979; Holley & Dansereau, 1984). Research on the effectiveness of these strategies and its application is one of the best examples of how cognitive theory has come to be used by instructional designers.

The assumptions underlying all information-mapping strategies are that if information is well-organized in memory it will be better remembered and more easily associated with new information, and that students can be taught techniques exploiting the spatial organization of information on the page that make what they learn better organized in memory.

A knowledge map presents a visual image as well as verbal information and therefore presumably taps into this dual-coding system. Knowledge-mapping conventions place bigger ideas above the central concept, smaller ideas below, with moving materials or event sequences on a horizontal plane reading from left to right. These consistent spatial patterns serve as memory prompts, much as in any landscape

6.2.2 Dimensions of representations

The greatest interest in mental models by educational technologists lies in ways of getting learners to create good ones. This implies, as in the case of schema creation, that instructional materials and events act with what learners already understand in order to construct a mental model that the student can use to develop understanding. Just how instruction affects mental models has been the subject of considerable research, summarized by Gentner and Stevens (1983), Mayer (1989), and Rouse and Morris (1986), among others. At the end of his review, Mayer lists seven criteria that instructional materials should meet for them to induce mental models that are likely to improve understanding.

(Mayer refers to the materials, typically illustrations and text, as "conceptual models" that describe in graphic form the objects and causal relations among them.) A good model is C^7 :

- Complete—it contains all the objects, states and actions of the system
- Concise—it contains just enough detail
- Coherent—it makes "intuitive sense"
- Concrete—it is presented at an appropriate level of familiarity

- Conceptual—it is potentially meaningful
- Correct—the objects and relations in it correspond to actual objects and events
- Considerate—it uses appropriate vocabulary and organization.

6.2.3 Multimedia Concept Maps

The purpose of concept maps is to visually represent knowledge of a subject or domain using the C⁷ model.

Indeed, Jonassen (1992) claims that concept maps are accurate reflections of their authors' cognitive structures. But this argument is based on concept maps that portray text-based propositions only. However, if concept maps are to be used to externally represent one's (internal) knowledge, they should allow for nodes to be something other than of a verbal or textual nature.

Intuitively, in addition to static imagery, *temporally dynamic* visual and auditory memories are also part of one's knowledge of an object or domain. E.g. Johnson-Laird (1983) asserts that some mental representations are of temporally dynamic nature. The incorporation of temporally dynamic visual and aural elements in a concept map knowledge representation tool enhances its "flexibility of expressiveness" (Heeren & Kommers, 1992).

Concept mapping tools should be able to represent multiple types or forms of knowledge, not merely text-based propositions. Specifically, incorporating multimedia in concept mapping software should (a) provide for greater cognitive fidelity in student-constructed concept maps, allowing students to more comprehensively represent their knowledge in ways similar to their own cognitive representations; (b) offer the illustrative advantages of dynamic visual imagery and audio to students learning new concepts and domains; (c) provide the capability of reifying concepts with concrete instances that can be seen and heard; (d) offer richer expressive power for concept map authors; (e) provide for a more engaging student experience; and (f) better capitalize on functionality available in modern personal computers (Alpert, S.R., and Grueneberg, K., 2001).

6.3 Theoretical considerations

Mayer has based the majority of his multimedia work on an integration of Sweller's cognitive load theory, Pavio's dual-coding theory, Baddeley's working memory model (*see Theoretical considerations of Chapter 1*) and Perrin's (1969) multi-image theory. The learner is thus viewed as a knowledge constructor who actively selects and connects pieces of visual and verbal knowledge.

6.3.1 Memory and retrieval

The information processing approach focuses on how the human memory system acquires, transforms, compacts, elaborates, encodes, retrieves, and uses information.

The memory system is divided into three main storage structures: sensory registers, short-term memory (STM), and long-term memory (LTM). Each structure is synonymous with a type of processing. The first stage of processing is registering stimuli in the memory system. The sensory registers (one for each sense)

briefly hold raw information until the stimulus pattern is recognized or lost. Pattern recognition is the matching of stimulus information with previously acquired knowledge.

STM can maintain information longer than the sensory registers through a holding process known as maintenance rehearsal, which recycles material over and over as the system works on it. STM is limited capacity for information, which is assumed to effect everything from decision making to the sizes of visual images that can be processed (e.g., Kosslyn, 1975). Klatzky (1980) defined STM as a *work space* in which information may be rehearsed, elaborated, used for decision making, lost, or stored in the third memory structure: LTM.

LTM is a complex and permanent storehouse for individuals' knowledge about the world and their experiences in it. LTM processes information to the two other memory structures and in turn receives information from the sensory registers and STM. First, the stimulus is recognized in the sensory registers through comparison with information in LTM. Second, information manipulated in STM can be permanently stored in LTM.

LTM contains large quantities of information that have to be organized efficiently so they can be effectively encoded, stored, and retrieved. These three processes are interdependent. For example, the method of presentation determines how information is stored and retrieved (Klatzky, 1980). Encoding is related to the amount of elaboration and rehearsal conducted in STM. Elaboration uses information received from LTM after the stimulus is recognized. As new information is compared to the old and manipulated information, it is either added or subsumed into the existing schema, then encoded in LTM (Anderson, Greeno, Kline, & Neves, 1981). As information is restructured and added, new structures are formed that result in new conceptualizations (Magliaro, 1988). These knowledge structures combine information in an organized manner.

Retrieval of information is also an active process. Information is accessed by a search of the memory structures. The speed and accuracy of retrieval are directly dependent on how the information was encoded and the attention being given to the stimulus. To be recalled from LTM, information must be activated. The level of activation seems to depend on the associative strength of the path. The strength of the activation increases with practice and with the associative properties (Anderson, 1985).

6.3.2 Information mapping

Regardless of format, information mapping has been shown to be effective. In some cases, information mapping techniques have formed part of study skills curricula (Holley & Dansereau, 1984; Schewel, 1989). In other cases, the technique has been used to improve reading comprehension (Ruddell & Boyle, 1989) or for review at the end of a course (Fisher et al., 1990). Information mapping has been shown to be useful for helping students write about what they have read (Sinatra, Stahl-Gemake, & Morgan, 1986) and works with disabled readers as well as with normal readers (Sinatra, Stahl-Gemake, & Borg, 1986). Information mapping has proved to be a successful technique in all of these tasks and contexts, showing it to be remarkably robust.

Information mapping can, of course, be used by instructional designers (Jonassen, 1990, 1991). In this case, the technique is used not so much to improve comprehension as to help designers understand the

relations among concepts in the material they are working with. Often, understanding such relations makes strategy selection more effective.

A large body of literature on the relevance to hierarchical structures to learning has shown that such well-defined structures are important to information acquisition (Bower, Clark, Lesgold, & Winzenz, 1969; Eylon & Reif, 1984; Kintsch & Keenan, 1974) and expert performance and problem solving (Chase & Simon, 1973; Chi & Koeske, 1983; De Groot, 1965; Friendly, 1977; Hughes & Michton, 1977; Johnson, 1967). Some studies have shown no benefit of a hierarchical system structure over other nonlinear hypertexts (Dee-Lucas & Larkin, 1995; Melara, 1996). Still other studies have demonstrated the pitfalls of an ill-structured system design. Gordon, Gustavel, Moore, and Hankey (1988) showing how a poor structure can mitigate learning by disorienting learners (Dias, Gomes, & Correia, 1999; Edwards & Hardman, 1989; Hammond, 1991).

6.3.3 Hypermedia

Hypermedia parallels mental models by permitting associations or links among various ideas to be formed, then constructing meaning among these relationships (Kozma, 1991). Tergan (1997) reviewed several empirical studies, conducted a theoretical analysis, and suggested that the literature made the following assumptions concerning hypertext and /or hypermedia research:

- Structural and functional features of hypertext/hypermedia mimic the structure and functions of the human mind (p. 258).
- Hypermedia/hypertext match instructional principles for self-regulation and constructivist learning (p. 262).
- Hypermedia/hypertext match cognitive principles of multiple modes for the mental representation of knowledge (p. 271).

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Much of the interest in using hypertext to promote learning is grounded in the notion that hypertext information structures may reflect the semantic structures of human memory (Bush, 1945; Jonassen, 1988, 1991; Jonassen & Wang, 1993; Tergan, 1997). Researchers have asserted that developing a hypertext that provides access to an expert's semantic structures could improve the learning and comprehension of non-experts who read it. The assumption is that "... the network-like representation of subject matter in a hypertext as well as the kind of links between information units which support associative browsing correspond to the structure of human knowledge and basic principles of the functioning of the human mind (Bush, 1945; Jonassen, 1990). Because of the suggested match, it is assumed that in learning situations information represented in hypertext may be easily assimilated by the

learners' minds" (Tergan, 1997a, pp. 258–259). Thus, researchers have attempted to determine whether non-expert users will assimilate expert conceptual structures modelled in a hypertext.

Jonassen and Wang (1993) developed a series of studies to examine whether university students' learning of the structural nature of hypertext content was enhanced by a "graphical browser" based on an expert's semantic map. The structure of the graphical browser resembled a concept map, with the concepts arranged in a web-like structure. Lines on the map indicated connections among the concepts, and descriptive phrases superimposed over the lines described the connections between the concepts. Results showed little evidence that learners internalized the expert's semantic structures after being exposed to the structural cues in the hypertext-user interface. It should be noted that when a task was introduced that required students to construct a semantic network about the topic, their ability to represent relationships among the concepts was affected. Nonetheless, the direct measures in this study did not reveal a strong effect of system structure on learners' conceptual structures.

McDonald and Stevenson (1999) used indirect measures to examine the effects of structural cues on cognitive structures. They explored differences in learning when students used what the authors referred to as a "conceptual map" versus a "spatial map." The conceptual map provided a representation of the key concepts in the text and specified the relations among them. The spatial map presented a hierarchical representation of the hypertext nodes and links showing what information was available and where it could be found. In the spatial map condition the structure of the text was represented but there was no attempt to show connections among the concepts. Results indicated that the spatial map facilitated navigation but that students in the conceptual map condition performed better on learning measures on a 1-week-delayed post-test. Thus, use of the conceptual map available in this hypertext appeared to help students gain more durable and useful knowledge.

There is little evidence, then, that simply working with a hypertext system designed to represent an expert's conceptual understanding of a topic can lead to a direct transfer of expert-like mental representations to the reader. It seems clear that some degree of cognitive engagement is required if readers are to benefit fully from HAL. As McDonald and Stevens' (1999) work demonstrates, though, traditional assessments of learning (such as short-answer and essay tests) are clearly affected by system structure.

6.4 Educational use of mind mapping

Knowledge mapping is consistent with the learning models proposed by theorists such as Ausubel (1963, 1968), Vygotsky (1978), and von Glasersfeld (1984, 1987, 1993). Constructing a knowledge network means actively engaging in the act of personal and social knowledge construction. Mapping is a simple strategy to promote desired mental activities. It promotes mindful learning (Langer, 1989, 1997), cognitive flexibility (Spiro, Coulson, Feltovich, & Jacobson, 1991), and conceptual change (Strike & Posner, 1985). Student knowledge-mapping has fairly consistent positive effects on science and mathematics learning.

Knowledge mapping is an external extension of working memory, which especially supports reflective thinking (McAleese, Grabinger, & Fisher, 1999). Knowledge mapping can capture both the learner's prior

knowledge (Jonassen & Wang, 1993) and the acquisition of new knowledge (West & Pines, 1985). Knowledge mapping can also capture concept elaboration, concept discrimination, and conceptual change (West & Pines, 1985; West, Fensham, & Garrard, 1985). It promotes comprehension skills well beyond simple decoding (Lehman, 1992).

In her review for evidence that the process of constructing Knowledge Maps helps learners Fisher et al. (2000b) concluded: when students engage in the activity of mapping knowledge, they generally tend to learn more and reflect more upon their own learning than with other study methods. Thus, the more powerful the mapping system and the more consistently it is used, the greater the gains in understanding tend to be. To the question: What makes Knowledge Mapping an effective learning tool, she summarised the most powerful ideas as: 1) chunking of information, 2) dual coding theory, 3) making relations between ideas explicit, and 4) broadcasting to the subconscious.

Some researchers claim to have worked out measuring instruments for mind maps. During the evaluation of the image-based, brainstorming-style, concept mapping task used at ImpacT2 on the theme "*Computers in my world*" done by children aged between 10-16, five quantitative measures emerged from heuristic analysis of the maps: counting the number of nodes and links, calculating the ratio between them to give a "connectivity score", categorising of maps through phenomenographic analysis into "*Spheres of Thinking*" and "*Zones of Use*". The correlations between the data obtained and other data gathered from students suggest that the concept mapping scores provide valid significant indicators of the pupil's experiences of ICT and the breadth and complexity of their "secondary artefacts" of networked technologies (Mavers, et al 2002). The evaluation further suggests inclusion of colour within these maps to allow a very sensitive representation of concepts that mirrors the mood and preference of presenter as well; however it was not included within this research.

Research has yielded fairly consistent findings concerning different levels of control (Balajthy, 1990; Dillon & Gabbard, 1998; Gall & Hannafin, 1994; Large, 1996; Tergan, 1997b). That is, low prior knowledge readers tend to benefit from more structured program-controlled hypertexts, whereas high-prior knowledge readers tend to make good use of more learner-controlled systems.

Another important individual difference that has received attention in the literature is the effect that learning style, or *cognitive style*, has on learning from hypertext under different treatment conditions. Individual differences in learning style are often important to the learning outcomes. This is so largely because they interact with other factors such as system structure.

Some researchers believe that there may be a relationship between types of navigational strategies in hypertext and whether the learner is field dependent or field independent. Field-independent learners tend to be more active learners and use internal organizing structures more efficiently while learning. Thus, it would seem that degrees of structure in hypertext will be related to the learning outcomes for field-dependent or -independent learners (Lin and Davidson-Shivers, 1996).

Beissner, Jonassen, and Grabowski (1993) tested the effects of two organizational strategies against learner differences at four levels of learning. Their findings showed an interaction between learner-generated concept vs. semantic maps and serialist or holist learners on the problem-solving questions only, with serialists performing better with semantic maps and holists performing better with concept

maps. Although this study did not compare their results with instructor-provided maps, it does contribute evidence to the importance of individual cognitive strengths and patterns of thinking when selecting organizational learning activities.

6.5 Learning styles

A learning style is a student's consistent way of responding to and using stimuli in the context of learning. There are various instruments used to determine a student's learning style.

- The VAK learning Style uses the three main sensory receivers - Vision, Auditory, and Kinesthetic (movement) to determine the dominate learning style.
- Kolb's learning inventory describes a learning process and a style, which is based upon determining the personality type.
- Howard Gardner theorized that there are multiple intelligences, and that we all use one or two for the most effective learning. Our culture teach, test, reinforce and reward primarily two kinds of intelligence: verbal/linguistic and logical/mathematical. His theory proposes that there are at least eight other kinds of intelligence that are equally important.

Conflicting assumptions about learning underpin mainstream ideas about learning and the best-known models of learning styles. Some theories derive from research into the functioning of the brain, where claims are made that specific neural activity related to learning can be identified in different areas of the brain. For example, there is no evidence from neuroscience that some people are right brained ,and some are left brained. Nor is there neurological evidence for the existence of leaning styles (Berninger & Richards, 2002).

Other influential ideas derive from established psychological theories, such as personality traits, intellectual abilities and fixed traits which are said to form learning styles. From this latter perspective, it is claimed that learning styles can be defined accurately and then measured reliably and validly through psychological tests in order to predict behaviour and achievement.

These various learning styles or intelligences are points along a scale that help us to discover the different forms of mental representation; they are not good characterizations of what people are (or are not) like. What these various instruments are doing is allocating the person along some point on a continuum.

6.5.1 Kolb's Learning Style Inventory

Kolb's Learning Style Inventory, as defined by (Kolb et al. 1979), includes four learning styles:

- *Accomodator*: Include role-playing situations where the computer provided a problem with many scenarios and people that could be chosen to solve the problem. Since Divergers are risk takers and are considered able to adapt to situations, then each scenario would have several different endings, some endings offering more reward, other endings less reward. The intelligence for this type of role playing is already available in interactive games, such as Doom.

- *Diverger*: Include case studies that offered several solutions to each case study based on many inputs which would need to be sorted out. Since Divergers are characterized as brainstormers (Kolb, 1979), the course needs to provide them with the ability to choose from multiple inputs to come up with an answer. This could even be accomplished by using adaptive learning, where one answer leads the learner to another subject, thus bypassing subject matter that the learner already knows.
- *Converger*: Provide hands-on examples that could be solved for a single answer. Role-playing could also be applied as the student could be given a problem and several solutions. The student would need to pick the best solution based on the facts presented. For these types of problems, many facts need to be presented so that the converger can sort the facts out and use their hypothetical-reasoning (Kolb, 1979) to solve the problem. This technology already exists in games, such as Sherlock Holmes, Consulting Detective.
- *Assimilator*: Provide detailed background information on how and why something is supposed to work and then supply examples that show the how but also illustrate the why. In other words, describe both the theory and practice. Problems where assimilators need to apply a theory would work best because assimilator's greatest strength lies in creating theoretical models (Kolb, 1979). Another technique that could work would be to present the assimilators with a problem, and ask the assimilators to provide reasons why the problem exists.

These four style are based upon established learning theories as described by Kolb: The ideas behind assimilation and accommodation originate in Jean Piaget's definition of intelligence as the balance between the process of adapting concepts to fit the external world (accommodation) and the process of fitting observations into the world of existing concepts (assimilation). Convergence and divergence are the two essential creative processes identified by J.P. Guilford's structure-of-intellect model. (Kolb, 1985). To determine a person's learning style, the person completes an instrument called Learning-Style Inventory by answering questions contained in the Self-Scoring Inventory and Interpretation Booklet (Kolb, 1985).

An additional note should be made about Kolb's learning cycles as the KLSI also measures learning cycle preference. Kolb defined four learning cycles (Kolb, 1985):

- *Concrete experience*: where learning from feelings or reactions to experience influence your learning.
- *Reflective observation*: where learning from watching and listening influence your learning.
- *Active conceptualization*: where learning from thinking or analyzing problems in a systematic method influence your learning.
- *Active Experimentation*: where learning by doing or results driven influence your learning.

These four cycles are tied into learning styles. For instance, a converger favors a learning cycle of Abstract Conceptualization and Active Experimentation, which fits since these two learning cycles are characterized by learning by doing and thinking. And since Convergents focus on reasoning and solving problems, the cycles and learning styles are closely tied together.

But, it should be noted, that while students prefer one learning style to another, students will move between learning cycles as Kolb states actual process of growth in any single individual...probably proceeds through successive oscillations from one stage to another. (Kolb, et al., 1979) Since students change or adapt to one learning cycle to another, whereas students have a preferred learning style, the problem statement does not include learning cycles as a variable.

Ruble and Stout also point out that Bostrom et al. state that the KLSI is expected to give unstable outcomes for an individual across learning contexts but is stable within a specific context. (Ruble and Stout, 1993). Kolb Learning Style Inventory has been in use since 1976 and continues to be used today. So whether the tool is flawed or not, but the inventory has been administered enough that the results are sufficient to use as benchmarks. Filipczak presents hands-on examples of learning styles outside of the traditional classroom setting. Author states that people are now expected to become lifelong learners (Filipczak, 1995) and as such, they must learn their learning preferences to better cope with what they learn, and how they learn. Learners must know how to adjust to fit the information they are learning.

6.5.2 The Myers Briggs Type Indicator (MBTI)

The MBTI is widely used in industry, management and education, its database consisting of hundreds of thousands of people (Myers and McCaulley, 1985; MacDaid et al., 1986), its being a self-report survey with a "non-psychopathological" focus, its having good reliability (Myers and McCaulley, 1985; Janowsky et al., 1999) and its having significant heritability (Bouchard and Hur, 1998).

The MBTI divides individuals into four dichotomous personality dimensions (Extroverted and introverted, Sensing and Intuitive, Thinking and Feeling and Judging and Perceiving) to create a total of eight personality categories. With respect to the individual MBTI scales, Extroverted individuals relate to the outside world of people (i.e. are sociable, interactive), whereas Introverted individuals relate to their own inner thoughts (i.e. are internally oriented, have limited relationships). Sensing individuals deal with the concrete and the here and now (i.e. are factual, practical), and Intuitive individuals tend to look toward future possibilities (i.e. are creative, speculative). Thinking individuals prefer to use their cognitive processes to engage in decision-making (i.e. are objective, impersonal), whereas Feeling individuals stress their personal relationships with others (i.e. are personal, humane). Judging individuals enjoy coming to judgments and decisions (i.e. are settled, decided, fixed), whereas Perceiving individuals like to keep things open (i.e. are adaptive, tentative, open-ended; Myers and McCaulley, 1985).

6.5.3 Modalities in learning materials

According to multiple intelligences theory, not only do all individuals possess numerous mental representations and intellectual languages, but individuals also differ from one another in the forms of these representations, their relative strengths, and the ways in which (and ease with which) these representations can be changed.

It is important to build an adaptable learning environment that presents the material in a variety of methods than try to determine each learners personal style. Likewise, recognizing your own style will help to ensure you do not unintentionally force one learning style upon the learners. The more styles one

addresses, the easier the instruction will be received by the learners. Also, material presented in a variety of methods keeps the learners interested and reinforces itself.

6.6 Authoring mind maps

Organizational tasks require learners to relate ideas from a passage together by using a variety of symbolic representations. Each addresses at least one of three key questions regarding the generative model of learning: the effect of learner-generated learning vs. the effect of learner-reproductive learning; the effect of learner-generated vs. instructor-provided constructions of meaning, including organization as a variable; or the general effects of generated elaborations.

All information-mapping strategies (reviewed and summarized by Hughes, 1989) require students to learn ways to represent information, usually text, in spatially constructed diagrams. With these techniques, they construct diagrams that represent the concepts they are to learn as verbal labels often in boxes and that show interconcept relations as lines or arrows. The most obvious characteristic of these techniques is that students construct the information maps for themselves rather than studying diagrams created by someone else. In this way, the maps require students to process the information they contain in an effortful manner while allowing a certain measure of idiosyncrasy in how the ideas are shown, both of which are attributes of effective learning strategies.

To summarize the findings, the results are mixed when comparing learner generativity. Some studies Wittrock and Alessandrini (1990) show that learner-generated activities are more effective in improving achievement than instruction-provided organizational schemes and that performance is increased even more when the text is organized. However, other studies (Smith and Dwyer 1995; Kenny, 1995; Taricani, 2002) found that instructor-provided activities produced better results when the instruction is disorganized and when feedback is provided. Finally, the selection of activities should be tempered by cognitive ability. Given these results, it is clear that more research is needed to understand these results more fully, especially in the area of concept map generation.

In summary, studies (Kourilsky and Wittrock, 1987; Laney, 1990) have shown that overt imaging is more effective than covert; learner-generated imaging is more effective than instruction-provided imaging; and visual images may be more effective than verbal ones, only in cases in which students have progressed developmentally to the point where they can understand images. The sequence of generative activity also played a part in the results found for imaging.

Wittrock and Alessandrini (1990) also investigated the effects of learner-generated summaries and analogies by analytic and holist undergraduates. The results followed the predicted rank ordering, with the most positive effects found for generating summaries, followed by generating analogies, both of which were significantly better than the control group containing no generative activities. They also found that individual differences in analytic and holist ability correlated with learning differently in the three treatments: analytic ability with learning in the generate analogies group, holist ability with the text-only control group, and both analytic and holist abilities in the generate summaries treatment.

6.7 Collaborative learning

Different theoretical precursors emphasise collaboration as a successful and powerful activity for learning and problem solving. During collaboration students discover, construct and become aware of their own cognitive structures by representing and explaining their concepts and ideas. Collaboration presents divergent ways of thinking and prompts new perspectives to the problem. It facilitates more flexibility cognitive patterns and stimulates critical and creative thinking.

Two concepts and research paradigms are closely related to the problem area of collaborative learning - *distributed cognition* and *shared cognition* (Stoyanova, Kommers, 2002):

- *Distributed cognition* is defined as an extension of the internal cognition of the personality in the outside world (artefacts and other people). It creates a 'person-plus' cognition (Perkins, 1993). Teams manifest distributed cognition through a variety of representations and through accessing knowledge ingredients of the group partners (Hutchins, 1991). While exploring the theoretical construct of 'distributed cognition' it could be assumed that in any form of collaboration the personal cognition of the students is constructed by reflection, absorption and by interpretation others' knowledge. For each student in a group the presentation of the others is a distributed information resource enabling the construction and reconstruction his/her own cognition.
- *Shared cognition* emphasises the mutual understanding of collaborators' perspectives and shared interpretations of the problem as an essential requirement of collaboration. It is very important that cooperating subjects acquire a common frame of reference in order to communicate their individual viewpoints. Only knowledge that is meaningful for individuals is internalised and integrated in one's cognitive structure. Shared cognition is built upon the individual inputs in the collaborative process.

Representing their cognitive structures and negotiating about the meaning of concepts, individuals reach a common vision on the problem. An essential feature of collaborative learning is the process of interaction between individual cognitions and between individual cognitions and the shared group cognition that Salomon (1993) defines as interdependence. Shared cognition at the same time is the way a group contributes to 'personal meaning' at the level of individual students. All components of shared cognition are meaningfully integrated in the cognitive structure of the contributing persons; they are interpreted on the same frame of reference.

Underlying research should basically focus on two aspects of distributed cognition in collaborative learning:

- the role of the mediating tools used in collaboration and
- the modality in which knowledge is communicated during the interaction process.

Some features of concept mapping promote the assumption that it should be an effective technique for collaboration (Stoyanova, 2000).

- Concept mapping is a unique technique for externalising the cognitive structure of the students. While using concept mapping students communicate based upon the *whole picture*

of the problem space; it represents their prior knowledge and vision. Elaborations of the various perspectives based on concept mapping are much more comprehensive.

- Meanings of the concepts and ideas are *clearly defined* by the position of the concept in the whole picture and its interrelations with other concepts. This *facilitates negotiation of meaning and promotes a deeper mutual understanding* between collaborators. It is supposed that the process of group negotiation should trigger *internal negotiations* at the students and the meaningful integration of the new concepts in the cognitive structure of learners.
- While interacting by concept mapping, students have the possibilities to take a look at the *whole* problem space as *visualised by other* group members. It should enhance the process of *critical reflection* as well as *creative thinking*.

Activity theory (Vygotsky, 1986; Leont'ev, 1978; Kuutti, 1991; Jonassen, 2000) characterises learning as a process of appropriation of the socio-cultural meaning externalised in artefacts. Learning is based on the adequate socially determined activity of a subject towards an object in which the knowledge is internalised in a meaningful way. Sharing 'knowledge in action', means 'sharing externalised knowledge', but also 'sharing activities against knowledge', thus 'sharing the process of learning itself'. Shared meaning is generated through exchange (Pea, 1993). It is a reliable base for developing a shared cognition.

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CHAPTER 7: Internal and External representations in advanced multimedia study materials: case "SQL Fundamentals"

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Abstract. In this chapter we have provided the description and analysis of multimedia solutions for the online courses developed at Riga Technical University Distance Education Study Centre using internal and external representation approach. The aim of this chapter is to acquire a new level of knowledge about multimedia supported learning and to set the priorities for further improvement of e-learning materials.

7.1 Introduction

With advances in new technologies the ability to deliver instruction in multiple ways has improved dramatically. Multimedia technology can provide instructions to students in a new, more advanced way the tutors are not able to. One of the most widespread ways of teaching – a lecture - has a number of disadvantages (Foreman, 2003); e.g. it is a one-way auditory communication rarely illustrated by static visual enhancements which are far from the multimedia potential used in films, PC, video games and advertising. Another disadvantage of lecturing is that a lecturer has to make certain assumptions about hundreds of students' perceptual and intellectual uniformity as he has to proceed at a certain tempo. The rate of student - tutor interaction, e.g., asking questions, discussions, problem solving remains quite low. Traditional approach represents tutor-centred teaching model that makes a student passive consumer of the teaching material.

By using multimedia for the instruction it is supposed that students can benefit from multiple and dynamic ways of material presentation and definitely benefit more compared to traditional ways of presenting information in printed/lecture format.

Multimedia enhanced online course delivery is based on different model – Learning model - that puts the student in the centre of the process and allows him to benefit from the different course delivery methods, develops course management, and time management skills. Above mentioned approach requires from the student active participation in the learning process.

Still the quality of multimedia enhanced learning is not defined as much whether we use multimedia but rather by how we use it. One of the most important tasks of multimedia enhanced learning is to find an answer how to use multimedia to support learning in a most optimal, effective and efficient way. The issue is multidisciplinary; on the one hand is determined by development of the technology and on the other supported by psychological/pedagogical research.

Fundamental to understanding how multimedia can help to deliver the instructions is the concept of multiple representations. As defined in the first chapter, *representation* is something that stands for

something else. Theory makes distinction between external and internal representations. *External representations* are external in relation to the learner's sensory and cognitive system and can be constructed using some representational code. *Internal representations*, in turn, are cognitive constructs internal to learner's cognitive system. Internal (mental) representations are constructed when a learner observes some external representation - a text, picture, animation, etc. Further in this draft we will concentrate on external representations.

Riga Technical University Distance Education Study Centre (RTU DESC) has been developing interactive multimedia materials for the needs of distance learning and blended learning for over 6 years. Most of the courses developed at RTU DESC contain three types of materials: printed workbooks, online or CD-ROM based multimedia, and online support forum. Further in this draft we are going to analyze elements of multimedia study materials, making use of the theoretical "language" described in the first chapter.

7.2 External representations

7.2.1 Multiple External Representations

Depending on the course there are a certain number of media elements on the CD-ROM combined to construct a multiple representation. From the theoretical point of view there are three main functions for multiple representation usage (Ainsworth, 1999):

- to complement (use representations that contain different information and different computational properties),
- to constrain (constrain possible misinterpretations of a representation or a domain),
- to construct (encourage deeper understanding of a situation).

According to sign systems representations are classified into descriptive and depictive (Schnotz, 2002). A *descriptive representation* system of signs has an arbitrary structure and is associated with the content they represent by means of a convention. A *depictive* representation is a representation consisting of iconic signs. Signs are associated with the content they represent through common structural features on either a concrete or more abstract level.

One of the courses recently produced at Riga Technical University Distance Education Study Centre – *SQL Fundamentals* - contains rich multimedia to illustrate important points of the course. The purpose of SQL Fundamentals course is to introduce students to multi-table databases and SQL as an international standard for creating, accessing and maintenance of the relational databases. It is a basic level SQL course for business informatics students.

7.2.2 Description of the representations, representational code and the modality

Most of the material included in the course represents MS SQL and Oracle server environments with databases, tables, indexes, SQL language syntax and procedures this is a *represented world*. Video interviews add a wider perspective of practical SQL application in real world. This is achieved by interviewing different SQL practitioners.

Representing world is multimedia based learning environment with animations and simulations that visually closely resembles the representing world lacking some functionality of represented world or adding extra when necessary for achieving study goals. Rest of the material presents the represented world in terms of text pictures, diagrams, tables, manipulable drills. The correspondence in the latest case is symbolic and not that obvious.

Representational codes used in SQL Fundamentals multimedia materials include:

- Text;
- Speech;
- Narration;
- Images;
- Graphics;
- Animation;
- Video;
- Simulation;

Visual and Aural *modalities* are prevailing throughout the material. Some parts are of the course material are built to involve tactile modality as in simulation performing the right sequence of actions. See detailed description of simulations available in the course.

The SQL fundamentals multimedia materials contain following types of representations:

- Concrete (pictorial imagery)
- Pattern imagery (depicting relationships)
- Icons or symbolic elements (numbers, expressions and formulae);
- Kinesthetic (manipulable) imagery (involving some kind of manipulation or activity)
- Dynamic imagery (including animations and also static representations structured so to express motion or transformation)

7.2.3 The dimensions of representations & forms of dynamic representations

The SQL Fundamentals course contains multiple media elements providing multiple *perspectives* of representing world. Simulations included in the material provide operational user experience performing sequence of actions. Animations included in the course are of two types; presenting SQL environment from operational user perspective and functional perspective. Static diagrams are typically used to reveal a functionality of the SQL environment.

The representations vary in *precision* in SQL fundamentals course; those revealing functionality and describing concepts of the environment are mainly qualitative, and those revealing user experience tend to be precise, like step-by-step execution of programme code or step-by-step joining of tables.

The SQL Fundamentals material organisation units 1 to 13 follow a classical sequence of *complexity* from simple to complex. Material organisation within unit follows the same principles. Separate simulations are either too short to follow that rule or use different organisation of the material; step-by-step development in time.

Animations included in SQL Fundamentals course materials are either *time-singular* as in sequence of actions on the screen or *time-implicit* as in step-by-step code execution.

7.2.4 Description of the course unit layout

SQL Fundamentals course consists of the following components:

- 13 Units of teaching material
- General course information
- Glossary
- Course Goals and Objectives

Each Unit contains online instructions about the specific topic related to databases and SQL.

Course delivery is based on the standard layout (see Figure 7.1):

The central and biggest part of the screen is allocated to learning material represented in a textual and static picture form. The contents of the main unit is split in slides each containing material just as much to fit well on the screen without scrolling. Along with the diagrams and pictures complementing the text there are action buttons to allow direct access to multimedia elements where appropriate. In the right lower corner of the slide there is a counter showing the sequential number of the current slide as well as the total number of slides in the current unit. The headline on the top of the window indicates the number and the title of the unit. In the lower left corner there are action buttons allowing access to the slide depicting the objectives of the unit. Below there is button allowing access to the *examples* section of the unit. Button *activity* allows access to the simulation or simulations that are relevant to the content of the current unit. *Video* button allows watching video interviews available in this unit, and shortcut “Main menu” leads to the start menu of the course. In the bottom part of the screen there are navigation buttons allowing moving forward and backward slide by slide, and also to move to the very beginning or the very end of the unit. When reaching the end of unit, the text “End of unit” is being displayed. On the right hand side there is a vertical bar that indicates the progress through the unit.

Unit 2 - Introduction into SQL

The advantages of SQL (Continued)

Unlike other languages (spoken languages like English, or programming languages like Java or Visual Basic), SQL is made up of very few words. SQL is designed to do one thing and do it well - provide you a simple and efficient way to read and write data from a database.

Example: Communication with a Content Management System database using SQL.

The diagram illustrates the communication between a database and a content management system. On the left, a database cylinder contains two tables: 'Pictures' (Picture1, Picture2, Picture3, Picture4, Picture5) and 'Topics' (Topic1, Topic2, Topic3, Topic4, Topic5). An arrow labeled 'SQL' points from the database to a 'My Newspaper' application window on the right. The application window displays 'Picture1', 'Topic1', 'Topic2', and 'Picture2'. Below the diagram, an 'EXAMPLE' box is titled 'Communication with a Content Management System database using SQL'. The slide number '6 of 27' is in the bottom right corner.

Figure 7.1. General layout of SQL fundamentals course unit

Next example helps students to create internal links between (1) commonly known objects, like the English language, (2) specifically known objects, like Visual Basic programming language and (3) the new learning object, SQL - database query language.

A consolidating element – one sentence – is used to show that all the three objects, represented in three different colours, belong to one logical category, namely the language. The student is challenged to (1) understand the sentence as a whole and (2) to think about the sentence as a collection of different classifiable parts in the context of the current learning course. Colours are used to support the information selection/differentiation process.

By contemplating the screens material student may discover the following:

- the learning object is a part of something that he or she already knows (already acquired knowledge);
- some parts of the already known belong or can be connected to the current learning object (recursive knowledge chains);
- not all the parts of what he or she already knows belong *solely* to what she knows: they belong to (reassessment of the existing knowledge).

The advantages of SQL

- Almost every major database supports SQL, so learning this one language will enable you to interact with almost every major database.
- SQL is easy to learn. The statements are all made up of descriptive English words, and there aren't that many of them.
- Despite its apparent simplicity, SQL is actually a very powerful language, and using its language elements you can perform very complex and sophisticated database operations.

```
IF YOU SELECT A CHICKEN THEN  
TRY TO ESCAPE THE NEXT FOX  
AND GO HOME
```

Black: SQL words
Blue: Visual Basic words
Red: simply some English words

objectives
example
video
glossary
main menu

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SQL FUNDAMENTALS

Figure 7.2. Illustration of selection and integration of knowledge

The next screen gives a complete list of common operators used with SQL conditional statements. The meaning of each operator is given in a short form right nearby. The screen is accompanied by two examples showing the most frequent usages of the current learning object (the SQL operators) and also a very common pitfall belonging to the matter (i.e. unquoted string).

Unit 7 Retrieving data from a table

Operator	Meaning
=	Equal to
!= or <>	Not equal to
>	Greater than
>=	Greater than or equal to
<	Less than
<=	Less than or equal to
in	Equal to any item in a list
not in	Not equal to any item in a list
between	Between two values, greater than or equal to one and less than or equal to the other
not between	Not between two values
begins with	Begins with specified value
contains	Contains specified value
not contains	Does not contain specified value
is null	Is blank
is not null	Is not blank
like	Like a specified pattern. % means any series of characters. (underscore) Means any single character.
not like	Not like a specified pattern. % means any series of characters. (underscore) Means any single character.

- In the WHERE clause, when referring to variables in character fields, you must enclose the values in single quotes.

Example:
 WHERE Weather = 'sun'.
- Variables that refer to numeric fields should not be enclosed in quotes.

Example:
 WHERE Speed > 120

SQL FUNDAMENTALS

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Figure 7.3. Information presented in table

The next screen attracts the eye by the means of three geometrical constructions. It turns out to be a representation of (1) Union, (2) Intersection and (3) Exception logical operations used also in SQL language. These concepts may already have been familiar to the student e.g. from the high school geometry course.

UNIT 9 Retrieving data from multiple tables

Set operations

The other way to retrieve data from many tables is combining the results of two or more queries. The combined results might be a simple aggregation of all records from the queries.
SQL99 Standard introduces the support for UNION, INTERSECT, and EXCEPT clauses that could be used to combine the results of two or more queries.

Now you have the two following possibilities:

(1) read about the steps which are necessary to apply the SET operations or
(2) visit our Activity that you can find in this page or in Activity area of this Unit.

ACTIVITY Demo of SET operations

objectives
example
activity
video
glossary
main menu

SQL FUNDAMENTALS

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Figure 7.4. Graphical representation of logical operations

The next screen introduces the concept of Stored Procedure. It demonstrates how the Stored Procedure helps to save the execution time and takes the overloaded traffic off the network lines. The elements used are as follows:

- a stylized clock shows to the student the time necessary to get the result.
- “Good” and “bad” colour concepts are utilized.
- It is emphasized that sending less information over the network is good (blue colour). And it is represented simply by the shorter announcement: ‘Single statement’ compared to the longer one i.e. worse (red colour) announcement: ‘Request possibly containing hundreds of commands’.

The intention here is to connect the learning object to the well-known paradigm: saving time is advisable. Simple “good” and “bad” colours concept is intended to make an association allowing faster decisions in the future.

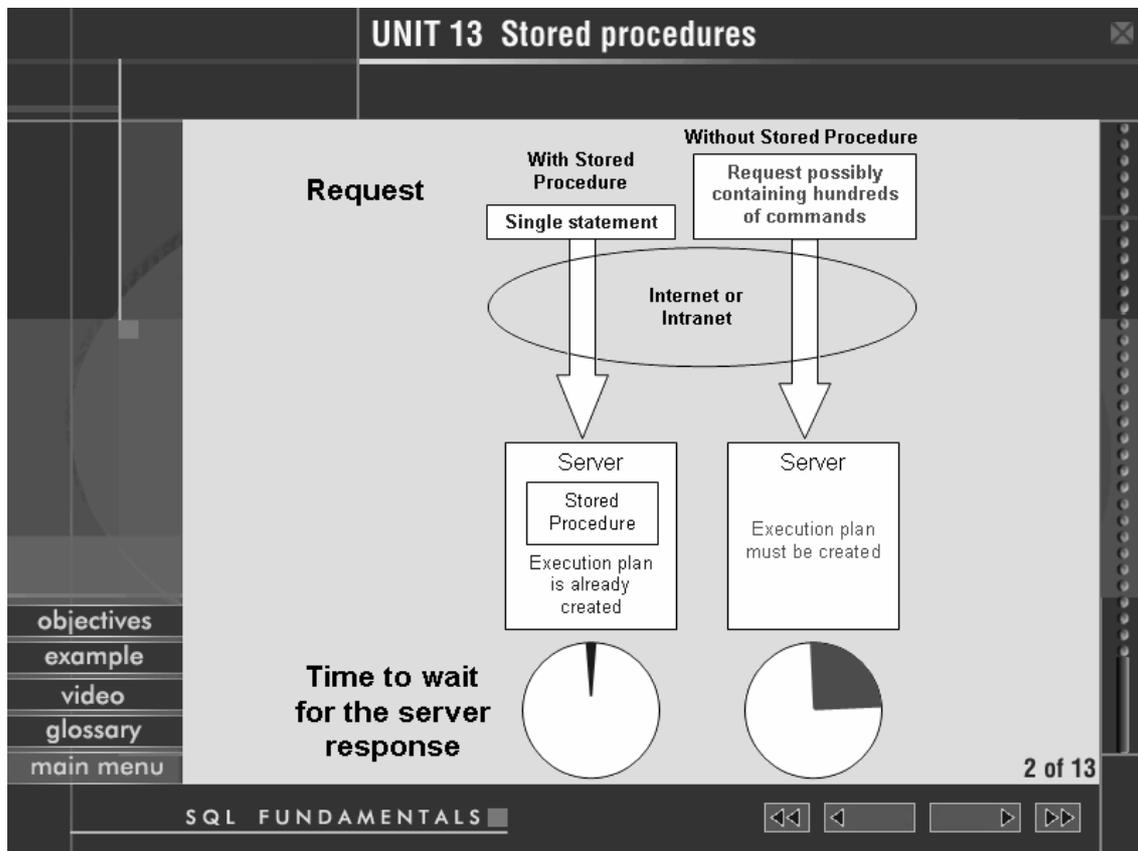


Figure 7.5. Representation of stored procedure concept

7.2.5 Description of the Examples

In this section of the course two instructor-side generated external representations are used: animation and narration, affecting visual and auditory channels of the students.

Most of the screen area is allocated for the *animation* – a screen recoding, representing actions performed by the tutor on his computer. Above the animation area there is a *slider* bar representing the actual progress of the animation. The slider allows controlling animation progress by dragging the progress indicator forward or backward. There are several *action buttons* placed to the right of the progress bar allowing *start, pause or stop* the animation. On the right side of the animation there is an adjustable vertical slider bar representing the sound volume level of the narration. In the upper right corner there is an action button for closing the animation.

The goal of this narrated animation is to teach students how to create a table in MS SQL Server database using Enterprise manager.

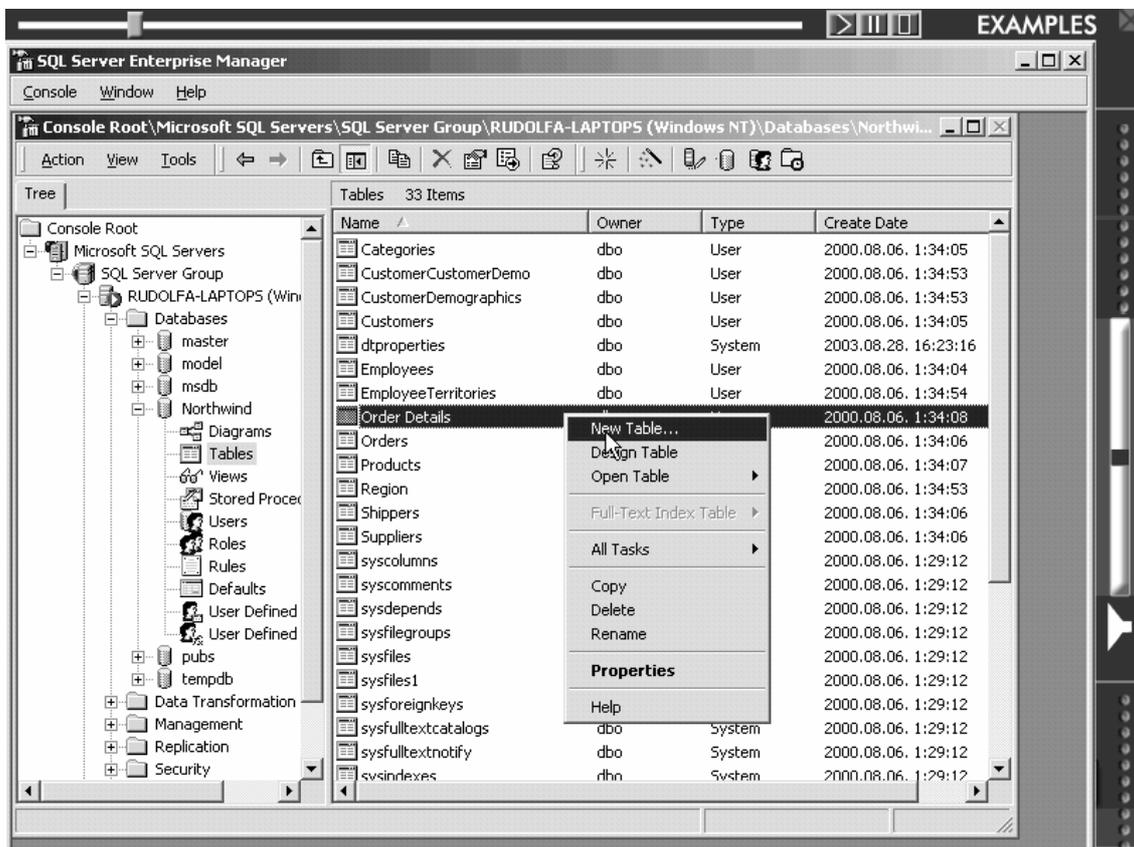


Figure 7.6. SQL Fundamentals course, the Examples section

In this case a narrated animation is used because it helps a lot to illustrate events on the screen and to learn more profoundly. Usage of a narrated animation fits well with dual coding theory and the principles described in the first chapter. Mayer (Mayer & Moreno, 2002) found out that the combination of animation and narration enhances the comprehension when they are presented simultaneously and synchronized in time, since the two code systems address different channels. In this case learner can use

the cognitive resources of both visual and auditory system for information processing (Brünken, Plass, & Leutner, 2004).

Single representation in this case, either text or narration, would not be sufficient for representing actions happening on the screen (a process). Text or speech description would become too complicated and too difficult to interpret. The situation could be improved only a little by adding static images and diagrams as we find them in textbooks. Learners generally do not like reading long texts on the screen and static information representation is not good enough for representing a dynamic process (creation of table in MS SQL Server database is used as one of the examples).

Although animation can present dynamic information that is either tacit or unavailable in static graphics, single representation would not allow adding extra details to the study material. In this case both representations have partial redundancy, i.e. have certain parts of the content in common, but also add some new aspects to optimise the learning process.

Despite its advantages, animation may or may not promote learning depending on the conditions of its usage. Researchers at Universities of California and Santa Barbara have carried out a series of experiments to find out conditions under which animations can improve learning process (Mayer & Moreno, 2002). The findings were summarized in a number of design principles based on cognitive theory of multimedia learning. The *examples* (narrated animations) designed for SQL Fundamentals course fit well with following principles listed below:

- *multimedia principle*: deeper learning is achieved from animation and narration than from narration alone;
- *temporal contiguity principle*: when corresponding narration and animation should be presented simultaneously rather than successively;
- *coherence principle*: deeper learning is achieved when extraneous narration, sounds, pictures, and video are excluded;
- *modality principle*: deeper learning is achieved from animation and narration rather than from animation and on-screen text;
- *redundancy principle*: deeper learning from animation and narration is achieved rather than from animation, narration, and on-screen text.
- *Spatial contiguity principle*: deeper learning when the corresponding text and animation are presented near rather far from each other, does not apply here.
- As regarding *Personalization principle*: deeper learning when narration or on-screen text is conversational rather than formal is realized only partially, because the style of narrations is rather formal than conversational.

From the practical point of view narrated animations have turned out to be very successful in demonstrating how to work with the server: they allowed a repeated viewing of the material as well as an arbitrary stop along the demonstration.

7.2.6 Description of the Activities

In this section of the course there are several types of activities available and it requires students' interaction with the course material. One of the most widely used activities throughout the course is MS SQL and Oracle server simulations; they are representing real servers. There are two instructor-side generated external representations: simulation itself and a textual hint affecting visual channel of the learner.

Most of the screen just as in case of animation is allocated to the simulation – an interactive area for the student. Above the animation there is a *slider* representing the actual progress of the simulation. The slider does not allow any interactivity and it is placed for indicative purposes only. In the right lower corner there is a hint for the next action to be performed by the student.

The simulation restricts student from doing any other action than the one asked for and displaying a warning message "Wrong action please follow the instructions below" when he fails to follow the instructions.

The goal of this simulation is to facilitate students in developing practical skills of creating backups for the SQL Server database using Enterprise manager. The simulation of the server is chosen for several reasons:

- It allows novices to act safely in the simulated environment without threatening the server stability by accidentally launched command.
- It allows simulating the environment of the server where the server is not available, for instance, at home or on the notebook computer.
- It allows students to simulate a diversity of platforms (this case MS SQL server and Oracle) and notice the differences.

They receive extra guidance compared to the real system (in the form of restrictions and hints).

Length of the backup process; depending on the size of the database, hardware and other conditions it might take quite a long time to wait for the server to create a backup of the database. Within simulation it is not necessary to make a student wait till the database backup is completed. It is equivalent for student to have it for few minutes and additional note displayed "Note on a real system this may take a long time for the backup to complete."

An important aspect is the choice of representation code of the hint; narration would be more appropriate according to dual coding theory. But as it is mentioned in chapter one, when there are multiple representations, student has to translate between representations. The problem might arise with people who do not know English so well, which is often the case in non-English speaking countries. When they receive a hint via the verbal channel, they might not be able to relate it with the corresponding menu title of the software as the spelling in English differs from pronunciation. Extra advantage of having the hint in writing is that it is available on the screen until the students perform the actions correctly and could be easily referenced when necessary.

However, in this simulation there is a danger of oversimplification, as many actions might be performed on the server in different ways and each way may be more appropriate under certain conditions. The

simulation does not allow the student to simulate every possible way of doing the action, just only one pre-defined way. Such approach is acceptable for the beginners, but they should always be aware that this particular representation is not the real system. Information discovered and knowledge gained in the simulation should be translated back to the real system. Another point must taken into account - the course itself has practical purpose and the online instructions must be considered as the introduction into the subject, and the practical sessions based on usage of real servers and databases should not be ignored.

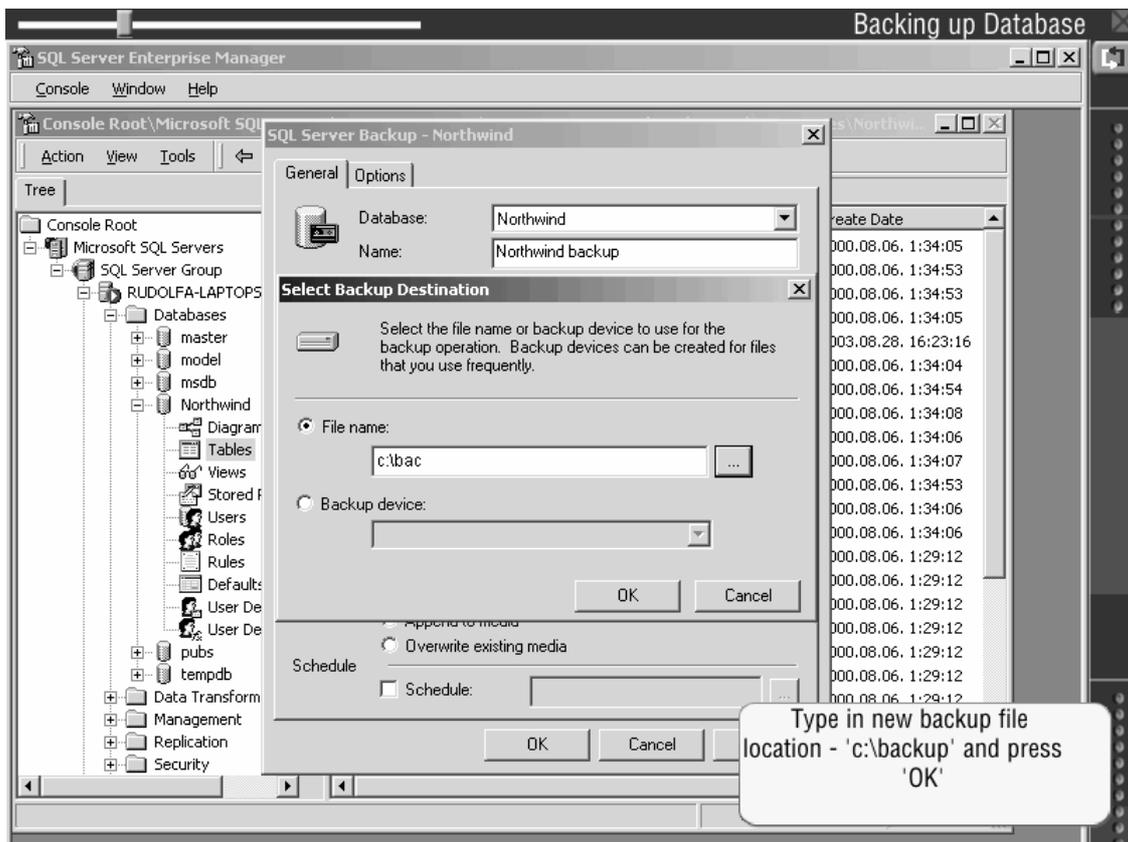


Figure 7.7. SQL fundamentals course, the Activities section

In addition to the types of activities described above there are a number of other activities included in SQL Fundamentals course. For example, in the picture below (See Figure 8) there is an interactive test/drill where the student has to select the proper function corresponding to the definition provided, drag it , and drop it into the proper cell in the table. When it is done he can click "Check result". The result of the practical exercise will be displayed: the right answers are coloured in blue and the wrong are coloured red. The Activity can be repeated until the student is happy with the result.

Agregate Functions **ACTIVITY**

Drag Functions below to corresponding field in table!

Check Result

Description	MS SQL Server 2000	ORACLE 9i
Calculates average for a range of numeric values	AVG (number)	AVG (number)
Returns number of rows in a SELECT statement	COUNT (number) COUNT_BIG (bigint)	
Returns max value among selected values	MAX (number)	MAX (number)
Returns min value among selected values		
Calculates sum of the selected values	SUM (number)	SUM (number)
	MIN (number) COUNT (integer)	MIN (number)

Figure 7.8. The Activities section – interactive test.

The next type of the activity is step-by-step execution of the certain actions and seeing the results in different representations. In this case there is an example of flight database being updated using data manipulation language commands. Learner has to "execute" a command by clicking the command line that normally would be sent to SQL Server and see the representation of the resulting data in two formats - SQL table and in user interface form that might be displayed to an airport operator.

The screenshot shows a software interface titled "INSERT and UPDATE". It features a table on the left, a user interface representation on the right, and an SQL command at the bottom.

Flight_No	Time_TakeOf	Time_Landing
DZ374	2003-11-21 17:30	2003-11-21 23:45
PR210	2003-11-21 17:50	2003-11-22 02:15

The user interface representation on the right shows the following data:

<i>Flight</i>	<i>Take Off/Landing</i>
DZ374	2003-11-21 17:30 2003-11-21 23:45
PR210	2003-11-21 17:50 2003-11-22 02:15

```
INSERT INTO Flight (Flight_No, Time_Takeoff, Time_Landing)
VALUES ('BD776', '2003-11-21 18:00', '2003-11-21 21:30')
```

Figure 7.9. The Activities section – step-by-step execution of commands.

The next activity illustrates a process of selection of data from the multiple tables using Join operation. . Initially the screen shows two tables filled with data that has to be joined in a third. Below Table B there is a code that normally is executed on the SQL Server. The third table illustrates the result of the action and step-by-step procedure how data are combined together.

Unit 9 Activity Joining of tables

A				
No.	Name	Surname	Birth date	Sallary
			11.02.1965	526.26
2	Silvia	Oras	1.04.1978	320.12
3	Erik	Oras	25.11.1980	295.59
4	Oto	Email	14.02.1978	356.22
5	Mia	Urmass	8.05.1977	250.00

B			
Store	Empl_ID	Department	Work. time
Otello	2	Food	
Otello	7	Jewelery	
Otello	3	Jewelery	
	1		
Otello	7	Food	

RESULT				
No.	Name	Surname	Store	Department
1	John	Smith	Marss	Food

```
SELECT No, Name, Surname, Store,
Department
FROM A, B
WHERE A.No=B.Empl_ID
```

Figure 7.10. The Activities section – joining the tables.

The next activity illustrates the concept of views in the database. The Learner is free to choose any *select* statements available and then see the results of the execution of the chosen statement.

The screenshot shows a window titled "Understanding Views" with a table of data and three SQL queries below it. The table has columns for City, Income, and Difference. The queries are: View 1: SELECT City, Income FROM DATA; View 2: SELECT City, Difference, Income FROM DATA; View 3: SELECT No_of_Stores, Difference, Investments FROM DATA.

City	Income	Difference
HELSINKI	123 443	+10
RIGA	2 300	0
MOSCOW	5 000	-2
STAMBUL	54 332	-4
BERLIN	1 012	+12
STOCHOLM	524 043	+1
KIEV	64 786	-2
BUDAPEST	4 544	-15
KANDAVA	786	+5
VILNIUS	12 432	+26
TALLIN	10 889	-43
DAUGAVPILS	5 432	0
TARTU	342	0
KAUNAS	127	+2
LONDON	1 234 332	-13

View 1
SELECT City, Income
FROM DATA

View 2
SELECT City, Difference, Income
FROM DATA

View 3
SELECT No_of_Stores,
Difference, Investments
FROM DATA

Figure 7.11. The Activities section – understanding views.

The next activity illustrates cursor orientation options in the database. The Learner is free to choose from 5 available commands and see the results of the cursor movement. The triangle on the left side of the activity screen shows the current Cursor position (row) within the table. The five illustrative Cursor movement actions show to the student what the Cursor does (it points) and what it is (something that points to a certain database table row).

Student learns that Cursor is not that Cursor he/she already knows (short blinking line inside the text editor's window), but Cursor may be also a synonym for 'currently selected row of the database table'. Student also learns that Cursor can be fetched, it can be relative (to the current row) or absolute (to the table as a whole) and it can move forward and backward by defined number of rows.

FETCH NEXT
 FETCH PRIOR
 FETCH ABSOLUTE 7
 FETCH RELATIVE 2
 FETCH RELATIVE -5

Click on command to see how it work!

Brand	Model	Type	Year	Y/N
Volvo	940	Sedan	1993	Y
Volvo	850	Universal	1995	Y
Mercedes	E230	Sedan	1994	Y
Volkswagen	Golf	Sedan	1996	N
Rover	214	Sedan	2003	N
Rover	612	Sedan	1994	N
Subaru	SVX	Sedan	1994	Y
Volvo	850	Sedan	1996	N
Subaru	Legacy	Universal	2000	N
Suzuki	Swift	Sedan	2001	N
Audi	80	Sedan	1989	Y
BMW	318	Sedan	1991	Y

Figure 7.12. The Activities section – cursor orientation options.

The next activity allows users to explore database Security Control functions available in SQL. The Example below illustrates how learners by clicking and navigating can find out command GRANT syntax.

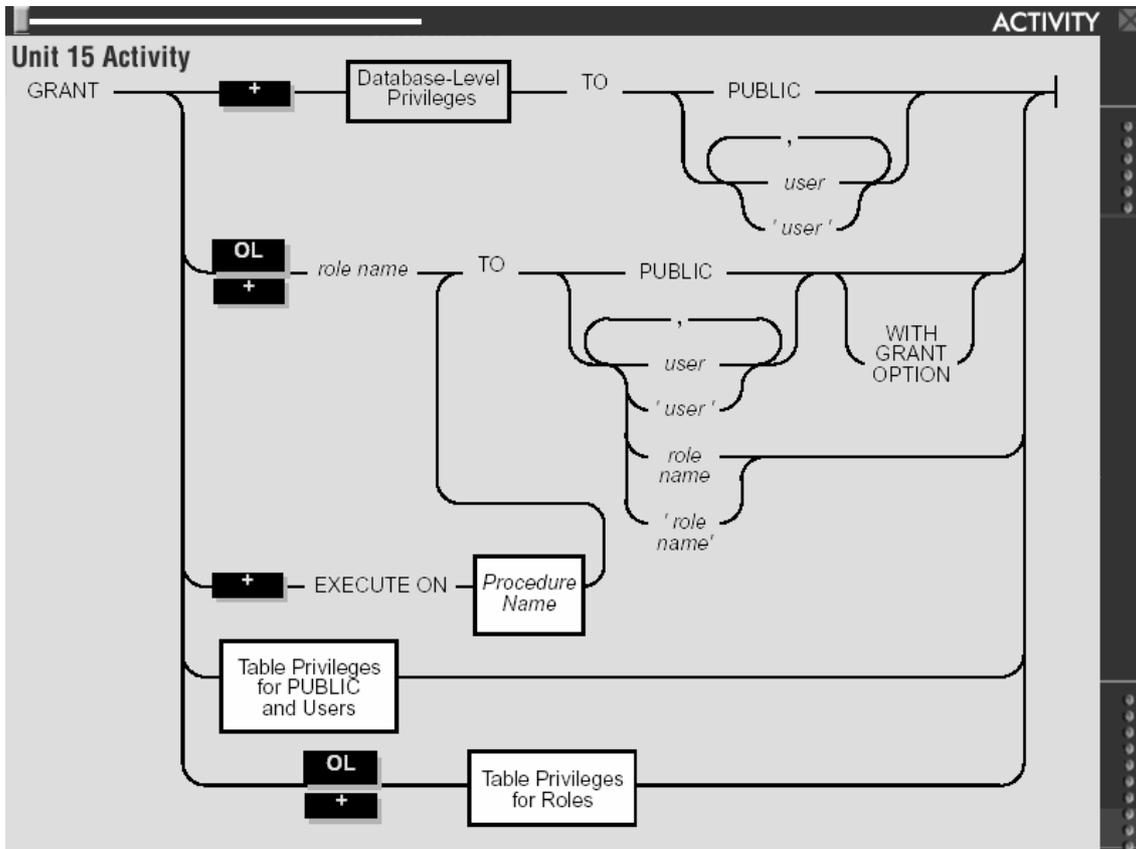


Figure 7.13. A screenshot of Activity – Exploration of Grant syntax

7.2.7 Description of Video Interviews

This section describes very important and valuable component of the course delivery material – the video interviews with IT professionals who are sharing their experience with the students. Obviously, it is impossible to invite such number of professionals in the classroom during semester and this feature of the online course essential enhancement for the course material.

Two instructor side generated external representation codes are used: text, speech and video, affecting visual and auditory channels of the learners.

On the left side of the screen the question and the answer of the interview appear in textual form. This representation is added for the purpose of easier interview content comprehension by non-native English speakers. On the right there is a video interview clip with standard set of action buttons for *start*, *stop* and *pause* of the interview. There is also interactive progress bar beneath the video indicating the progress of the interview and allowing fast forward and backward feature.

On the right side of the video there is an adjustable vertical slider bar representing the sound volume level of the interview. Beneath the video window there is basic information about the person being interviewed as related to the topic of SQL.

The goal of video interviews contained in this course is to give novices a practitioner’s perspective on how the SQL is used and applied in real life situations. Video-interview adds an extra perspective to the learning material illustrating how knowledge they gain could be applied in practice.

VIDEO
Unit 3

Question: How Databases can help us in everyday life?

Answer: All information about every airport in the world is stored in so called Global Airport's Database. What kind of information do you need to land airplane safely? So you need the longitude and the latitude of the airport you need the elevation of the airport too. So all this information you can feed into very modern autopilot. So it can land the airplane absolutely safely and absolutely automatically.

Armands Strazds
Nine years industrial experience in SQL development

SQL FUNDAMENTALS

Figure 7.14. SQL fundamentals course, the Video section

In the video interviews there are two representations used containing partially redundant information. Video in this case sets the context and shows the working environment of the professional. Text on the other hand does not provide much detail, but helps in comprehension. It is especially useful for non-native speakers of English. Upon necessity they might even want to look up an unknown word in a dictionary or a technical term in the glossary.

An extreme situation would be where two representations offer exactly the same information as this has been done in one of the courses “Business Planning for Open Markets” developed at RTU DESC five years ago. Students along with the written text on the screen were presented with a voice-over repeating the same information in speech. Only illustrations added an extra dimension to the material. According to Ainsworth (Ainsworth, 1999) there is considerable evidence that due to different *computational properties* of representations learners derive different information even if theoretically the information in each is identical.

On the other hand Kalyuga (Kalyuga, 2000) describes a similar example when such a redundancy may not be beneficial for learning and may cause a cognitive overload. He argues that concurrent duplication of the same information using different representations increases the risk of overloading working memory

capacity. He states that in such a case auditory explanations may become unnecessary when presented to more experienced learners who are able to process textual information more quickly. This was also stated by a number of students taking the Business Planning for Open Markets course (BPOM). It was not a serious problem though the learners were given freedom to mute the audio part when necessary, and to skip to the next slide when done with the current one. The example above shows that redundancy should be reduced as expertise grows or at least it should be controllable by the learner.

7.2.8 Student feedback

The course SQL Fundamentals has been offered to CNET (computer networking) students during last Semester (Jan.-Jun, 2004). Online studies, online quizzes, in-class practical sessions and tests were used to deliver course material. Students' feedback may be represented by the following table:

Table 7.1. Student feedback

Positive feedback	Negative feedback
Course user interface is simple, easy manageable, and clear. Clear instructional text, basic terms are highlighted, examples are clear and describe the basic functions and options available in SQL. It makes learning more effective, and easy.	Some units have too many slides and there is no link to the Unit content page to see the paragraph title that is discussed currently. It causes some confusion. Wish to have more examples in the textual part, and demonstrate not just simple options and features but provide and analyse more complicated cases.
Direct access to Glossary, and to the terms needed to be explained	Some interviews are too long and students loose the attention and concentration.
Flexible navigation, direct access to video interviews, examples, activities without the necessity to read all the text	Course material contains some grammar and Syntax mistakes.
Examples are created very carefully and provide very essential help in understanding of the Unit content	System Guided activities may cause some confusion because error messages appear and then do not disappear automatically, Error message box must be closed manually.
In most verbal description and the animation are combined successfully to make the learning process effective and fast. It helps to understand the topic better.	

7.3 Conclusions

By using the approach of internal and external representations, we were able to explore the landscape of multimedia solutions more precisely. Our study demonstrates the usability of external and external representation approach for conceptual and technical improvement of quality of multimedia learning materials.

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CHAPTER 8: Extension of external representation to Interactive and Multisensory Simulation of Physical Objects

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Abstract. This chapter is dedicated to a case study, the GENESIS software for musical creation with computer thanks to physical modeling and simulation, and its general didactic environment. The latter is a work in progress and uses for its beginning material already created in the context of real learning experiences (in composition master classes in conservatories). But these works are also pretexts to introduce a new concept dealing with the “external representation” in general, and the proposition of its extension to what we call “Interactive Multisensory Simulation of Physical Objects”. This extension is only thinkable and achievable within the new representation possibilities introduced by Information Technology, and more precisely by the computer. So, as the latter bring up deep mutations in the way we can represent, transmit, communicate, understand, manipulate... it appears necessary to us to reintroduce some basic discussion on Representation itself. The chapter is then composed of three parts, the first dedicated to these considerations, the second to the introduction of “Multisensory Interactive Simulation”, and the last to an analysis of GENESIS environment according to theoretical issues given before.

8.1 Introduction

“Unlike the animals, the human can (...) evoke absent objects, far in time and space, thanks to various substitutes: portraits, diagrams, symbols, signs, terms of language, mental images, concepts. The portrait represents the person, the statue the divinity or the saint, the ambassador, the head of the state, (...), the map the country, the word the mental image or the concept or the thing. Knowing, in its more general aspect is nothing else than *get representation* (...)”⁸ (Paulus, 1969).

Representation is per se a very rich and wide question that constantly concerned thinkers of all sorts since Antiquity, philosophers, scientists, mathematicians, ... As a linguist, Paulus considers that there is no difference between *to know* and *to get representation*. Of course, learning, being to get knowledge, representation is not only a practical or technical question we have to do with, but a central point, which is all the more important since the Information Technology (IT) introduced deep mutations in the means and the ways through which we can “represent” everything.

Before considering this question specifically within the context of new technology (Information Technology) for learning, it may be useful to bring to mind some basic, which sometimes may be obvious, but important points on Representation in general.

⁸ Translation from the French by C. Cadoz

8.2 General considerations on "representation"⁹

As Paulus said, with various other authors (cf. Palmer, 1978): to represent is to take *something that stands for something else* in order to "apply it some actions of a special kind: symbolic, verbal, mental, more economical and practicable, although not less gratifying than the motor actions they stand for" (Paulus, op. cit.).

This very general sentence holds by itself all the essential questions concerning representation: what a thing is and how a thing can stand for another? What are the purposes of the actions? What are the actions? How an action can stand for another? It also points out these very important notions of *economy* and *practicability*. Our purpose is not here to answer all these questions (an entire life could not be enough for that!) but to try to set down an appropriate entry point for the representation problem while it is newly and profoundly questioned by Information Technology (for example, the notions of "object", "objectivity", "reality", "presence", are quite problematic when we have to do with "Virtual Reality").

Thus we think it is necessary to start with at the general level of the "object" or "objective world" (however less general than "thing"), and we claim that it is possible, even if the way may be long, to link all the questions of representation(s) (iconic, pictorial, symbolic, descriptive, depictive...) to this anchor point. Indeed, what is always present in front of us, or around us, on which we act, thanks to which we communicate, and that we transform, is the objective world, the physical objects, even when we use very sophisticated computers and software environments for our most abstract and immaterial activities.

As soon as we bring in the word "object", we are lead to consider simultaneously at least four inseparable notions: the objective (external) world, the subjective (internal, mental) world, action and perception.

The notion of "object" relates to two complementary ones: an object is something *objective*, but it is also something that we can *distinguish* from a whole and / or from others entities of the same status. Objectivity is one of the two poles that allow us to speak of internal and external worlds. The internal world has not to be proved, it has just to be experienced by each of us. As Descartes said, "I think, therefore I am" ("*Je pense donc je suis*"). But a primary experience is that this internal world is changing, bringing up the feeling of *time* and of difference, and consequently difference along the time. Therefore, we can ask us a question: is there something existing independently of us, "external" to us? If it is, then we can speak, as subjects, that something is "subjective" and something... "objective". The two terms are only mutually definable. However we know that we can act, and, actually, we not only think, we also act! So, generally, when acting, we modify what we have in mind. As a result we build perception: perception can be defined as the process that creates in our mind, when we are acting, the feeling that something exists that is invariant e.g. permanent, out of us, with some different and distinguishable features, independently of what we feel and how we act.

⁹ A large part of these considerations is extracted from a long article by the author, published in 1994, following an international workshop on physical modeling for musical creation hold in Grenoble in 1993 and organized by the ACROE-ICA laboratory: "*Simuler pour Connaitre, Connaitre pour Simuler*" (To simulate for know, to know for simulate) – see (Cadoz, 1994).

In the same time, we conceive also that, at another scale, these permanent things can be modified, independently of us, or through our own actions. Then, we conceive that we have to understand and that we can transform the external world, creating ourselves while creating the world, and conversely.

In other words, as well as we can't dissociate subjectivity and objectivity, we can't separate action from perception and this second dipole from the first and from transformations.

Going faster ahead, we usually consider that action and perception are performed, for every living being, thanks to specific organs: the body, the limbs, the muscles, ... for action, and the senses for perception. Motricity, although very complex, is nowadays a well-studied domain (see for example Bonnet & al, 1994). Sight, hearing, touch, smell, taste have also, individually, been considered and studied for long time, and more and more understood today, particularly thanks to new technology in the field of experimental psychology, bio-physics and psycho-physics.

Our sensory-motor organs are biological "devices" that transform *phenomena* from a given nature to another: mechanical movements, acoustical vibrations, electromagnetic waves into nervous (electrical) impulses for the tactile sense, hearing, sight, and conversely nervous impulses into mechanical movements for the gesture, and acoustical vibrations for the voice. We know that our internal world and activity are built from these internal phenomena for and from what we will very quickly designate for the moment by our *cognitive system* itself supported by physical (biological) components.

The *phenomena* are the only things that we can attain, in both directions (action or perception). We can say that they are objective, but not that they are objects, however we can experiment, and we then *postulate*, that they are manifestations of, or that they can modify some entities, existing independently of us in the external world. We call that the *objects*. We no more can't be *a priori* sure that, if such objects exist, they produce only the phenomena we perceive, nor that there are no objects producing phenomena that we can't perceive. So, we are lead to *postulate* 1) that there are phenomena that we can perceive (or produce) – we will call them globally *sensory-motor phenomena* - and others that we can't, 2) that the objects exist independently of us and that they can at any moment produce phenomena that we have not perceived before or that we will never perceived, and 3) that the external world can contain objects that we have never perceived before and objects that, may be, we will never perceived. We will associate to these remarks the notion of *infiniteness* of the external world, not *actual* (which has until now never been confirmed or infirmed by anyone) but *potential* infiniteness in the sense of mathematics: "however large is a number of arbitrary choose, it always exists...", that never we can actually verify, because our life time is finite. We will call this the *infinite ontology* of objects and real world.

So, this is through our action / perception activities, supported by our action / perception organs and our cognitive system that we get knowledge that there is an external world, independent of us, containing objects. And we can say that between internal and external worlds, there is a *representation* process in the sense that the first, in a certain manner, stands for the second. We can add that, necessarily, as in every representation process, they are in a certain way necessarily, at the same time, the same and not the same. But we will come back later on this point.

We must now take into account that, even though the senses, by the fact that we can associate a specific organ to each of them, have been considered until recently as quite separable functions, a strong trend in experimental psychology is today to consider them as a whole. Perception must not be considered only as a simple (internal) output of our sensorial organs. It is more appropriate to speak of *perceptive system* (Gibson, 1966) that creates mental "images" (in a general sense that is, precisely not only "visual") and for which, even before deep cognitive treatments, it is not appropriate to say that they are visual more than aural or tactile, etc. Furthermore, an important current in psychology is now to consider that, as stated previously at a very general level, action and perception are intrinsically interrelated: we can't perceive without action and we always perceive when acting (see for example: Varela, 1991, Dennett, 1993, van Gelder, 1999, O'Regan & Noë 2001, Rutkowska, Stoffregen & Bardy, 2001). Some very simple examples can convince us of that: we need to move our eyes in order to analyze a visual scene, we have a good mental image of space not so much because we have two eyes giving us two (few) different points of view of the (objective) world, but more because we can move in the space. The tactile sense can give us a quite complex and sophisticated mental image of shape, weight, plasticity of the objects when we *act* on them, *manipulate* them.

Coming back to the previous idea, (the perception as a whole and as a system), we can evoke the famous McGurk effect: a videotape with the audio syllable "ba" dubbed onto a visual "ga" produce, independently of any entertainment or advertising, the perception of "da" (Massaro & Stork 1998)¹⁰

This "intersensoriality" or "bisensoriality" is observable in various different situations, involving different senses. For example, the author and his colleagues experienced, in the 1970's, the very simple but troubling following situation: using a stick with a force sensor and a force-feedback device to control the horizontal displacement of a spot on a screen, they asked several subjects to describe their tactile sensation. Surreptitiously blocking the stick at a fixed position and using the force signal obtained by the force sensor to control the displacement of the spot, and artificially (electronically) stopping the displacement of the spot at the middle of the screen, they asked the same question. All the subjects concluded that, at the moment when the spot reach the middle of the screen, the stick become harder. Actually, it was always hard, since it was fixed! The visual information influenced the tactile perception.

These are reasons why, at this first step, we consider that "internal" and "external" worlds, action and perception, in fact *interaction* and *multisensoriality* must be the first global conceptual framework in which we must approach everything, even if we soon simplify the things in a pragmatic attitude, for practical reasons. Note that we must be aware in order to be able to anticipate further researches and developments.

8.2.1 Sensory-motor phenomena / action-perception loops

Considering the objective phenomena that concern our sensory-motor capabilities, we will admit that they are quite defined by physics (which is by itself, of course, a system of representations). They are, for the human being:

¹⁰ (see also: http://www.media.uio.no/personer/arntm/McGurk_english.html, <http://www.haskins.yale.edu/haskins/HEADS/mcgurk.html>)

- The light (electromagnetic waves in a certain frequency range that we call "visible")
- The sound (aerial or material acoustical vibrations: alternative variations of pressure, length, etc., in a given frequency range called audio-frequency)
- Mechanical forces and displacements occurring at the frontier between our gestural organs (our arms, legs, hands, fingers, but also our entire body) and a material object during gestural activity.

We left apart the phenomena corresponding to the temperature and the chemical ones relating to the smell or the taste.

In order to simplify the writing, we will use in the following, respectively *visual phenomena*, *acoustical phenomena*, and *gestural phenomena*.

Let's go into more details:

Mechanical forces and displacement occurring at the contact between our gestural organs and material objects or environment are not emitted or received, neither by the subject, nor by the objects, there result from the mechanical interaction. We are equipped with internal sensors (in skin, muscles, articulations, internal ear) that can give us sensations of temperature, positions and displacements of the parts of our body, efforts, verticality, etc., and of motricity organs (muscles acting on parts of our skeleton, etc.). We can contract our muscles, but doing that, we don't emit a displacement of a force, we produce a mechanical energy that will be converted in a certain combination of movements and forces according to what mechanical object we are interacting with. We call this intrinsic capability of gesture organs, independently of its subsequent use (to inform, communicate or to simply physically modify or transform the physical world) the *ergotic* function of gesture (Cadoz 1994, Cadoz & Wanderley 2000).

So, what we call usually the *tactile* sense, is not so simple. It is non dissociable from action and it is more convenient to speak of *tactilo-proprio-kinesthetic* (TPK) sense, that, intrinsically combining action and perception, can give us rich information on position, size, shape, movement, deformation, etc. of the material objects we manipulate. As a consequence, we can say also that gestural action is not achieved in an only "emitting" way, but is always concomitant with TPK perception.

This is the deeper argument in favor of action / perception paradigm.

Let's remark, in another hand, that the light can only be received (perceived), but not emitted by the subject, and that the sound can be perceived (aural perception) and emitted (vocal expression). This leads us to see the action / perception interaction in a global scheme made of several nested loops (see figure 8.1), and distinguishing the situations where there is an object, to be know or transformed, an object used as a media for material operation (a *tool*, or an *instrument*) or for communicational purpose (*communication instrument*), and the situations (*natural situations*) where there is no intermediate object between the communicating subjects.

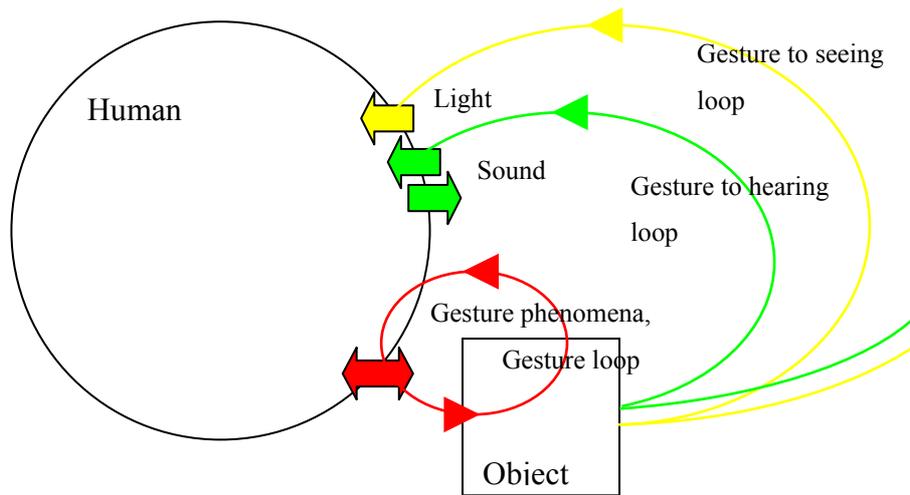


Figure 8.1. The action / perception loops

As said before, according to the current trends in experimental psychology, we assume that this is through these loops that the human being builds his mental representations. This position leads then to an *active / perceptive phenomenology*, or *interaction phenomenology*¹¹ that differs from the classical *perceptive phenomenology*.

Remarks on terminology: multisensorial / multimodal / multi-media

In specialized literature *sensoriality* and *modality* (for example in the terms *multisensorial* and *multimodal*) are currently uncaringly used for the same meaning. We prefer attribute to the first the strict meaning of what is referring to the sense organs, biologically described (e.g. the eyes with the retina which is sensible to the light), and to the second what is referring to the perceptive process, including a part of the cognitive one (e.g. the sight). That is why it is problematic to speak of “sensorial modality” and preferable to speak of perceptive modality (or just *modality*) on one hand, and of sense (*sensoriality*) on the other hand. In this way, visual modality and visual sense are two distinct things. The visual modality can be considered as the modality that mainly involves the sight (and consequently, of course, the sense of vision). However a given modality, sight for example, can be in a certain extent multisensorial if we consider that our visual mental image of something can be influenced by what is occurring in the same experience on other senses, like aural or tactile senses. In addition, we can consider the specific situation where all our senses are involved together at an equivalent level as a modality by itself: the *multisensory modality*. Finally, multimodal situations can be built with several uni- or multisensory modalities. Thus, multimodal and multisensory have not the same meanings.

Concerning “multi-media”, it stands at a totally different level that refers to the specific supports bearing representations according to current technology (paper, audio or video devices, CD-ROM, interactive CD, DVD, etc.) that can support differently textual, aural, visual, static or interactive representations, etc.

¹¹ According to the current tendency about *enaction*, we can propose also the term *enactive phenomenology*.

8.2.2 External representation

Coming back to the main purpose, the next question is then, considering a given external world, how to link up the individual internal representations of several different people? This is the fundamental question of every human being as soon as he gets the representation of the existence of others “subjects”. More pragmatically this is the question of human communication, and, as part of it, of learning of course (in the latter, the goal is indeed to try to make a part of the internal representation of a learner identical to a “given knowledge”).

But there is no other way to create or verify that than to turn to real objects or, at least objective phenomena. The simplest human communication way, the oral communication, uses the acoustic phenomenon as objective media. But thanks to the technology (which is contemporary of the human being – see Leroi-Gourhan, 1964), and even more the new technology, the human being used for long time and in a very wide extent *objects* to communicate.

What we can call external representation is then nothing else than objects and / or objective phenomena used as well as representations of our internal world so as representations of the external world. We must underline the fact that, except for the natural situations these objective media are necessarily material objects. So, the basic framework for action, perception, communication and ... learning can be “represented” with a triangle (figure 8.2) with, at its vertexes: internal representation, external world and external representation. We can consider it in a more essential understanding by generalizing the notion of “external world” to the one of “given world”, meaning by that all the existing things (real objects, phenomena, knowledge, etc.) that are, at a given moment, for example the learning experience, the purpose (the “object”) of the learning.

But the most important feature is here the absolute tri-symmetry of this triangle. We have to envisage as well:

- External representations to represent the given world or to represent the internal world,
- Internal representation to represent the given world or the external representation,
- Interactions (action/perception) between internal and given worlds,
- Interactions (action/perception) between internal and external representations, and even
- Interactions between given world and external representations that don't involve for every phases the human being, particularly since the robot technology.

There is no reason *a priori* to consider that the three vertexes can or must be in exact correspondence. We will see below that in fact they never can but that we only can try to make them arbitrary close according to given and restrictive criteria. There is no *a priori* possible attitude about that because, if we can make the hypothesis, for example, that a good external representation for learning could be a one that anticipates the internal representation to produce, we can as well consider that they must also be different in order to install a kind of “multiple representation” with the same properties and benefits, not between external representations, but between internal and external ones.

There is no reason why what is available between external representations can't be also available between internal and external, since internal representations are, as well, representations. In any case, the only way we can adopt to study the internal representations is to give external representations of them.

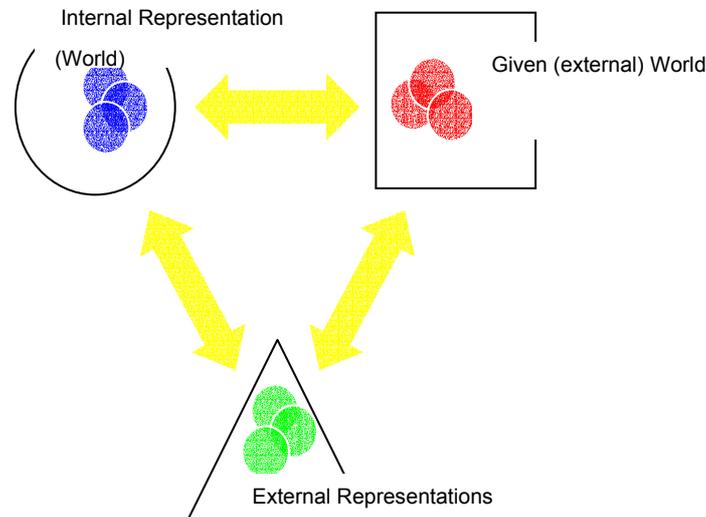


Figure 8.2. The Representation triangle

We focused until now on the notion of object, in fact “physical” object. It is indeed easier to start with this because we have this reassuring feeling to speak of tangible things. But can we speak in these terms of, for example, the reasoning we do (and we may have to teach) to solve a mathematical problem? Reasoning can be objective in the sense that it can exist independently of the teacher and the learner. But obviously, we are not inclined to consider it as a physical object. More generally, we usually judge from very different orders, in one hand concrete and material things and their phenomenological manifestations, and, on the other, ideas, emotions, concepts, abstractions, etc. Nevertheless, we consider that the seconds, as well as the firsts, can be objectively represented, ... which is different from to consider that they are objects! This question is obviously very arduous and we don't claim to rigorously answer it here. However we can maintain that it is possible to find something, generally as a system of objective entities (rather than a simple object) that sustains, for example, what we call reasoning. In any case, if we consider that reasoning is something inside of the human being, then, as human being (his body, his brain, etc.) is made of matter, we are lead to admit that reasoning is, somewhere, sustained by matter, and, consequently that there necessarily exists a way to go from material object to thinking, feeling emotions, reasoning, etc. But it is not the purpose of this paper to travel all along this way, just to try a humble and reasonable attempt to sketch some tracks that are possible to follow if we have nothing else to do.

The first elementary steps

To represent is a necessity of the living beings in order to create and evolve, i.e. at a first step, to "understand" the present and to anticipate the future, not only to know it by advance but, particularly for the human being, to built it, to determine what actions he has to do to transform his material world. The internal representations resulting from the direct sensory-motor experience has already the function to allow us linking the past and the present (literally to re-present) and to anticipate the future: we are able to feel as identical two sensory-motor experiences performed at two different moments, i.e. to recognize that the same actions on something lead to the same perceptions. Concluding then that there is an object, or at least something permanent from the past to the present, we can predict, without physically acting, that if we apply the same action to the object, it will adopt the same behavior. Thus our mental representation *stands for* the real object.

Let's notice that this prediction is nevertheless based on a *postulate*: that the object does exist and that its permanence will extend to the future, which can never be absolutely certain since, as we said above, the objects exist independently of us and they can at any moment generate phenomena we have not perceived before. They can also have changed after an interaction with another object or another subject, independently of our own action. Moreover, they can change because we are interacting with them. Think for example, according to the quantum physics, that at the scale of small particles, the minimum interaction needed to observe them changes their determination. At this scale, it is impossible to define the object independently of the actions the subject does to observe it. At the scale where we are concerned, fortunately the things are simpler, and we will distinguish actions to perceive from actions to transform, although the latter are also intrinsically associated with perceptions. Let's notice however that the frontier is partially arbitrary and depending of a decision we can take, for a given experience, to consider some part or some aspects of a whole, rather than the whole itself, as the object of our interest.

The intrinsic limit of this first "phenomenological" internal representation is that we can't *a priori* know all the possible behaviors of an object without experiencing them; which is not prediction but real experience.

In a second step, the first of *external representation*, may consist on taking another physical object, "identical" to the first and standing for it. We can call it the "*representing* object", the first becoming the "*represented*" one. Then we can establish with the representing object, in absence of the *represented* the (sensory-motor) interactions we could have with it.

This very elementary situation allows us to bring to the fore several fundamental features that will be inescapable whatever the representation situation we will consider:

Firstly, the notion of object itself, as distinguishable from others or, even as a separable part of the universe in its whole, can't be absolute, since we can't never be sure that there is not an interaction we have not yet experienced.

Think for example, in reference of the Chaos Theory, to its famous "butterfly effect" - the idea in meteorology that the flapping of a butterfly's wing will create a disturbance that in the chaotic motion of the atmosphere will become amplified eventually to change the large scale atmospheric motion, so that

the long term behavior becomes impossible to forecast¹². Consequently, in the absolute, we must consider that the only object in the universe, is the universe itself, including ourselves...

Secondly, assuming that, in the framework of a given experience, we can consider an object as isolated from its environment, as we said earlier, he has its own "*infinite ontology*", i.e. whatever the knowledge we have of it at a moment there is always something in it that we may discover in a next experience.

Thirdly, as a consequence of the previous, between two separate objects, experienced as identical in a first step, it always may exist a difference that a further experience will reveal.

And finally "identity of objects" leads to "identity of phenomenological experiences". We can only decide if two objects are identical after having established with them action/perception interactions giving us mental representations of each of them. We can call that first necessary step the *initial* identification, or *initial link*. Then, in what extent can we say that two mental representations are the same? It supposes that we are able to get present (mentally re-presented) at the same time several things and that we can compare them - we know that our "mental charge" is limited, thus we never can be sure that all the features are correctly and completely invoked. In fact, in general, we decide to consider things as identical (or not), assuming the consequences, ... "for the best and the worst". And there is always the necessity to verify, at certain moments, that the "identity" is preserved. We can call that the *closing link*.

As a conclusion, this simplest and basic case of representation leads us to admit that absolute representation can't exist. The only absolute possible representation is the representation of the universe in its whole... by the universe itself! Which is precisely not a representation and definitively what we want to avoid.

Now, we can assert that "to represent is to take *something that stands for something else*" and which is *a priori* different. The question is then in what extent and for what purpose can we replace the interactions with the one by interactions with the other? Or, how interactions with the one can stand for the interactions with the other? If it is possible, we will be allowed to speak of, not identity, but *equivalence*.

From here, we can adopt a part of the terminology and questions from Palmer (1978), with:

- (1) The represented world
- (2) The *representing* world
- (3) What aspects of the *represented* world are being *represented*
- (4) What aspects of the *representing* world are doing the modeling
- (5) The correspondence between the two worlds

But we claim that the typology he proposes, with *Non-equivalent*, *Informationally equivalent*, and *Completely equivalent* representations, founded exclusively on the relations inside the two objects is very partial, even for the learning purposes. Indeed, before this order of considerations there are a lot of

¹² The "Butterfly Effect" is often ascribed to Lorenz. In a paper in 1963 given to the New York Academy of Sciences he remarks: "One meteorologist remarked that if the theory were correct, one flap of a seagull's wings would be enough to alter the course of the weather forever."

essential points concerning how we can take an object for another in such a way that, for a given purpose, they are *equivalent*.

And first, it is essential to take into account now the second part of the Paulus (op. cit.) words: to represent is to take something that stands for something else ... in order to “*apply it some actions of a special kind (...) more economical and practicable (...) than the motor actions they stand for*”.

Two objects (things) being in a representation relation are different. Some features present in the one are not in the second, **and conversely**. Every representation leads to a *reduction* (suppression of features that are in the *represented* and not in the *representing*), but also, unavoidably, to an *extension* (adding of features that are in the *representing* and not in the *represented*) – (figure 8.3.)

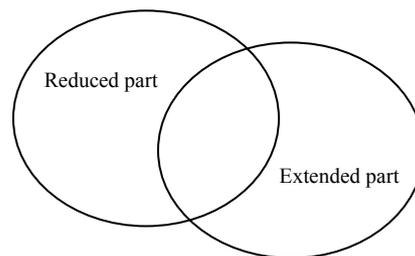


Figure 8.3. Reduction / Extension in representation

In a certain way, the *representing* has his “own life”. We must put behind this an important property of representing world (representing things in general: objects, systems, ideas, concepts, etc.), which is its (relative) *autonomy*. It is particularly important because it is not always a drawback: in Art domains, it is specifically one of the ways through which we can create (represent something that doesn’t exist before). In science, this is very often through only the auto-consistency of their theories and of mathematics that physicians for example created new descriptions of the universe (like the one of the “Big Bang”), before any experimental verification.

The reduction, as well, is not (always) a drawback. More, it is an essential necessity because it is thanks to it that we can determine, for example with a map, the route we must follow to reach a town before actually traveling, in a very shorter time and lower expense of energy than the real travel needs. This is to this aspect that the notions of *economy* and *practicability* are related, a better practicability being often a consequence of an economy.

The ways according to which we can practice or accept reduction from the *represented* to the *representing* entities are in the following point.

Economy of representation – The three main categories of signs

In order to articulate the following of our discussion, we will adopt a global arrangement sustained by the classical triad *index*, *icon*, *symbol* commonly invoked in linguistics and semiology (Peirce 1931, Eco 1976, 1984, Chandler 1994, 2001). Under this over drawn plan, we will use several sub-divisions allowing a sequential introduction of the main basic concepts we need.

The starting stage (degree 0) of representation, which is actually primary mental (internal) representation, is to consider the real world in its whole and to interact (act/perceive) with it. The second one (degree 1) is to substitute an object to the initial one, both considered as isolable objects and as *equivalent* within a given finite sensory-motor experience. The next degrees can be formally understood in correspondence with the various possible reductions.

8.2.3 Index

As we are dealing with external material representations (letting aside the simple objective phenomena), those are necessarily material objects. Hence, reduction means inevitably substance reduction, namely reduction of the matter of the representing object. The simplest way is to break the object in several parts and to keep one of them standing for the whole. Obviously, the two parts are *a priori* not equivalent to the initial object or between them. This is in fact the etymological (Greek) meaning of the term “symbol”¹³: *sumbolon*, a piece of an object shared between two persons used as a recognition sign. In this case, the representation function is symmetrical: anyone of the two parts can play the role of representing the other. The initial whole object naturally makes the *initial link*. The actual sensory-motor interactions between the persons and their respective parts can’t however stand for each other. In this limit case, only the *closing link* has relevance: the checking that the two parts mutually match. But when separate, the different parts can “evoke” (i.e. recall in the mental representation) for each person, the experience of the initial object in its integrity, representing the integrity of the link between the two persons. This is an occasion to underline this permanent alternation between mental and material representations that clearly illustrates the close links between the three vertexes of the representational triad, even in the simplest cases.

One step further when an object or a set of objects and phenomena physically interdependent can be separated, or individually experienced (or simply perceived), one of the separate objects and / or phenomena can play the role of *representing* for the whole. For example, the arrow can represent the complete arm (the bow and the arrows) and can evoke the actions a hunter can do with it, or simply a fast movement.

These cases correspond to one of the main categories in the current taxonomies of signs, the “**index**” corresponding to “a mode in which the signifier is (...) *directly connected* in some way (physically or causally) to the signified - this link can be observed or inferred: e.g. 'natural signs' (smoke, thunder, footprints, echoes, non-synthetic odors and flavors), (...)” (Chandler, *ibid*).

8.2.4 Icons – analogy / phenomenological equivalence

In the previous limit case, we must underline that, whereas an objective thing (object or phenomena) actually stands for another, the respective material actions (interactions) can’t correspond. Only the

¹³ Let’s notice that this primitive meaning of *symbol* is not at all the current one.

mental recalling of the actual initial interaction with the *represented* can play. The next step is different on this point.

Coming back to the idea of identity, ask us the question: is it possible to preserve a "certain identity" of the objects in another way than by taking two "identical" objects (which is impossible), and assuming a material economy?

Since we never know anything in another way than by the mental image we get through an interaction, the question of comparison of objects turns into the one of comparison of mental images.

Primary mental capabilities / mental categories and functions

Assuming that a given action / perception experience leads to a certain "mental state", before to conclude or postulate that it corresponds to an object, we already said that the first internal experience is the one of *time* while this state is changing. So at the same time, we get the feeling of variation, difference, and of their opposites, permanence, identity, over the *time*. Further, let's consider that we are able to get in mind at a given time (present) the feeling of *multiplicity*, i.e. that several differentiable features are coexisting in our mind. Among them, some ones are due to our *memory* faculty that can literally re-present (make present) some prior result of experience. More, built on the multiplicity, we have in a certain extent the capability to *associate* or *dissociate*, i.e. "draw" a frontier leading us to consider that several differentiable features constitute a single whole, or, conversely, that a previous given whole is dissociable in several differentiable features. So, it becomes possible, for a given whole, to "analyze" it as a combination of different features, and to make a comparison between several "wholes" according to what features are, individually, identical or different over them.

This can be considered, in human being (and in various ways in living being in general), as given primary capabilities, or *functions* of what we can call the very basic *cognitive equipment*, complementing the basic action and perception organs in a global *cognitive system*.

Several remarks

In the previous, we didn't have to specify if this set of features, initially considered as correlated to a given sensory-motor experience, could occur independently of any such experience (when dreaming for example). De facto, we have within the previous considerations no means to actually bring up such discrimination. This question is not so simple. It is interesting, in our context, to link it to the following one: how can we get the proof, in the Virtual Reality context that what we are experiencing is "real" or "virtual"? This merges with the current question of "Presence" in the VR domain (Luciani & al 2004).

Supposing that the mental state is correlated to a real experience, we can also notice that we have no need for the moment to attribute it to the perception exclusively; our actions may also be correlated to mental states. We just can differentiate the two by saying that the former are, at least partially, issued from a conscious will. Apart this, we have to consider that both actions and perceptions lead to mental states on which we can apply the previous considerations as well, but that (in a certain extent) we are able to mentally separate or associate them. However, concerning the mental states associated to our will of action, it is not quite appropriate to speak of "representation", since it comes as first, but simply of "presence". .

Coming back to the "given primary capabilities" we can notice a difference between the very first (the feeling of time) and the subsequent. The latter are some kinds of "functions" as we said. The former is not. Time is something that can't be defined, just experienced. It may be the same for what we called very evasively the "features" that we can compare, differentiate, associate, etc. Here appears a difficult problem: evoking for example this feature that we call the red, one can say that this is a feature, experienced as identical amongst several ones issued from multiple experiences of different objects. Then, referring to any of these objects, we can evoke this feature. More, we can choose a set of objects in such a way that this feature is the only one that is common to all the objects. So, there is no more ambiguity. Even more, considering all the features we can encounter in the world, we can draw up all the formal system that establishes in a non ambiguous way all the relations between these features, there identities and differences. Do we obtain for all that the explanation of the feeling of red?

We must suppose that we can speak of the color of objects independently of the objects and that we can associate them according to this "property", so, that we can have a feeling (a mental state) beyond the sensory motor experience of each object. That is in contradiction with the principle according to which our mental representations are built from the sensory-motor interaction.

So, we are de facto lead to consider that something exists in our mind, in which we make a certain projection, that is difficult to completely characterize and that is intrinsic and given a priori, namely independently of any experience. As well as it is difficult to describe these categories - all the more than, as we already said several time, it is impossible to describe our mental representations in a different way than by the means of external representations – it is necessary to admit their existence. The time was the first of them. Let's call that the primary (innate) mental categories, distinguishing them from the one that are built (acquire) through sensory-motor experience.

We have also to keep in mind that even if it is possible for example to consider time as a primary category, it is not so easier to say the same about space, which is considered by certain psychologists as acquired through motion (gesture) loop experience (more than by motion-vision loop) (see for example Hatwell 1986, 1987, 2003). This is more and more obvious as we go to more and more complex sensations, as the psychophysics domain in its whole teaches us.

In any case, we will go ahead relying only on the idea that such primary categories does exist even if the descriptions, characterizations and words used to evoke them in the following are voluntary a little simplistic regarding the current and well elaborated theories of mental representations and their building.

Coming back to the cognitive categories, we will rely, in the subsequent discussion, upon the following: time, space, quality (i.e. everything that cannot be assigned to space or time but that can be extended over time and space¹⁴), complemented by location in time, extension in time (duration), dimensions of space (dimensionality), location in space, extension in space (shape, volume), movement (variation of location over the time), deformation (variation of extension in space over the time), variation of quality over time and over space.

¹⁴ Note that, as we can spontaneously think of color, for example, the visual attributes are only one part of the whole we have to consider. Particularly, aural attributes are also important and relevant.

We consider now the human being as capable to get in his mind at a given present several different features corresponding to several different objective phenomena or objects actually present at the same time or (thanks to his memory) he has experienced before. We admit then that he is also capable to distinguish, decompose and compare them, i.e. to say that some aspects within these features are identical or different.

Analogy and similarity

We are mentally able to associate and compare features in various ways. Let's introduce now more precisely what we can understand behind *analogy* and *similarity* and their different forms.

Temporal analogy, temporal similarity

Before to feel and say that, for example, two evolutions concerning location or size of an object are identical (through an eventual difference of scale), we can focus on a more global comparison: the object is going further or nearer, its size increases or decreases... Then, we can associate to such a feature in the *represented* a feature in the *representing* that is just identical on this reduced aspect. It is sufficient if, for our actual purpose the others aspects have no importance. Further, this allows us to use predefined objects satisfying this condition we have already at our disposal, without to look for any more. And more, we can eventually use the free indetermination as support for another feature representation.

What is true for the basic spatial features can be true for the others: evolutions of shape or volume, evolution of quality. In all the cases, we can speak respectively of temporal (dynamical) *analogy* when the identity is full, *similarity* when the identity is just on a reduced aspect.

Temporal anamorphosis, time scaling

Another capability is to apply the previous analogy or similarity (in certain limits) to the evolutions in time of two features while they run over different (stretched or expanded) durations in two different situations. This is particularly useful with regard to *practicability* since, for example, it allows us to experiment a situation in a shorter time than in reality, or to get a representation of events that are too fast.

Spatial analogy, spatial similarity

The same approach can be done within the extension of features over the space. For example a specific quality at a given time can be variously distributed on the different parts of an object. We can be more or less sensible on the precise variations, or, as well, more or less concerned according to our actual purpose. So, we can get a substitute that presents these distributed features in a roughly way, preserving only some global relative locations.

Let's, then, speak of spatial analogy and spatial similarity.

Spatial anamorphosis, space scaling

We designate by that the same aspects as for time, above, transposed to space, with the same kinds of benefits in terms of economy and practicability.

Exchanging time and space

As we are able in a certain extent to get present in mind at the same time results of several previous experiences, we are also able to do the same for several temporal phases of a given experience running in

time. It is then possible to find some object presenting in a single instant, i.e. in its spatial extension, at least a certain part of the features extended in time in the initial experience. And conversely, it is possible, considering the second object as the represented one, to find another (for example the one experienced before) that exposes along the time the features gathered in the spatial extension.

These exchanges are not always possible, but if they occur, then, they play the role of *representation of time within space* and *representation of space within time*.

One can evoke, for the latter, this common experience that consist to try to represent us how far is a place by associating it to the time we need to reach it (by feet for example).

Exchanging qualities

And finally, we are able (in a certain degree) to compare evolutions in time or variations in space of features that are of different qualities between two different objects and to say that their evolutions are analog or similar. When it is the case, we can say that the representation is, for example, a visual representation of an acoustical event, a tactile representation of a visual event, etc..

Identification

We said that nothing in the world (physical or mental, the latter being somewhere part of the former) could be identical to nothing. We can't bear it! Fundamentally because we can't admit the impossibility of permanence, of ourselves, of the world, of ourselves in the world. This is the existential contradiction of human being (may be of the world itself!): the will of both evolve and stay permanent.

More pragmatically, we need, for economy and practicability, to be able to consider two things as absolutely identical or, said differently, to *identify* the things¹⁵.

Identification is a strategy we use, consciously or not (supported by our cognitive system, and even, sometimes by our sensorial organs themselves), in order to get, under certain conditions, a kind of "absolute" identity. In its principle, it consists to separate the features (in large sense) that are strictly analog, from the ones that are not, and to associate the things only according to the former. This can be done at a high cognitive level, when for example we said that every real cats we met in our life are *identical* in spite of their different breeds, fur or color, as well as at a very low level, through our sensorial organs that lead us to consider for example that several audio frequencies differing only by a low value (under a certain threshold) are the same note.

When declaring, in a given experience and within a given purpose that two things are identical, we eliminate all the features that can contradict it. When we experiment two things that don't show differences according to this, we consider them as identical. Then, in this case and only in it, we can absolutely replace one by the other, keeping in mind that this "absoluteness" is "relative to given experimental field and purpose, and particularly, that we will be never sure that this identity will be always guaranteed.

¹⁵ It's not a pure coincidence if the word has two uses: a "monopolar" and a "bipolar" ones for example in "identify a person or a (flying) object" and in "these two objects are identical". In fact it is the same sense in both cases. To identify a person or an object is to identify them to a previous thing which can be a global or abstract knowledge we have already in our culture.

Abstraction

The previous "exchanging of qualities" can correspond to a first approach of the idea of *abstraction*, according to its literal sense: the common things between the *representing* and the *represented* being abstracted from their matter and from their specific qualities. Let's notice that there is no object bearing only temporal evolution, or spatial variation (for example) without a given quality that is evolving or varying. But we can speak of these evolutions or variations, amongst various different objects independently of what is evolving or varying.

More generally, we can imagine a set of objects that, after cognitive experience are comparable only on one of the previous characteristics. For example, we can find flowers or plants for which we can put all the fingers of one single hand on all of its petals or leaves. This leads us to conclude that something is analog for all a set of objects (those with which we can do the same, plus our hand) and also that there are objects, analog within other features, that are not analog on this one. In such a case, we can decide to focus only on this characteristic, *abstracted* from all the others, and to give it a name. Let's call that *abstraction* and notice that it can't be evoked in another way than by choosing one of the objects that "incarnates" it in a specific concrete way. The name we give that allows evoking it is also a representation, of a totally different order that supposes other order of considerations to be completely characterized. But the word and what it represents have in any case to be experienced in a specific initial situation in order to create the *initial link*.

Let's underline that, although abstraction shared with mental representation in general, the impossibility to be evoked without an external representation (object or objective phenomena), we must not confuse mental representation in general with abstraction. We can get from a physical object a deep and accurate mental representation of its phenomenological properties, thanks to the sensory-motor phenomena occurring during the sensory-motor experience, that remains at any moment we feel or recall it, as a non dissociable whole in our mind. This is a mental representation but, namely, not an abstraction.

Categorization / Discretization

Within the global purpose of representation, we may be led to do some economy of a new order, not only from a given *represented* to its *representing* but in trying to associate a set of different things to a single *representing*, and, more generally, to use a small number of different *substitutes* for a great number of different objects.

Categorization is the way to do this. Namely, categorization consists, from the initial sensory-motor experience, to *identify* different objects according to a certain number of features, these features being not absolutely identical in a certain range. If their differences exceed this range, then we consider that we get another category. By essence, categories are exclusive and denumerable. For a given set of features, if several objects can enter a category, a single object can't enter several categories. However, a given object can be associated to different categories when the latter are established on a different set of features.

As for identification, and because it is founded on it, categorization can be performed consciously, at a high cognitive level, deliberately or not, or through our sensory-motor organs. More, material devices can perform, without any human operation, some categorization. The most typical example being of course the one of digital electronic components in a computer: in spite of continuous variation of voltage at the input of a "analog to digital converter", we get at its output only discontinuous states according to a predefined set of values. The intermediary values at input are identified to one of the latter.

A correlative notion of categorization is discretization that applies categorization within the features of a single object. Decomposing the whole group of features in separate sub-groups and applying (when possible) categorization to the latter, we get a "discrete" representation of the initial object.

Categorization and discretization are the single way for a practical and economical identity, but of course they may eliminate features that will be appeared as fundamental in a further experience, and they are entirely conditioned by an initial choice that cut us from the *infinite ontology* of the world.

Finally, the concept of *icon* deals with all these considerations that allows us now to speak quite clearly of the kind of correspondences we may associate with this "category" of representation.

We can make more explicit in what the *signifier (representing)* "resembles or imitates" the *signified (represented)* or be "*similar* in possessing some of its qualities", but one must outline two important remarks:

- We don't evoke qualities as properties of the objects (that remain intrinsically unreachable) but as carried by the sensory-motor phenomena and leading to mental representations through our sensory-motor organs and cognitive system. A strong consequence is that we don't dissociate a priori action and perception, and, consequently, that we don't speak only of "how the signifier is perceived" but how it is experienced, including how it is "acted".
- Imitation or resemblance can go over a lot of situations including analogy, identification, similarity, temporal and spatial reductions and / or anamorphosis, and even abstraction, categorization and discretization.

Example of iconic representations

In order to enlighten the representation schemes we will examine now common representing objects corresponding to this "icon" category.

Picture and sculpture

Regardless of the way they are elaborated, they both use a physical matter (rock, wood, animal skin, paper, etc.) on which are put some substances with visual properties, and, for the latter, that can be shaped. Let's call that the *support* or the *medium*.

There is already an economy, only by the fact that these supports will be practical, and even chosen according to that. But some other reductions are achieved.

When experiencing, we can compare a picture or a sculpture to a real object (or set of objects), physically present in front of us or reminded, and feel some correspondences. Having present in mind the previous

considerations, we can now analyze what kind of correspondences can exist between the *representing* and the *represented*.

First, picture and sculpture (statue) are both static objects, i.e. they are fixed in the time, and so they can't temporally represent any feature evolving over the time (that doesn't exclude static representation of such features).

As static objects, they can represent spatial features and qualities corresponding to those of the represented objects at a given fixed time. This can correspond to a part of the sensory-motor experience, strongly reduced in comparison with the real one: in the case of picture the instantaneous sensory reception we get at a given instant in a given spatial relation with the object, in the case of sculpture the multiple instantaneous perceptions we will get if the object was fixed during the initial experience while changing our spatial relation with it. In both cases, evolutions of objects, by themselves or as consequences of our interactions with them are lost, as well as our mental representations of our own actions.

The gestural interactions we can carry out with the representing are possible: we can manipulate the picture or the sculpture. But they are different from the ones with the original and they don't produce corresponding variations of the sensory phenomena.

However, we can perform a gestural interaction that will give us mental representations of shapes, volumes, sizes, etc. of the statue. Let's remark that there is here a specific example of reduction / extension process: because of the specific matter of the support, different from the one of the original, we can't get perception of properties of the original's matter that may have a relevance, while we get perception of new material properties. We can also get more accurate perceptions of shapes or volumes than in the real experience which is less practicable for material or cultural reasons.

Having the mental capability to feel a similarity of shapes or volumes in spite of size differences, we can take objects that are reduced in material size, making them more economical and practicable.

Summary for pictures and sculptures as icons:

- Features evolving in time can't be temporally represented
- There is a reduction of the spatial definition (tri-dimensionality to bi-dimensionality) with the pictures
- A size transformation can be performed
- Instantaneous qualities can be preserved
- There is no correspondence, between actions with represented and actions with representing

The last point is quite important since it lead us to absolutely exclude these two categories from what we will call further the interactive representations in which we can not only interact with the representing but interact with it in a way that corresponds to the interaction with the represented.

Static representation of dynamic features in pictures or sculptures

We said that features evolving over the time (in fact, location, size, shape, volume, as well as quality) can't be *temporally* represented, i.e. represented by an evolution of the *representing* (which is static). But this doesn't mean that these evolving features can't be *statically* represented. Indeed, as we are able in a

certain extent to get present in mind at the same time results of several previous experiences, we are also able to do the same for several temporal phases of a given experience running in time. In certain conditions, it is then possible to superimpose pictorial representations of these different phases in a single picture. In these conditions, we can speak of *static* representation of *dynamics* features, that we must distinguish from dynamic (or *temporal*) representation of dynamic (temporal) features.

This is an occasion to underline the necessity to be very clear, in representation terminology, and not confuse, for example between the qualifying we use to speak of what is represented and of what represents it. If we qualify a representation as a "dynamical representation", it means that the *representing* is dynamic, not that it represents a dynamic object.

After this approach, we can observe that, even very common, picture and sculpture are quite limited. Fixed (no time extension), mainly dedicated to visual perception, they can't support any correspondence between the action / perception loops. We could envisage and analyze numerous other representation situations among the more usual but this is not the purpose of the present discussion. We would like to introduce now what could be a representation that preserves not only perceived features, but the action / perception loop itself. We will call this hypothetical case "integral representation".

Integral representation

We claimed that the two poles sustaining the elaboration of our mental representations are the sensory-motor experience and our cognitive system (including sensory-motor organs). We would like now to remark that the reductions leading to classical icon forms like picture or sculpture are in some way imposed by technology but are not a cognitive necessity. Said differently, since reduction is unavoidable (for practical reasons and because it is a condition of the *economy*), can we try to preserve in priority action / perception, even with drastic reduction on the other factors?

Let's recall the main features of action / perception loop (see figure 8.1):

- The gesture channel is at the core, supporting by itself a loop, between gestural action and Tactilo-Proprio-Kinesthetic perceptions.
- The gestural loop is itself a part of two greater ones, the gesture to auditory and the gesture to visual perceptions, that leads us to this "nested loops" form.
- The tactile, visual and auditory perceptions are not separated.

We specifically reserve the terms *interactivity* (in its strong sense) to the nested loop form, and *multisensoriality* to the last feature and we will define *a priori* the notion of *integral representation*, independently of the ways and the details of its achievability, as the situation in which multisensoriality and interactivity are completed, whatever the reductions over the other factors.

We claim that if this is technologically achievable, we may get other, different but not less relevant, benefits than in representations that preserve strong analogy between perceptive features but break out the action / perception link. And more, that we will get new ways to understand or to complete the link between sensory-motor experience and abstraction.

Actually various form of *integral representation* do exist for a long time, in particular in the world of toys, that play a so essential role in children understanding and evolution (and also sometimes for adults).

A children playing with a car toy is very strongly motivated in manipulating it in order to simulate, at a small scale, all the real situations. His gesture is actually interactive and stands for the driving. He can experiment relations and interactions between his "icon" (that shows sometimes very-well fashioned spatial-, shape-, volume-, color similarities with the original, under spatial reduction and occasionally clever anamorphosis) and represented environments.

However, he has in general to complete the multisensoriality by producing himself the motor noise. Adults use as well, in full legitimacy, such kinds of *integral representation* when they built mock-up of car, of buildings, ... in order to experiment and to predict behaviors, relations, and possible interactions before actual achieving. Let's remark at this occasion, that representation is not necessarily representation of things that already exist but may be representation of things that should exist in the future. Creation is, namely, founded on representation of things that do not yet exist.

However, in these kinds of *integral representation*, something is yet lacking: the possibility of abstraction from the material features and, consequently to show inherent internal properties and functional relations that constraint the experiences and that we would like to control or even decide.

One step further in iconic representation: phenomenological, vs. structural models

It is generally well considered, and, actually common to use the word "model" in serious disciplines. We get mathematical models in physics, cognitive models in psychology, models of economy, models in sociology, etc. We can adopt it also within the representation when we need to specify, classify and make taxonomies. So let's use it in the following, to present several different possible attitudes, particularly in *integral representation* but that can be used for any iconic representation.

Just before saying that we can only know the external world through a sensory-motor interaction supported by sensory-motor phenomena, we said that these phenomena were parts of phenomena in general, among which some are neither producible, nor perceivable by human being. So, let's consider that, may be over other kinds of phenomena, physical objects can interact between themselves as well as we can interact with them. In the case where an object is itself composed of several such interacting sub-objects **and** where we can interact with each of them, then, we can spread a new step in our representation. Indeed, we can decompose the correspondence between the *represented* and its *representing* in 1) an individual correspondence between sub-objects, and 2) a correspondence between their interactions.

This is actually a new understanding of the reality, conceived as a structure rather than a global whole, and this offers new possibilities: we can try to suppress one or several components and achieve an economy if we can continue to *identify* the two wholes despite this elimination. We can also replace one or several components by different ones just assuming that the interaction phenomena are preserved. This allows also an economy if the partial substitutes are individually more economical.

Considering that we now enter the *structure* of objects, we will say that we are achieving a *structural* representation, namely, a *structural model*.

Having no reason to stop in such a good way, each sub-object can now be considered on its turn as a whole, decomposable again in sub-sub-objects. We will say then that we get a *deeper* structural model.

And we can characterize a structural modeling in terms of its *depth*. The next question is, of course, how far can we go in this way?

Actually, there is always a moment where we stop the disintegration, either because we can't decompose the object in sub-parts that we can directly or indirectly experience at our sensory-motor scale, or simply because we have no time enough for that. So, at this moment, we stand with a pure phenomenological knowledge of the concerned component. One can say that absolute structural modeling can't exist and that there is always a phenomenological limit at its base.

However, we can try to build substitute to such unbreakable component by combining interactive or simply linking sub-parts that globally supply the same external interaction phenomena, not considering the correspondence between the sub-structures of the *representing* and *represented* components. We will then speak of *functional* modeling. Again, a limit appears here, sooner or later, when we can't get any other solution than an already made element achieving the suitable function. We will call that the *functional* limit.

In summary, modeling is achievable according to three possible nested protocols:

- Pure phenomenological modeling
- Structural modeling
- Functional modeling

A given model can then be characterized by its *depth*, according to *structural* or *functional* criteria (or a combination of the two). Let's observe that whatever is the depth, i.e. the limit of the decomposition, the lower element has always an "intrinsic meaning" in the sense that it has by itself (isolated from the others) a phenomenological or, at least, a functional consistence.

Systems

Now, we can apply to the sub-components, in this structural approach, all the previous modes (temporal or spatial analogy, similarity, scaling, anamorphosis, exchanging, identification, discretization, etc.). We just have to guaranty coherence among the internal interactions by assuming that the reductions applied to a component will be compatible, in terms of exchanged phenomena, with all the components with which it is interacting. Having achieved such conditions, we will say that we have got a *representing system*. Let's remark that *integral representation* may be compatible with such a systemization.

8.2.5 Symbol

All along the previous considerations we were looking for some resemblance between the *representing* and the *represented* in terms of some correspondence between the phenomena or the experiences they respectively bring up. Before, starting with the "primitive symbol", we discussed about *Index* for which there is no resemblance but an *initial link* through a direct physical or causal initial connection.

The *Symbol*, in the classical taxonomy of signs, is a third category in which there are *a priori* neither resemblance nor direct physical connection, but only an *initial link*. More, this link may be completely arbitrary and, then, must be learned within a specific initial experience.

Let's state below the Chandler's (Chandler, 1994) definition:

"Symbol/symbolic: (is) a mode in which the signifier does *not* resemble the signified but which is fundamentally *arbitrary* or purely conventional - so that the relationship must be learnt: e.g. language in general (plus specific languages, alphabetical letters, punctuation marks, words, phrases and sentences), numbers, Morse code, traffic lights, national flags, etc."

Arbitrary or purely conventional link means that there is actually an initial sensory-motor experience, but without any correspondence between the associated sub-parts. For example, when associating the word "tree" to a particular tree or to all the trees, the word is an acoustical phenomenon produced with our vocal organ and perceived with our hearing, while the actual tree is the object of various other sensory-motor experiences. The learning experience is a sensory-motor experience in which the two previous, or the former and a mental reminding of the latter, are simultaneously present. Then, the whole experience can be compared to the "primitive symbol" one where two parts of the whole can be separated and used separately. The strong difference is, however, that in this case, the link is exclusively mental, not physical.

Focusing now on specific features that we experience as common to a specific tree and a set of other objects, we get an abstraction. Then, adopting the same word for this ensemble, we give a name to this abstraction: we represent it.

A third protagonist can also intervene if we add in the learning situation a drawing or any graphic element (for example a set of letters), actually in presence of the two previous or at least of one of them. Then, we get an external representation that can stand for a specific tree, the word "tree" acoustically performed, or the "tree" as abstraction. This corresponds to the classical triad "significant" / "signified" / "referent".

This arbitrary approach has a high cost, since we can't be helped by any intrinsic property of the objective things and must only count on our memory. But at the same time, this is a relevant way for compelling economy. Indeed, we can choose as symbol for a given thing, the most economical substitute we can find, i.e. with a minimal effort for its production, its perception or its memorization. The ultimate condition is then that we must be able to distinguish the various symbols we use for several different objects. And we are free to achieve this without any other constraints regarding the relationships between these objects. In the same way, there is no necessity, at this step, for any constraint that links the symbols between them, other than distinguishing. The *representing world* get a certain autonomy and can be built, in a certain extend, with its own economy and consistence.

Going ahead now very quickly, because we need another time and occasion to discuss these elements, we can envisage that speech, writing, languages in general can be built on these basis. A sequence of words can evoke several objects present at the same time. Adding a new symbol can indicate, after the corresponding learning, that they are temporally successive or, more, that they always occur together or in a fixed order, etc.

Considering symbols themselves as things that can present temporal and / or spatial extensions, and qualities, all the considerations that lead us previously to the concept of *system* are applicable here, in such a way that we can speak of *systems of symbols*.

A strong difference however, between *physical systems* and *symbolic systems* is that in the latter, we can decide that only relationships between elementary symbols lead to a correspondence with an object (or an action or an event) that get some meaning in regard with real (sensory-motor) experience or with an abstraction. This is not possible within a *physical system* where the smallest element always keep an intrinsic property in relation with the experience we can perform with it. Well-known in linguistics, this circumstance is named *double articulation*. This summarizes the idea of autonomy of representation, particularly within the symbolic mode.

At the end of this tour over the three main categories of signs, we must add that, as for every taxonomy, while it is necessary to understand and operate, it generally doesn't apply so "categorically". For real cases, we are generally led to invoke a combination of the constitutive categories - a given *representing* should be often described as partially symbolic, iconic or even indexical, with a more or less preponderance of one of the types - and more a « composition » of them, in the mathematical sense of functions composition.

Finally, even after this very partial discussion on Representation, we can be convinced that, obviously very complex, it may (must) be nevertheless a minimum sketched before approaching its translation in the New Technology and the Information Technology context.

In the following, we will refer to the main notions introduced here to characterize the external representations we use in our specific applications.

Mainly:

- The distinction between Indexes, Icons, and Symbols
- Analogy and similarity (temporal or spatial)
- Anamorphosis, scaling (temporal or spatial)
- Exchanges between time and space
- Exchanges between qualities
- Identification
- Categorization / Discretization
- Abstraction
- Integral representation

These notions being not complete or sufficiently detailed, we will introduce supplementary ones according to needs.

8.2.6 Information Technology

"Information Technology" is nowadays commonly used, rather than "New Technology", or simply "Computer". "Information" is there generally understood according to the Schannon (Schannon & Weaver 1949) theory established in the middle of XXth century. It includes of course computer, but adds to it the key notions of transmission and wide diffusion of information through the new mass-media (CD, video, etc.) and of course Internet. It is more general than "multi-media", which refers to the specific supports commercially spread today, but we can consider that it includes also it.

However, it minimizes the fact that, with computer in particular, information is not only stored or transmitted, but also treated, and more, produced. And finally, it hides an important feature: the fact that information, for its transmission as well as for its production, needs always some energy expense, as small it can be.

Leaving aside the transmission and diffusion aspects and the strict Information Theory concepts, we will focus on the relation between human and computer, in particular as it comes in addition or substitution to the sensory-motor experience. We assume that "external representation in multi-media environments" can be approached from this general entry point.

Computer is a physical object. Given to us as it is, we can submit it to all the experiences discussed above. Then, it appears as a material *system*, with its smallest components, internal interaction phenomena, interaction phenomena with human being and real world. But this concerns the approach of engineers that have to built or repair it. As normal users, we obviously approach it in another way. This needs some elucidation.

Elementary entities

We commonly consider that everything in a computer is "made" of binary digits and processed by "logical" or "Boolean" operators. What is the status, by the light of the previous considerations, of these things?

A digit is not an object, it is associated to the state (electric, magnetic, etc.) or a phenomenon we can observe from a physical object (semi-conductor component, magnetic support, etc.) and which can influence the state of other objects of the same kind. These components are built in such a way that they can get two, and only two different and individually identifiable states – that correspond to a physical categorization process, and need some particular physical conditions. Considering several objects showing the same state, we associate them (the states). This is an *abstraction* process. Then we give a name to this sharable state ("true", "false", "0", "1", etc.). This is a sophisticated external representation joining verbal, textual and graphical representations.

But the most important here, is the fact that we also get another external representation of these states. Indeed, the phenomena that concretize this abstraction within the electronic components are not sensory-motor phenomena. Hence, if we want to know or determine them, we need such sensory-motor phenomena. This is the function of these essential technologic components that we call *transducers*.

Namely, and in its basic definition, a *transducer* is a physical device that can transform (as the action and perception organs did) a given physical phenomena in another one, assuming a correspondence between the two. This correspondence can be analyzed within the same criteria than the ones we introduced before (temporal identity, analogy, similarity, anamorphosis, etc.). This is actually a representation process, but physically (not humanly) achieved. Hence, as supporting a representation process, it could (should) introduce a reduction. For the usual transducers like acoustic-electric (microphones) or its symmetrical, electro-acoustic (loudspeaker), this is well characterized and quantified with the notions of bandwidth and signal / noise ratio. Considering a video camera as a visual to electrical transducer, we can characterize it also by the 3D – 2D spatial reduction it does.

In general, this transduction is augmented with supplementary sophisticated ones achieving the correspondence with graphical, visual, textural... presentations for the machine to man path, with gestural actions from man to machine path. The complete devices are called *peripherals*.

There are in a computer some devices that memorize the digits (that are able to keep their state over the time) and some that "operate" on the digits. The last term refers to *mathematics* but it has a concrete counterpart, actually in a physical (electronic) interaction between two (electronic) components: a given state on one place of such a component (called its *input*) can imply its opposite on another place (called its *output*) of the same operating component. Operating components can present several inputs and outputs and achieved correspondence between them that we can fully abstractly describe thanks to the Boolean algebra. Two important remarks must be done at this step:

If we envisage the computer as a *representing* we can already say that it is a representing *system* and, more, that it includes *interaction* in its representational function.

Nevertheless, *interactions* are not general since they are, by essence in computer as well as in every "digital technology", *oriented*: a given component can act on its subsequent but not the contrary. This will have fundamental consequences.

Digits are symbols

Except for strict Boolean algebra purposes, the digits and their treatments have no meaning by themselves. Of course we know that we use the digits as elementary components of much more sophisticated things, thanks to a wide variety of transducers and peripherals. Whatever could be the latter, one can say from now 1) that we will be in the *symbolic* mode since there can't be another link than *arbitrary* or *conventional* between these things and the digits, and 2) that it will be typically in *double articulation* conditions, leading us to the general language context.

Finally, the last but not the least: we *program* computers, i.e. we can decide and define the internal arrangement of digits and operators in order they achieve a given (through appropriate peripherals) sequence of treatments.

In summary, a computer is a *system of interactive symbols* we can practice in the same way than a language, including writing, graphical supports and representations, etc. but with which we can, thanks to transducers and peripherals *interact*, even in a sensory-motor way.

Let's now introduce the core of our purpose: the Multisensory Interactive Simulation of Physical Objects.

8.3 Multisensory Interactive Simulation of Physical Objects

Soon in its history, the computer was used in order to represent things concerning our real or mental world, being at the same time better and worse than us or the real world. Less soon, but for a significant time, we tried to adapt the "man-machine" interaction to the human subject, rather than the contrary. Man-Machine interaction became a research domain by itself and led to the development of text editing, speech analysis and synthesis, image synthesis, graphical display, etc. leading us progressively to the WIMP paradigm (Window-Icon-Menu -Pointing device) commonly in use since the middle of 1980's.

In the arts domain, researchers worked since the end of 1950's for sound and musical synthesis (see for example: Mathews 1963, Risset 1965, Risset & Mathews 1969, Risset & Wessel 1982, 1991), image, animated image synthesis, trying to give more and more realism or richness to the phenomena going from the computer.

But we must enlighten that until the 1980's, it was quite difficult to compare the interaction with computer to the one with real beings, objects or environments. This is only with the significant current of Virtual Reality (born in the 1980's), among many others works that for the first time physical interaction between human and its environment has been taken explicitly into account.

Multisensory Interactive Simulation of Physical Objects, introduced by the author and his colleagues (Cadoz, et al., 1978; Cadoz et. al., 2003) corresponds fully to this aim.

Considering the primacy of sensory-motor experience in knowledge as well as in early learning and creative processes, the purpose was to use the computer as a means to support it fully, rather than a simple device to produce sounds, images, etc. supplementing the ones produced through traditional technology.

This leads to introduce two first fundamental research axes:

On the peripherals that could allow a genuine multisensory-motor interaction with the computer, and particularly regarding the gestural interaction, which is dramatically reduced and poor with keyboard and mouse. There, was introduced the works on *gestural force-feedback devices* (Cadoz & al 1981, 1984, 1990, 1993).

On the representation of physical objects with the computer, this representation having to take into account the dynamic behavior of the objects, like in real world, that are at the core of internal phenomena and interaction phenomena (sounds, dynamic images, gesture action and perception phenomena). This leads to the *simulation* paradigm in which the physical dynamic properties, evolutions and interactions of real objects are targeted.

Namely, these two points aimed to achieve what we called above an *integral representation*.

But it was also fundamental to go further, i.e. to immerse this approach in the essential new potential offered by the computer as *system of interactive symbols* and as support of language, that allows doing much more than a simple (better or worst) replica of the real world.

Hence, we considered the possibility to represent the physical objects as systems of interacting sub-objects, representing the later through the *interactive symbols* within the computer, increasing then the *integral representation* with all the possibilities of absolute memory (of things and events), writing, analysis, multiple representations, etc. not possible with real objects.

This was an exciting way, allowing to envisage very new attitudes in artistic creation, but, transposing and generalizing the role of instrument, also in number of other fields. We are developing these concepts and techniques in applications for physics (Marlière & al 2004). We introduced the concept of "Interface for Instrumental Communication", studied and experimented its application in man-machine interaction. These concepts are also involved, at this moment, in an important (European) project concerning *enactive interfaces*¹⁶. And we claim that these conditions may allow to approach, even if it needs long time and lot of works, a new understanding of the complex links between our internal and external representations.

And finally, we believe of course that it can have little things to do with *learning* within computer environments.

The main others axes are then dedicated to language for simulation (namely the CORDIS-ANIMA simulation language) and user interfaces for artistic creation with this language: GENESIS, for musical creation, and MIMESIS for animated images creation.

Putting aside the theoretical and technological questions related to gestural interaction and force-feedback devices¹⁷, we would concentrate now on the CORDIS-ANIMA language and GENESIS.

Then, we will envisage several different points of view from these tools and their associated concepts.

Indeed, GENESIS is first a tool for musical creation. So, we have to explain in what, and according to what approach it allows creating sounds and music. In this aim, it has to be learned and needs for itself a didactic environment.

This is the main purpose of the "informed analysis" we present below, trying to apply the given theoretical issues, but also to introduce some supplementary points issued from the present considerations on Representation. We will summarize these points just before introduce them.

But, through GENESIS, and more generally the Multisensory Interactive Simulation and its languages, one can develop an analytic approach of the creative process itself. This leads us to consider this environment, more generally, in the aim of *learning of creativity*. That is of course a quite different learning domain than mathematic or physics. But we are convinced that it is a legitimate one, which can take large benefits from new technology.

And finally, we would like to propose, as a further axe of research, to start from this support to study the potential uses of Interactive Multisensory Simulation and its derivatives in other fields of learning.

¹⁶ European Network of Excellence – IST-2002-002114 – Enactive Interfaces

¹⁷ One can refer to lab. bibliography on the subject.

We just mention here that an important distinction must be done concerning the gesture, and consequently the gestural devices, between the ones that need physical interaction (then, force-feedback), and the ones that don't need. See the "typology of gesture" from the author (Cadoz, 1994; Cadoz & Wanderley, 2000).

8.4 Informed case analysis: The GENESIS Environment

In this section, we propose an analysis of the GENESIS environment representations design, in the light of the theoretical issues emerging from this state of the art. The present GENESIS environment results from 10-years design and development, thus we concentrate on basic features and pedagogical-guided design, in order to illustrate the above theoretical contributions in the context of learning.

The GENESIS environment is a CORDIS-ANIMA system-based environment dedicated to musical creation and composition learning with physical modeling. It is not only a simulation-based software, but it also includes a strong educational support that has been built in the same time.

Both use representations of CORDIS-ANIMA objects: In the former case representations are used within the GENESIS user interface, in the latter one representations are used to make understand the formers. For example, these representations are jointly used in the collaborative process Instructor-Learner when learning GENESIS.

Actually, musical creation with GENESIS is not an easy task: even if its user interface representations are very simples, handy and easy-to-understand by any learners, the processes behind are more complex and need to be explained.

Firstly, we present the CORDIS-ANIMA modeling and simulation language that is the support for Multisensory Interactive Simulation softwares and devices.

Secondly, we propose an overview of the main GENESIS features in order to both link the CORDIS-ANIMA simulation model with the GENESIS user interface, and highlight the complementarity need of an educational framework.

Thirdly, we focus on one single GENESIS object and we concisely analyze all the existing related representations. We then present typical cases when these representations are combined together or substituted to each other, in order to make easy translations between representations or to better match learner's preferences.

Finally, we present the perspectives and possible extensions of the GENESIS environment's representations.

8.4.1 CORDIS-ANIMA – a micro world

CORDIS-ANIMA (CA) is a digital object modeling and simulation system. The simulated objects can be seen, heard and manipulated. This system has been built at the ACROE-ICA (INPG) laboratory in several stages since 1978 (Cadoz & al 1978, 1981, 1984, 1993).

As modeling system, CA allows us to get, firstly, a certain mental representation of objects, specifically in terms of physical objects with which we can interact and that can, in the same way, interact between them. Independently of the nature of sub-objects and interaction, this constitutes by its own a specific way to "understand" the physical world in an interactive and structural approach.

But CA is also a modeling system in the sense where each of its basic elements is at the same time an elementary simulation algorithm calculating the physical states and evolutions of the elementary physical components they stand for.

And finally, CA is a language by the fact that it is governed by a set of formal elements and rules that are completely defined in a symbolic system.

Formal elements

An interaction between two physical objects (hands, fingers, etc. and instrument, or different components within an instrument) is physically (and mathematically) described by invoking two physical variables, for example forces and displacements. But one cannot say that they are applied by one of the objects to the others. They results, according to the Newtonian approach, of the action-reaction principle and are involved in a differential equation that gives their relation at each instant. In the computer digital context, there are only unidirectional interactions (input / output pattern). Therefore, a bidirectional relation like in a mechanical interaction can't be immediately represented. Thus, the first concept on which CA stands is in the definition of "interaction points". An interaction point is an input-output pair taking in charge separately the two (force and displacement) physical variable. This leads to consider two dual possibilities: one in which the input is a force and the output a displacement, and one where this is the opposite. We call "M" points the former; "L" points the latter.

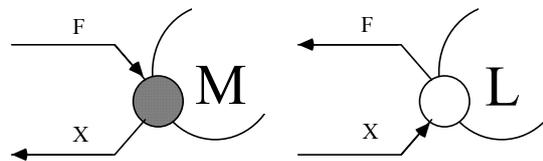


Figure 8.4. Representation of physical interaction – the "M" and "L" points

Hence, an interaction is represented by connecting a "M" point to a "L" point, taking the output of the one as input of the other. From this dissymmetry derives a first syntax rule: it is possible to connect several "L" points to a single "M" point, but not the contrary.

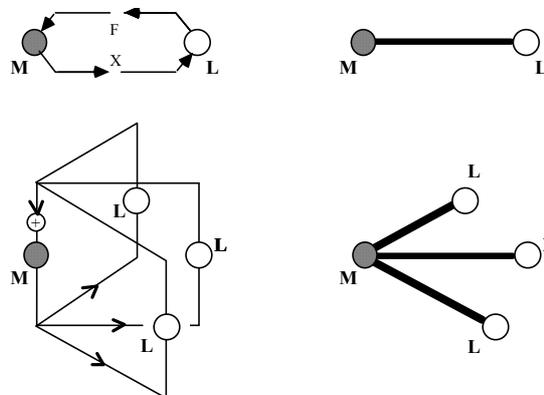


Figure 8.5. Examples of connections with "M" and "L" points

At a upper level, a CA “object” (virtual object) is a set of sub-objects having each a certain number of different “M” and “L” points, connected over sub-objects, giving it the formal structure of a network (*CORDIS-ANIMA network*). The whole object being itself of the same nature, i.e. having “M” and “L” points that can be used for connection with other objects among which can be the human user, through the appropriate transducers.

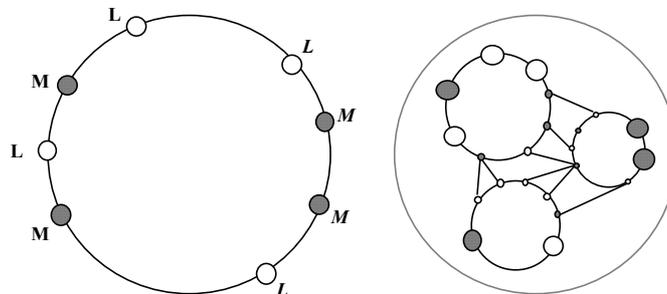


Figure 8.6. CORDIS-ANIMA “objects”

A third feature is the elementary basic objects from which every network can be built. They are of two complementary natures: one having only a “M” point, and another having two “L” points. They are respectively named Material element (<MAT>), and Link element (<LIA>). The former are algorithms calculating successive positions (X) over the (discrete) time in function of the successive forces (F) applied to their inputs. They can represent a punctual mass evolving in space. The latter are algorithms calculating two (interaction) forces applied to the two <MAT> it is connected with, according to the two positions they give it in input. They can represent interaction components like springs or dampers.

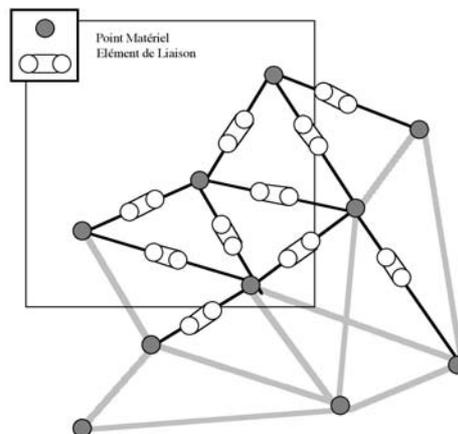


Figure 8.7. CORDIS-ANIMA network

Then, a more synthetic representation can be used, in the form of a network where the nodes are <MAT> and the link <LIA>, in abstraction of the detailed “M” and “L” points and the forces and displacement exchanges. This abstractive representation is helpful since it give a simpler view of the “objects”, but somewhere a little dangerous since it hides the fact that the inputs and outputs actually exist and also that an incompressible delay (of one period of sampling) exists between any input and any correlative output.

However, this network, the <MAT> and the <LIA> element, and the rules to assemble them constitute the global general syntax of CORDIS-ANIMA.

The simulating algorithms

Under each of the two basic elements can be developed several set of specific algorithms corresponding to various material objects and categories of mechanical interaction.

The main algorithms are: MAS (mass), CEL (cellule), SOL (ground), for <MAT> elements, RES (spring), FRO (damper), REF (spring & damper), BUT (butée – for collisions), LNL (non-linear link), etc. for <LIA> elements. (see below GENESIS basic elements for more explanations, and see (Cadoz op. Cit.) for detailed descriptions).

A simulation, within the CORDIA-ANIMA system consists then in designing such a network (qualitative or *topologic* description of the structure), specifying parameters (for example the inertia of a MAS, the elasticity of a RES, etc.), and initial states (initial position and velocity), and to run the program compiled from this description. Consequently, various force or displacement input can be used by the program, and the various evolutions over the time of force and displacement variables can become signals for sound, image or force-feedback outputs.

To achieve this quick presentation of CORDIS-ANIMA, we would like to enlighten a specific feature, inherent to this system as it can appear in any representing system and illustrating the idea of *autonomy* of a system of representation. It is obvious in the case of the mechanical oscillator representation through the CEL element.

The design of CEL algorithm derives from a discretization of the second order differential equation of a physical pendulum (oscillator) and leads to a second order "difference equation". The solutions of the first and the second can be, through a time-quantification translation, identified in a good extent, but, in fact if we give parameters that have as result frequencies compatible with the Shannon theorem (less than half the sampling rate). The behaviors of the two (virtual and physical) oscillators differ significantly when we don't respect this condition. Being given that there is neither formal nor satisfying pragmatic solution to this question, we are lead to consider that this is an intrinsic property of the representing system, and then that we cannot *identify* absolutely the representing and the represented universes. This condition doesn't invalidate the global approach if we are advertised and if we know what we do at each moment.

8.4.2 GENESIS main features overview

The GENESIS software is a micro-world in which it is possible to explore and experiment on representations of "virtual" objects as if they were material ones. GENESIS allows creating virtual physical sounding objects on a workbench within direct manipulation by (resp.) assembling, editing and simulating a network of basic elements. Each step of the creation process is related with representations of (resp.) topologic, parametric and dynamic properties of the model emerging from the network built.

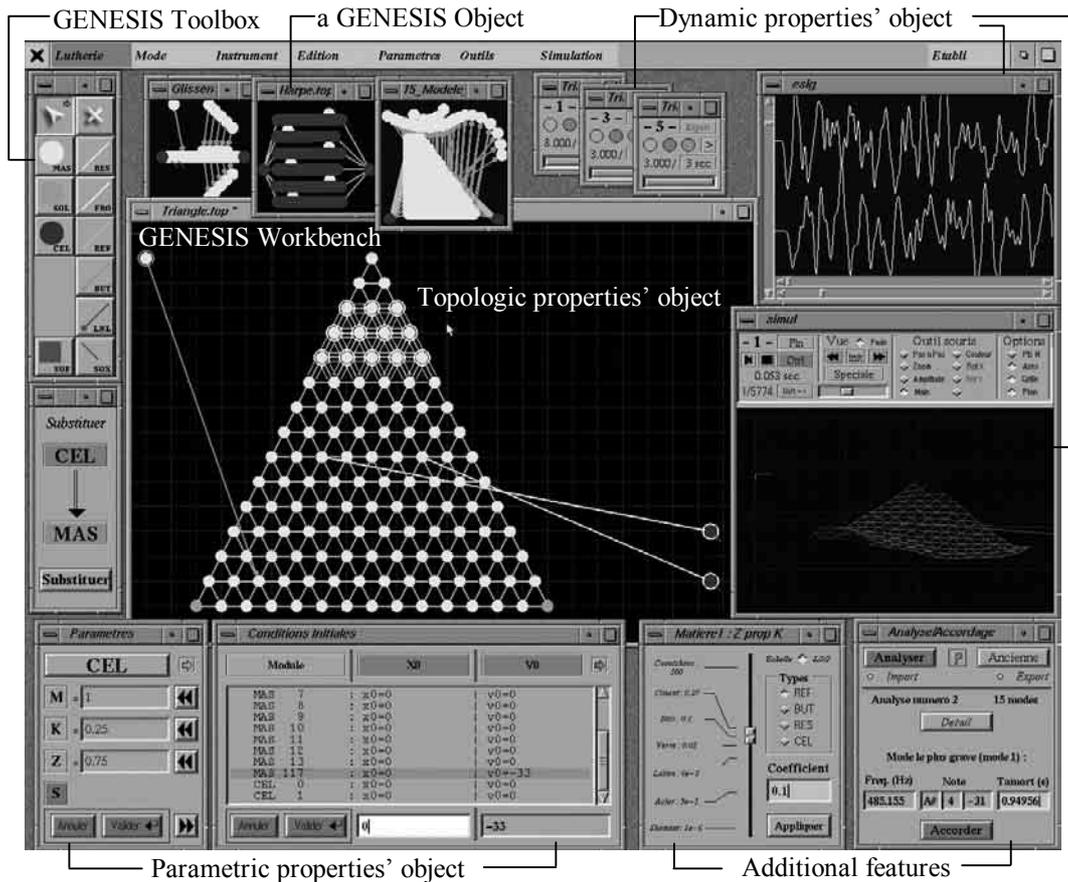


Figure 8.8. GENESIS User Interface screenshot with basic features

All opened features are centered and linked to the GENESIS object on the GENESIS workbench. We only present the representations related to the key steps of the creation process of a GENESIS object. The others features dedicated to super editing or composition are not taken into account for further analysis.

Simulation model

The simulation model under GENESIS is not exactly the CORDIS-ANIMA system, but a more constrained version. There are two main differences: the dimension of the simulation space and the basic elements. The GENESIS simulation is also differed time (see criteria's guide for more explanations).

CORDIS-ANIMA space simulation can be of any dimensions. However, experiences proved that 1D-simulation-space-model are of interest for music creation: they are easier to design, quicker to simulate and efficient for interesting sound generation. Thus, GENESIS is built on the 1D or *topologic* version of CORDIS-ANIMA, where mass-like element state is determined along a single movement axis named (OX).

The GENESIS basic elements are built from CORDIS-ANIMA elementary MAT and LIA elements. The simulation of each basic element model represents a typical physical behavior specified with both mechanical parameters (behavior's nature) and initial states parameters (behavior's evolution).

- The **MAS** element is a punctual mass moving on a one-dimensional axe (OX) and characterized by its inertia (M). It can be given initial conditions at the beginning of the simulation: an initial position (X0) and an initial velocity (V0).
- The **SOL** element is a MAS element with an infinite inertia, that can be given an initial position, but that cannot move.
- The **REF** element is a visco-elastic (spring-damper) interaction connected between two material elements and calculating two opposite forces addressed to them and depending in a linear way on the difference of their positions / velocities and of an elasticity parameter (K) and a damping parameter (Z).
- The **CEL** element combines SOL-REF-MAS in a single embedded module and is often used for more synthetic representation.
- The **BUT** module is an asymmetric REF. Oriented from a first toward a second material element, and according to a threshold (S), the corresponding spring-damper is active only when the position (X2) of the second element is less than the position (X1) of the first plus the threshold (S). This element is the basic means to simulate collision between particles.
- The **LNL** (non-linear link) module allows to define non-linear interactions by direct design of the F(X) or F(V) characteristics thanks to graphical or algebraic definitions. It is used for example for the basic simulations of the plectrum-string, bowstring, reed-mouthpiece interactions, etc.
- The last element is the **SOX** (X position output) that allows addressing the movements of any chosen material element to one, two or four loudspeakers.

User interface representations

In an extend way, the design of the GENESIS user interface representations has been lead by pedagogical metaphors and HCI theories and backgrounds.

Basically, each kind of property of the model is split into a different representation matching with a specific task of the creation process. We give a synthetic overview of a usual way to create a sounding object with GENESIS:

- First step: Building the network with the basic elements (available in the toolbox),
- Second step: Editing the elements' network parameters (M, K, Z, S) and initial states values (position and velocity),
- Third step: Simulating the network model produces a sound phenomenon, which can be heard and seen.

The last step consists in going back and forth between the last and the previous steps in order to verify, to understand how the model works and (thus) to improve the quality of the sound produced.

We now present the main characteristics of representations related with each kind of model's property.

Topologic properties' representations

The basic idea is that the representation of the basic elements has to make the learner accept the elements as neither algorithms, nor concepts or models, but in a more concrete way like elementary physical objects such as masses, springs, etc. Typically, mass-like elements representation is a colored disk and interaction-like elements representation is a colored segment with mass-like connector at each extremity.

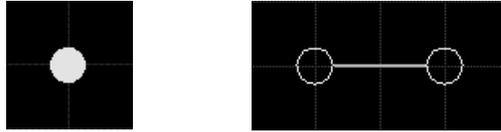


Figure 8.9. GENESIS MAS and REF basic elements representations

Moreover, using this representation is supported by the strong metaphor of the LEGO®-like system thanks to usual direct manipulation processes such as selection, connection and drag and drop.

The metaphor of an instrument-maker or "lutherie" workbench is also required for supporting the 2D topologic properties' representation mainly for both organizing the basic elements network and helping translate between representations (see typical case "smoothing effects"). The GENESIS workbench is a resizable black plane with a red grid that indicates the current space scale.

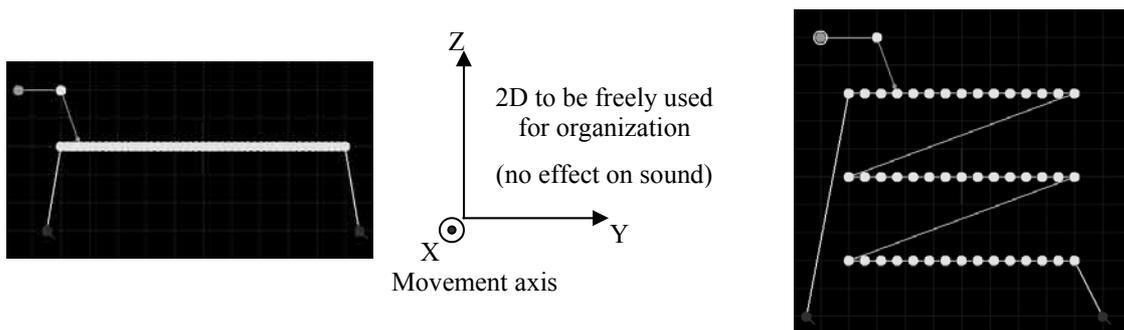


Figure 8.10: GENESIS (2D) representation for topologic (1D) properties: these are the same object

As the figure try to explain, only the topology (which elements are connected together) is important for the (1D) simulation. There are no geometrical properties. This is a main educational challenge to make it the new learners understand easier and quicker. This typical case is subsequently described in details.

Zooming and panning tools allows having different views on the same representation in order to support mental organization and macro-construction (constructing with already-made GENESIS objects, not with the basic elements).

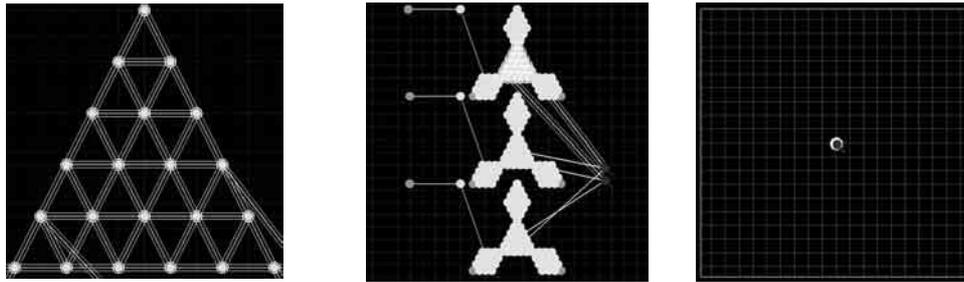


Figure 8.11: Three different views of the same GENESIS object

From left to right: selection object zoom in, whole object, whole object zoom out.

Parametric properties' representations

The parametric representations are supported with ergonomic windows that allow manipulating numerical values of the model's mechanical parameters and initial states. By selecting elements, the learner displays and can modify the numerical value of the mechanical parameters (inertia, damping, stiffness, etc...) or initial states (position and velocity). Mechanical parameters edition is mainly based on the homogeneous properties of matter. It is possible to edit in the same time all the values of a given parameter upon the whole network. Thus, it is easy to detect inhomogeneities in the network.

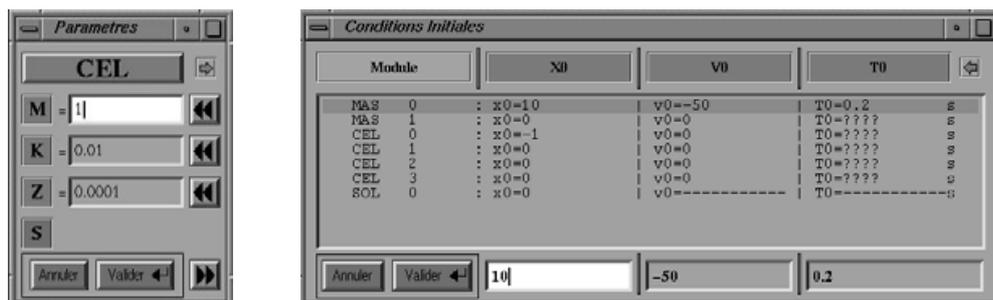


Figure 8.12. Mechanical parameters and initial states representations windows

Dynamic properties' representations

Simulation is the main way to validate models by observing their phenomena. Dynamic properties' phenomena are represented in two dynamic representations: sound playing and its visualization animation.

Behind the sound produced by the simulation process three different representations should be pointed out: The sound that is playing trough speakers, the audio file that had been created and also a graphical representation of the sound signal. Only the first is a dynamic representation, the two others are static. The former may be considered at a first level as a representation of a sound produced by the represented object (that exist or not) and at second level as a representation (external) of the (internal to the computer) audio file representation thanks to analog/digital converter (see table 8.11 to for details).

These representations make the sound produced able to be controlled with a playing console and to be exported in usual audio formats.

Visualization is used to make understand the phenomenon so that to link the whole of the GENESIS object representations and the sound produced. For example, it is possible to slow down the process of the visualization animation in order to make the audible vibrations visible. The 3D visualization space includes both the 2D topologic space representation and the 1D space simulation, which are complementary (see the typical case “smoothing effects” for translating between this three spaces).

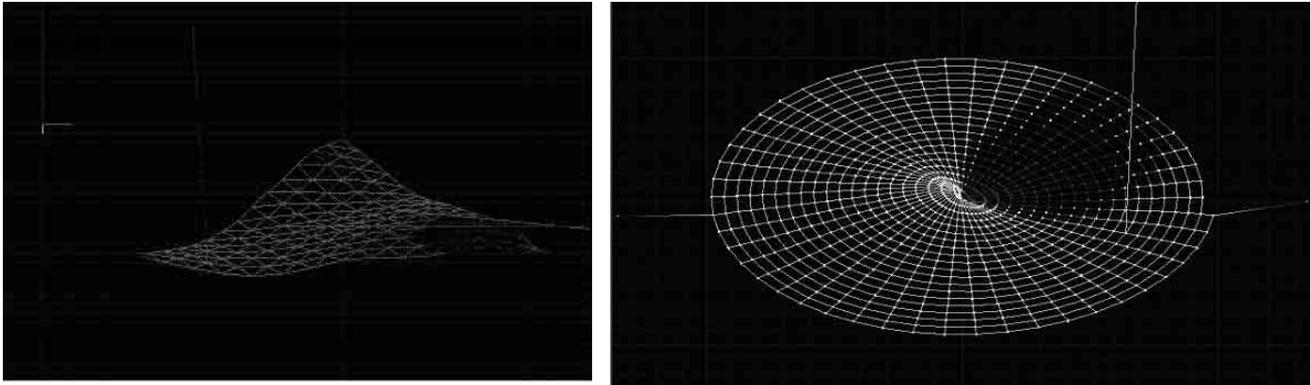


Figure 8.13. Examples of dynamic visualization process

We can guess the sound wave propagations thanks to the variation of colors.

8.4.3 GENESIS representations analysis

Among an educational approach of CORDIS-ANIMA and GENESIS, several representations and materials have been created and are used in different kind of learning situations: manipulating with GENESIS, autonomous learning or instructor-learner collaboration learning.

In order to concisely analyze all the representations, we focus on a single GENESIS object, the CEL basic element (briefly described above), by applying common and specific criteria from the theoretical issues. The CEL basic element was chosen because “The CEL basic element is the lowest GENESIS sounding object” and has a wide range of related representations.

We first specify the criteria used to make the analysis and we then describe sequentially all the related CEL representations. In addition, we present typical cases where some of these representations are combined to fill a learning or representation understanding objectives.

Sequential analysis

Based on relevant criteria, this analysis tries to sum up the main properties and to register all CEL’s related representations from the whole GENESIS environment. The current location of representations (basically available either in or out the GENESIS software or both) is for some of them mostly a technical fact rather than a functional choice.

Criteria’s guide:

This set of criteria falls into 2 parts: the former is composed of the *Name*, *Location*, *Description* and *Function* of the representation, that basically informs on what the representation is in terms of learning

context. The latter is the complex *Type* criterion that falls into the *Sensory Channel*, *Time*, *Space*, *Interactivity*, *Nature*, *System* and *Code* sub-criteria. These criteria are more specific to the representation itself and especially in the whole context of Multisensory Interactive Simulation. In addition, we provide a picture of the representation if it addresses the visual modality and relevant comments for both explaining the classification made and for linking representations with each other.

We now specify concisely the definition of the criteria:

- Name: Common name of the representation in the GENESIS environment
- Location: Current location of the representation in the GENESIS environment
- Description: Raw description of the representation, what is basically seen, without any interpreting context, whether it is possible

We can distinguish several locations namely the GENESIS user interface (UI), GENESIS user manuals, instructor MS-PowerPoint (ppt) presentation or course, instructor speech presentation or course, and with the use of real physical materials.

- Function / Role: In which purpose this representation has been built and is used
- Type: Characteristics of the representation that allow to categorize properly the different GENESIS representations and to point out multisensory interactive simulation as ideal system of representation
 - Sensory channel: Channel(s) / Modality addressed by the representation: *Visual*, *Aural* and *Tactile*.
 - Time: The time is either *static* (spatially represented) or *non static* (time represented) in representations.

We can distinguish several cases in both situations:

- Static time: Time is represented in a spatial extension. We chose to use the terminology proposed by Ainsworth and VanLabeke (2004), *time-singular*, *time-persistent*, *time-implicit* (see Chapter 1 for definitions) and we add another case: *multiple time-singular* or snapshot representations, which is to associate a sequence of the same representation at different instants.
- Non-Static time: There are two main situations: *real time* and *non time-differed*.
- Real time: A representation *is not* real time or not, it complies or not with real time requirements, i.e. the digital calculation time that allows producing the digital signals at the suitable sampling rate. These sampling rates are different for each modality: Around 48 kHz for aural, 25 Hz for visual and 1kHz for tactile (gesture).
- Non time-differed: A representation is time-differed if its evolution (in time related to modality) has been previously calculated or is delayed, with the user action.

Typically, sound simulation and animations could be both real time compliant and time-differed by delaying. Hence, it is possible to control the inherent time process step-by-step, or by accelerating or slowing, etc. Tactile simulation involves the previous calculation in order to support "action-reaction"

system with the user. The concept of Multisensory Interactive Simulation is both real time compliant and non time-differed.

- Space: The space's dimension of the representation: 1D, 2D, 3D.
- Interactivity: Can be qualified as either Null or Low or High-symbolic or High-ergotic.
 - Null: There is no possible action on/with the representation.
 - Low: The representation allows simple action whose result is binary such as yes/no, or like selection / no selection by clicking once on the mouse button or choosing an item menu.
 - High: Action that involved a more complex gestural action, like direct manipulation in a graphical representation with a mouse, or with a force feedback transducer.

At this high level, we can distinguish two types of interaction: The former is in a certain manner an iconic representation of the interaction we would have with the represented object, by "anamorphosis" or "discretization" for instance (as explained in the 8.2 section). This interaction is characterized with a gestural function that is called *ergotic* (Cadoz 1994, Cadoz & Wanderley 2000). The latter is a *symbolic* representation that is to say that the link with the represented interaction is arbitrary. We can even imagine such a kind of situation with force feedback transducer like in the "mapping" techniques in computer music.

- Nature: In order to insist on the relation between the signifier and the signified. Without entering in complex typology, we stay at the basic level of the Pierce's approach with the triadic Symbolic-Iconic-Indexical classification (see section 8.2 for definitions).

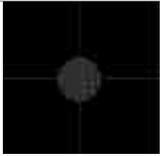
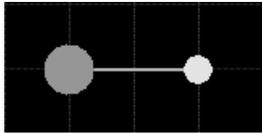
Actually, it is difficult to attribute one mode per representation, because of the mixed nature of signs that are used. Hence, as the Group μ (1992) proposed, we will indicate proportion between the different mode rather than choosing an exclusive mode, supported by comments if necessary. The Group μ contribution deals with the redefinition of the analogy's relation based on action/perception (instead of meaning-based), as it was already proposed by Eco in 1970: this is not strictly the opposition of arbitrary and motivation or also digital and analogical, or conventional and natural (Eco, 1970), that may allow categorize the relations, but more a kind of proportion.

- System: The production system of the representation: We follow the Duval's point of view that there is a basic distinction between semiotic and physical/organic representations, that is the system in which the representation is produced (Duval, 1999). For instance, this system classification allows to make the distinction between animations and visual simulation.
 - Semiotic system: The content of the representation denotes the represented object: it is an explicit selection because each significant unit results from a choice.
 - Physical system: The content of the representation is the outcome of the physical action of the represented object on some organic system or on some physical device. Typically such representations are simulations, imitations, or

photographs. Thus, we can distinguish the *physical* or *material* device from the *virtual* one.

- Code: System of representation used to support the content of the representation. In case of semiotic system it could be text, graph, diagram, speech etc. In case of physical system the code of the representation is dynamic and mostly defined by the modality it addresses: sound waves, visual waves and gestural waves.

Table 8.1. CEL’s GENESIS representation analysis

Name	GENESIS representation				Location	GENESIS UI, manuals or ppt								
Description	A small-colored disk on the GENESIS workbench													
Function / Role	Topology (which type of elements are connected) is completely defined: Shape allows distinguishing mass-like from interaction-like elements, the color codes the type of basic elements.													
Type														
					Non Static		Static							
	Aural	Visual	Tactile		Real Time	Non Time differed	T-singular	T-persistent	T-implicit	T-singular multiple		1D	2D	3D
Sensory Channel		✓		Time			✓ ²				Space		✓	
	Null	Low	High-symbolic	High-ergotic		Symbolic	Iconic	Indexical			Semiotic	Physical material	Physical virtual	Code
Interactivity			✓ ¹		Nature	+	++			System	✓			Pictorial
Comments														
<p>¹ This representation is manipulable within the construction process by connecting elements with each other and by organizing the network (see below comment on direct manipulation).</p> <p>² At initial simulation state.</p> <p>The single prior knowledge for the topologic properties’ representations is the knowledge of the GENESIS workbench.</p> <p>This GENESIS representation is equivalent (in terms of model) to the SOL-REF-MAS network GENESIS representation:</p> <p>If the mass-like elements representation shape is iconic by evoking concrete “matter” (also size according to the inertia value), it is conversely arbitrary for the interaction-like elements.</p>														
														

Comment on direct manipulation: We should point out that the relation between the gestures made to manipulate a graphic representation on the computer screen with a mouse -in a usual way such as objects’ displacements- is slightly similar (as we can consider several degrees of similarity) with the gestures made in real world (typically in this case catching and placing actions). For instance, it is not obvious to construct an object from elementary bricks by first clicking on the toolbox icon of the elementary brick we want, then by going on the workbench to insert the elementary brick by moving the mouse’s cursor

and clicking again on the right place. This sequence of elementary actions is directly linked to a specific use of the artifact supporting representation. This *scheme of usage* (Révillon & Rabardel, 1995) could be considered as a representation of the actions effectively made in the real world.

We should be careful when using computer, we are used to work with “metaphors”. In addition, when moving objects on the screen with the mouse, we do not strictly move the objects on the screen: this is done by the computer program in response of mouse inputs.

Table 8.2. CEL’s toolbox icon analysis

Name	CEL’s icon				Location	GENESIS UI toolbox						
Description	A small-colored-named disk and a label											
Function / Role	Icon that allows inserting a new CEL element on the workbench											
Type												
					Non Static		Static					
	Aural	Visual	Tactile		Real Time	Non Time differed	T-singular	T-persistent	T-implicit	T-singular multiple		
Sensory Channel		✓		Time			✓				Space	
	Null	Low	High-symbolic	High-ergotic		Symbolic	Iconic	Indexical			Semiotic	Physical material
Interactivity		✓ ¹			Nature	++	++			System	✓	Physical virtual
												Code
												Pictorial/text
Comments												
¹ This representation can simply be selected (see comment on direct manipulation).												
Established a relation between the element’s name and the color that may change according user’s preferences.												

Table 8.3. CEL's functional description analysis

Name	Functional description		Location	Manuals, speech presentation											
Description	A text with mathematical symbols and familiar basic element name in capital letters.			<i>CEL moves along the axis (OX), its position at each instant is X. This is the first oscillating object and has the same properties as a SOL + REF + MAS model.</i>											
Function / Role	Describes the behavior of the CEL's model by introducing how is the movement in space and an equivalent model.														
Type															
					Non Static		Static								
	Aural	Visual	Tactile		Real Time	Non Time differed	T-singular	T-persistent	T-implicit	T-singular multiple			1D	2D	3D
Sensory Channel	✓	✓		Time					✓		Space		✓		
	Null	Low	High-symbolic	High-ergotic		Symbolic	Iconic	Indexical			Semiotic	Physical material	Physical virtual	Code	
Interactivity	✓				Nature	++	+		System	✓				Text/Speech	
Comments															
This description illustrates the functional representation (see below and see typical cases).															
In order to explain the model behavior, we also use short stories on everyday physics that allows changing the context of the reasoning activity with a more familiar one. They need the participation of learners by choosing or predicting the story issue.															

Table 8.4. CEL's functional representation analysis

Name	Functional representation				Location	Manuals or ppt presentation								
Description	Two colored disks linked with spring and damper symbols. Axis introduces relations with space (X).													
Function / Role	Allows understanding the (mechanical) behavior of the CEL element, how the model works and becoming familiar with the 2D representation of 1D phenomenon (see typical cases).													
Type														
					Non Static		Static							
	Aural	Visual	Tactile		Real Time	Non Time differed	T-singular	T-persistent	T-implicit	T-singular multiple		1D	2D	3D
Sensory Channel		✓		Time			✓ ¹				Space		✓	
	Null	Low	High-symbolic	High-ergotic		Symbolic	Iconic	Indexical			Semiotic	Physical material	Physical virtual	Code
Interactivity	✓				Nature	++	+		System	✓				Schema
Comments														
¹ At given simulation state. Link the 2D-GENESIS topologic representation with both the behavior's model and the 1D simulation space domain (the 2 axis are the same). This representation exists in animation code (for ppt presentation uses). It may also exist in multiple t-singular format (for manuals uses).														

Table 8.5. CEL's paper modeling representation analysis

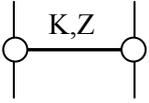
Name	Paper modeling representation				Location	Paper and pencil environment								
Description	Disks linked with spring and damper symbols.													
Function / Role	This representation allows modeling GENESIS objects with a representation adapted to paper and pencil environment for supporting the autonomous modeling without user interface computer.													
Type														
					Non Static		Static							
	Aural	Visual	Tactile		Real Time	Non Time differed	T-singular	T-persistent	T-implicit	T-singular multiple		1D	2D	3D
Sensory Channel		✓		Time			✓				Space		✓	
	Null	Low	High-symbolic	High-ergotic		Symbolic	Iconic	Indexical			Semiotic	Physical material	Physical virtual	Code
Interactivity			✓		Nature	++	+		System	✓				Schema
Comments														
Codes of technological environment representation may deeply differ from what they are in a paper and pencil environment. In this case, it more close of the topologic GENESIS representation and less than functional representation: it is similar but the color was abort for the benefit of the precision of the type of the basic element with symbols parameters.														

Table 8.6. CEL's graphical movement representation analysis

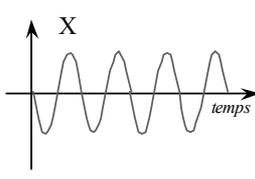
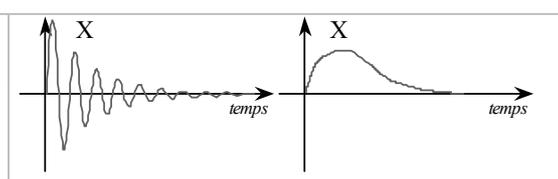
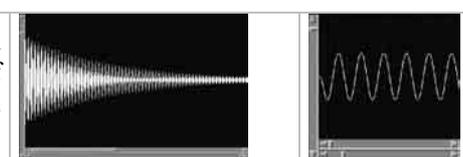
Name	Graphical movement representation				Location	Manuals or ppt presentation								
Description	A regular undulated line along the time axis towards X-axis.													
Function / Role	Evolution in time of the CEL's movement along the (OX) simulation axis, when there is no damping (viscosity parameter $Z=0$).													
Type														
					Non Static		Static							
	Aural	Visual	Tactile		Real Time	Non Time differed	T-singular	T-persistent	T-implicit	T-singular multiple		1D	2D	3D
Sensory Channel		✓		Time				✓			Space		✓	
	Null	Low	High-symbolic	High-ergotic		Symbolic	Iconic	Indexical			Semiotic	Physical material	Physical virtual	Code
Interactivity	✓				Nature	+	+ ¹	+ ¹	System	✓				Graph
Comments														
<p>¹ This is an iconic representation of an indexical representation which can be obtained in particular conditions (in this case, the trace of the moving object for instance). It is iconic because it is a representation of the time with the space.</p>														
<p>There are additional graphs for pseudo-periodical regime ($Z \neq 0$) and for critical regime:</p>														
<p>These kinds of representations are available directly from the GENESIS user interface by observing the signal of the phenomena produced by the CEL's model simulation and also manipulable with multi scales window:</p>														

Table 8.7. CEL's digital mathematical expression analysis

Name	Digital mathematical expression				Location	Manuals or ppt presentation								
Description	Formula (second-order recurrence equation)				$X_n = X_{n-1} \left[2 - \frac{K+Z}{M} \right] + X_{n-2} \left[\frac{Z}{M} - 1 \right] + \frac{1}{M} F_{n-1}$									
Function / Role	For each sampled time n, (corresponding to the sampling rate), X(n) position is calculated in response of the (two) previous positions and to the sum F(n-1) of the input forces.													
Type														
					Non Static		Static							
	Aural	Visual	Tactile		Real Time	Non Time differed	T-singular	T-persistent	T-implicit	T-singular multiple		1D	2D	3D
Sensory Channel		✓		Time						✓	Space	✓		
	Null	Low	High-symbolic	High-ergotic		Symbolic	Iconic	Indexical			Semiotic	Physical material	Physical virtual	Code
Interactivity	✓				Nature	++				System	✓			Formula
Comments														
This expression can be formalized under the Newtonian approach (FRD): $m\ddot{x}(t) + z\dot{x}(t) + kx(t) = 0$														

Table 8.9. CEL's mechanical parameters representation analysis

Name	Mechanical parameters representation		Location	GENESIS user interface																				
Description	User interface window with symbols and numerical values ergonomically organized																							
Function / Role	Window that displays and allows manipulating numerical values of the CEL's mechanical parameters model (M inertia, K stiffness, Z damper). It is possible to edit available mechanical parameters for each type of basic elements (item menu on the top of the window) simultaneously if there an homogeneous selection																							
Type																								
						Non Static		Static																
		Aural	Visual	Tactile		Real Time	Non Time differed	T-singular	T-persistent	T-implicit	T-singular multiple											1D	2D	3D
Sensory Channel			✓		Time ²										Space								✓	
		Null	Low	High-symbolic	High-ergotic			Symbolic	Iconic	Indexical					Semiotic	Physical material	Physical virtual							Code
Interactivity			✓ ¹		Nature		++					System	✓											Window ³
Comments																								
<p>¹ Some kind of activity is involved by giving and controlling parameters values.</p> <p>² Given that the represented object is "static" (value parameters), the time characteristic is not appropriate in this case.</p> <p>³ Actually, it is a complex code, it involves text, symbols, graphic, etc.</p> <p>There is a "dynamic linking" between the currently selected part of the GENESIS topologic representation and the displayed values in the parameters window.</p> <p>There is the same kind of representation for the initial state values (see fig. 8.12).</p>																								

Table 8.10. CEL’s audio file

Name	A CEL’s audio file				Location	Outcome of the simulation process								
Description	Digital data that are stored on the computer													
Function / Role	This file is a kind of internal representation (of the computer) of sound phenomena, by double discretization in time and space.													
Type														
					Non Static		Static							
	Aural	Visual	Tactile		Real Time	Non Time differed	T-singular	T-persistent	T-implicit	T-singular multiple		1D	2D	3D
Sensory Channel ¹				Time				✓			Space		✓	
	Null	Low	High-symbolic	High-ergotic		Symbolic	Iconic	Indexical			Semiotic	Physical material	Physical virtual	Code
Interactivity	✓				Nature	++			System		✓	✓		Magnetic
Comments														
¹ This file is an internal representation of the machine, it is not accessible to our sensory channel but only through an external representation such as analog/digital converter when hearing or letters when reading the representation of the file.														

Table 8.101. CEL’s sound phenomenon analysis

Name	A CEL sound phenomenon				Location	Outcome of the simulation process								
Description	A sound with a single pitch													
Function / Role	This sound is produced by simulating the CEL element model. Playing the sound allows to give a “concrete” form of the model and to establish a qualitative relation between the parameters values and the sound produced.													
Type														
					Non Static		Static							
	Aural	Visual	Tactile		Real Time	Non Time differed	T-singular	T-persistent	T-implicit	T-singular multiple		1D	2D	3D
Sensory Channel	✓			Time	Yes	No					Space	✓ ¹	✓ ¹	✓ ¹
	Null	Low	High-symbolic	High-ergotic		Symbolic	Iconic	Indexical			Semiotic	Physical material	Physical virtual	Code
Interactivity			✓		Nature	+ ²	+ ²		System		✓			Audio wave
Comments														
¹ It depends on both the number of microphone used and their localization.														
² This representation is indexical with the audio file representation and iconic with the sound of the object that the model simulation is representing, even if the represented object doesn’t really exist.														
For instance, a qualitative relation is the one between the spring parameter and the pitch of the sound: the more the spring is hard, the more the pitch of the sound is high.														

Table 8.112. CEL's visualization process analysis

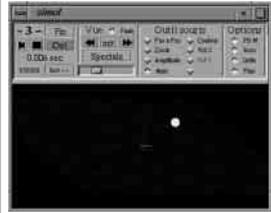
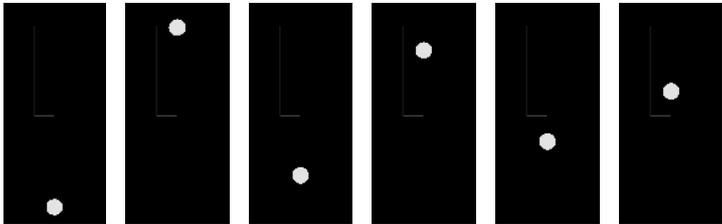
Name	A CEL visualization process				Location	GENESIS user interface									
Description	Moving mass-like element linked to other static one, in three-dimensional space.														
Function / Role	Visualization process which allows to see the phenomena produced by simulating a GENESIS object model and which is controlled with zooming, slowing/accelerating tools. ¹														
Type															
					Non Static		Static								
	Aural	Visual	Tactile		Real Time	Non Time differed	T-singular	T-persistent	T-implicit	T-singular multiple			1D	2D	3D
Sensory Channel		✓		Time	Yes	No					Space				✓
	Null	Low	High-symbolic	High-ergotic		Symbolic	Iconic	Indexical			Semiotic	Physical material	Physical virtual	Code	
Interactivity	✓				Nature	+	++	+	System	✓				Animation	
Comments															
¹ Slowing/accelerating tools allows to make the audible vibrations visible.															
This representation in transformed in video code for ppt uses.															
It exists also in multiple T-singular representation: (quantitative cues: OX simulation axis blue line=1cm)															
															

Table 8.123. Multisensory Interactive Simulation analysis

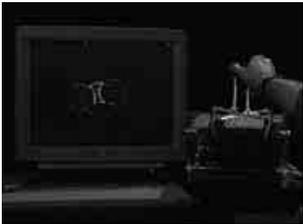
Name	Multisensory Interactive Simulation				Location	Outcome of simulation processes								
Description	Aural and visual (computer) interfaces strictly coordinated with force feedback transducers													
Function / Role	Targets the dynamic properties, evolutions and interactions of physical objects that are represented with the simulation model.													
Type														
					Non Static		Static							
	Aural	Visual	Tactile		Real Time	Non Time differed	T-singular	T-persistent	T-implicit	T-singular multiple		1D	2D	3D
Sensory Channel	✓	✓	✓	Time	Yes	Yes					Space			✓
	Null	Low	High-symbolic	High-ergotic		Symbolic	Iconic	Indexical			Semiotic	Physical material	Physical virtual	Code
Interactivity				✓	Nature		++		System			✓	A,V,T wave	
Comments														
According to the grid criteria, this is the stronger representation in terms of multisensoriality and interactivity (see 8.3 section as well).														

Table 8.134 Educational small suitcase analysis

Name	Educational small suitcase				Location	GENESIS educational materials									
Description	A small suitcase full of material objects such as balls, various springs, saw, etc...														
Function / Role	Allow supporting basic explanation with physics real life experiment. Especially, encouraging the prediction of physical phenomenon depending on the characteristics of the material used.														
Type															
					Non Static		Static								
	Aural	Visual	Tactile		Real Time	Non Time differed	T-singular	T-persistent	T-implicit	T-singular multiple			ID	2D	3D
Sensory Channel	✓	✓	✓	Time	Yes	Yes					Space				✓
	Null	Low	High-symbolic	High-ergotic		Symbolic	Iconic	Indexical			Semiotic	Physical material	Physical virtual	Code	
Interactivity				✓	Nature		++		System		✓		A,V,T wave		
Comments															
These materials could be compared with the ones used in molecular chemistry education or in the trend of "Hands on" program developed by the French scientist Georges Charpak, in order to revitalize the teaching of sciences in the primary school in France (www.inrp.fr/lamap).															

Typical cases

2D representation of 1D topologic properties

In order to make understand that there is no influence on the model with the positions of the basic elements on the workbench, but only with the topology of the network (which type of basic element are connected with which others), see fig 8.3 for instance, we usually associate, at first stage (that is basic elements behavior understanding) 3 kinds of representations:

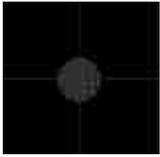
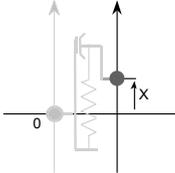
		<p><i>CEL moves along the axis (OX), its position at each instant is X. This is the first oscillating object and has the same properties as a SOL + REF + MAS model.</i></p>
<p>GENESIS Representation</p>	<p>Functional Representation</p>	<p>Textual / Speech Description Representation</p>

Figure 8.14. Typical multiple representation

The description highlights easily that the simulation of the CEL model is one-dimensional and makes the equivalence with a SOL-REF-MAS model. The functional representation that represents strictly a SOL-REF-MAS model plays an important role because it links the two others. In addition, the way the 2 mass-like elements are connected (with schema of damper and spring) induces a vertical interaction and not a horizontal one, which is more usual when 2 masses are in front of, like in the 2D representation. The identification of the 2 axes allows to switch from the 2D representation to the 1D simulation one. The functional representation was declined in animation in order to support both complex mechanical behavior (constrained interaction for instance) and one-dimensional movement.

Smoothing effects

The translation between the 2D and 1D representation is inherently supported by GENESIS software during the visualization process of the movement, based on the school blackboard metaphor for a student: On one hand, the GENESIS workbench stands for the blackboard (front of view, plane (Y, Z)) and on the other hand, in the visualization process, this is a rotated view such as a student may have on his own sheet (X, Y, Z space):

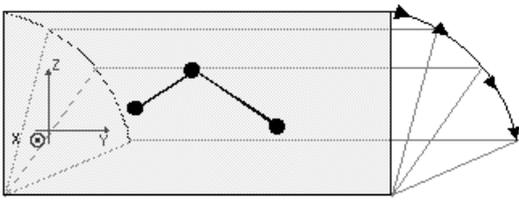
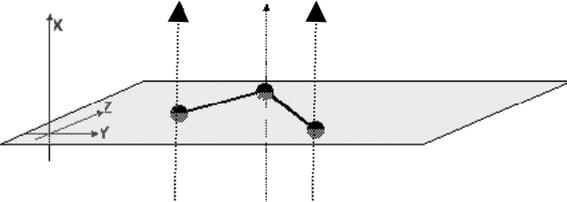
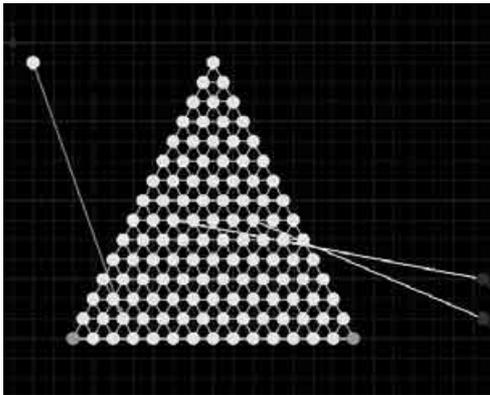
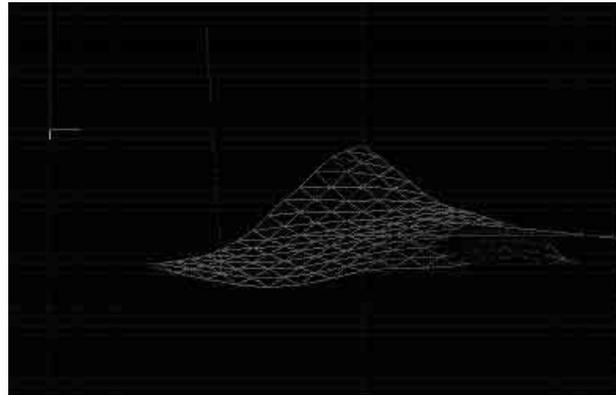
	
<p>Front of view</p>	<p>Tridimensionnal view</p>

Figure 8.15. Schemata of the space representation rotation

This rotation is automatically performed at each launch of the visualization process. In addition, tools allow modifying the point of view so that to make the GENESIS workbench appear (i.e. red grid).



GENESIS representation



GENESIS visualization process

Figure 8.16. Translation between the representation and visualization spaces

Complex multiple representation

Briefly, we give this example of GENESIS complex multiple representations issued from modal analysis and tuning features. The following window displays all the modes of the model, the global frequency-response of the model between two basic elements of the network model and the modal shape of a chosen mode. Tuning is then possible on each mode and these representations are dynamically linked.

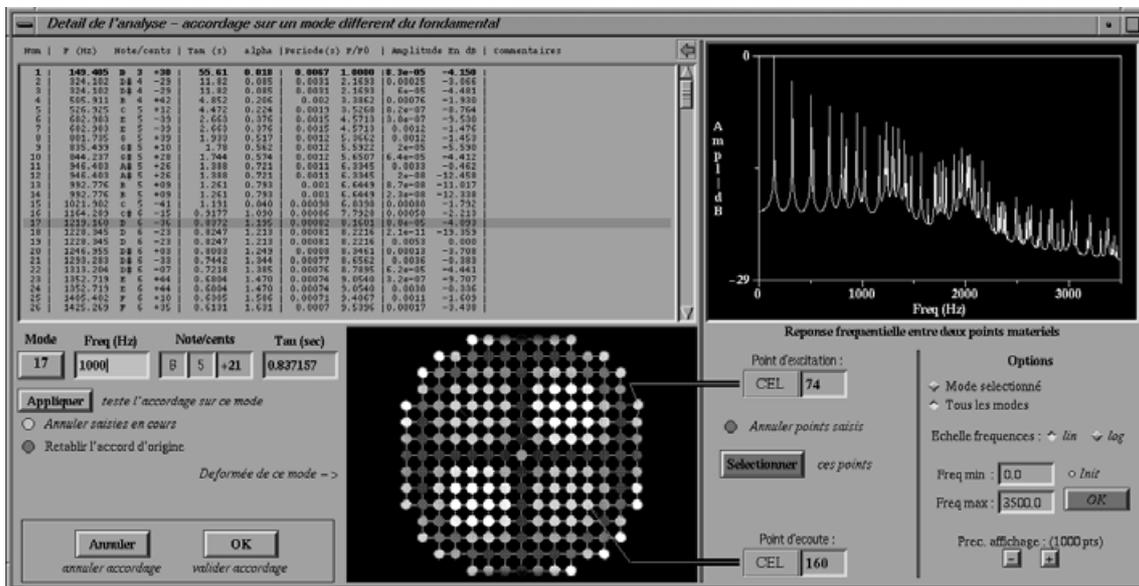


Figure 8.17. Example of complex multiple representation

Analysis conclusions

As a conclusion of this first ever made analysis in the light of the representation characterization and association, based on criteria that have been coherently elaborated with Multisensory Interactive Simulation, we can point out the following points and propose some research guide issues:

Criteria's definition

What emerges from this analysis is that studied representations can be compared thanks to the criteria:

There is a fundamental distinction between animation and visual simulation that are usually put in the same visual dynamic representation set.

The Multisensory Interactive Simulation and the educational small suitcase have strictly the same characteristics according to the defined criteria, except the nature of physical production system (virtual for the former, material for the latter).

A trail research issue could be and may be definitively useful to make the criteria used to characterize representations with deeper definitions and so as they form a non-redundant base in the integral representation framework.

Doing this analysis has already pointed out the need of a more concise definition of some criterion and also the way they are combined.

System representation and multiple representation

There is a wide range of representations and there are a lot of possible associations in order to match a same or several learning objectives or tasks. In our case, these associations were built with experience and educational intuition. In order to build more relevant and efficient associations so that at least representations highlights different properties of the represented (information splitting), there is an easier translation between the representations and using efficiently of computer representation potentiality.

Among all the others theoretical issues proposed in this state of the art, we may address the question of "multiple representations" under the notion of semiotic register introduced by Duval (1993) in Mathematical education, and that may allow designing more relevant "multiple representations" for (digital) learning environment than a simple association of multiple system of representation (Balacheff, 2000). We briefly present what this notion of semiotic register is:

The underlying hypotheses are that the distinction between an object and its representation is a "strategical point for the comprehension" and that the coordination/interaction between representations of the object in several registers should be considered absolutely necessary to form the understanding of the object: A development of a single register is not enough, except if the learner has already understood the concept. Semiotic representations are productions made of the use of signs that belong to one system of representation or semiotic system, which has its own constraints of meaning and function. A register is a semiotic system that allows three fundamental activities:

- Formation of an identifiable representation as a representation of a given register
- Treatment of a representation inside the same register (e.g. rephrasing of a sentence or transformation of an equation in order to find x)
- Conversion of a representation into another register referring to the same conceptual object but highlighting others qualities of the object (as for instance a graphical representation of a line highlights other qualities than its underlying equation).

Typically in geometry education, there are three registers used: the natural language register, the symbolic register and the graphical register (Robotti, 2000). But, in fact the nature of a register depends on the

community of practice questions, so on various cultural frameworks and social convention. For instance, mathematical registers have been extended in several didactical physics education teams for hypermedia development and analysis, with an image register and a dynamic register including animations and simulations (Séjourné & Tiberghien, 2001).

8.4.4 GENESIS Environment perspectives

The GENESIS Environment perspectives could be to have a double identity: to be a learning environment for GENESIS and to allow learning with GENESIS. Furthermore, it could be extended with tactile transducers. Experiments of creation and pedagogy carried out since 1996 with GENESIS in collaboration with high-level artists, several organizations for artistic education and various centers of creation, at a local level as well as an international one, made it possible both to validate the design of GENESIS software and to consolidate its CORDIS-ANIMA conceptual basis. But this led us to consider that this approach not only needs, as well as any tool or approach, a clever pedagogy, but also that it can be a very convincing tool for education of artistic and scientific creativity.

Indeed, there are two main educational contexts, where the GENESIS environment may support learning: The primary context of the musical creation with physical modeling and the secondary but not least context of basic scientific backgrounds and concepts understanding (mechanical, acoustical, psycho-acoustical knowledge's, etc...). We previously developed the former (because it is our current learning context) and we want to extend properly the latter. Simulations are already commonly used in the physics education and have proved to be efficient, but we want to address the basic scientific concepts in the micro-world of GENESIS from modeling to simulating virtual sounding objects and conversely. In addition, force feedback transducers could enhance strongly the understanding of procedural knowledge such as the stiffness of an interaction while controlling the nature of the spring.

There is more specifically a running project in the ICA laboratory called Nanoman, based on manipulation at nano-scale with force feedback manipulators. This project will target to have a tremendous potential to teach experimental physics at all levels.

It will allow not only students but also children to put their fingers at the nano-scale and to come into direct contact with molecules, the nano-worlds and other entities helpful for understanding the difference between the nano-scales physics and the macro-scales physics. This will even provide a fecund way to adapt teaching of science and to reconcile human perception and abstract with mathematical and scientific views of reality. This is a central challenge in teaching physics or chemistry.

Thus, our project is to extend the current GENESIS environment by developing a complete learning environment for both GENESIS users (artists, music and scientific students, etc...) and teachers. This environment will rely on a wide database including various knowledge, representations and media. It will have to build new representations and definitely need to build relevant multiple representations according to the learning objectives by taking into account the whole theoretical issues that emerge from this JEIRP framework.

8.5 Conclusion

One may be a little perplex, considering the gap between the first part of this chapter, quite theoretical and general, and the second, and perhaps the pragmatic questions we have to solve in this WorkPackage.

In fact, we should convene that there is a missing transition giving better concrete links between the two levels, for example providing a clear and consistent table of criteria to classify the representation processes in the context of external representation within multimedia. This is a not so short work but we consider that it remains to be done. More, we would be very happy if it can be considered as a part of subsequent sub-tasks in this project. But we decided for this impudent attitude, after many questions and doubts, for several reasons, ready to accept its consequences.

We are deeply convinced that Representation is a fundamental question, in every discipline but may be particularly in the learning field. We personally think (knowing that this could be very trivial) that for learning, it is the first question, and a question on which we can work more easily than on "motivation", for example, that depends on a so wide variety of complex factors (psychological, sociological, etc.). This conviction is not at all theoretical or "academic" but comes from a lot of pedagogical experiences we carried out in real learning contexts since the beginning of our researches, with a quite wide variety of learning subjects. We experienced the importance to discover the good way to "present" (in fact, represent) things, between these two poles of abstraction and sensory-motor experience. We experienced also that the result is spectacularly increased when the learner is himself the actor of this process.

In the same time, we know that representation is a very difficult question, with very different approaches according to the different disciplines and domains, each of them having their own "objects" and own particular vocabulary, differently defined and differently associated. Coming ourselves from a "foreign" discipline, we discovered a lot of new viewpoints, concepts, paradigms and... vocabulary in front of which we got new deep understandings.

But we were a little disappointed to discover also, according to our habitual terms, some... confusion, may be on the terms only, may be on the concepts, may be on our understanding. In any case, this motivate us to work on the point, and to start with these "general considerations on representation", hoping that it would have some little utility, after been revisited, corrected, modified, adapted, etc.

Now, we would like to propose some paths for further research works.

We said somewhere in the discussion that the road from sensory-motor experience to abstraction in a long and complex one, but that it can be covered if needed and if time for that is saved. What we want to propose here, is, in fact, the reverse road, i.e., considering a given example of "abstraction", to try to determinate which sensory-motor situation, achieved thanks to a multisensory interactive simulation could offer a good solution to learn it. And in this aim, a first example could concern the representation of algorithms...

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CHAPTER 9: Psycho-physiological parameters in the interaction between learners' internal and external representations

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Abstract. The aim of this case study is to examine the interplay of external and internal representations in a virtual gaming environment. The main focus was on investigating which instructional technique, that is reading, listening, graphical representation or java tutorial, resulted in a better performance in an online game on visual perception, combining main aspects of cognition. The study outcome was mainly derived from psycho-physiological measurements based on a cognitive approach towards the complex field of representations. The analysis of data focused on the cognitive strategies followed by the users, their abilities in visual perception and logical thinking. To describe the mutualities and differences between these factors we applied the External Cognition framework. Using this framework we analysed how external representations, presented to users in various kinds of instructions, influenced the gaming task.

Keywords: cognitive learning strategies, emotional and motivational factors, external and internal representations, external cognition framework, re-representation, graphical constraining

9.1 Introduction

Cognitive Science is a rapidly expanding field of study aimed at understanding the mental processes that underlie cognitive abilities. The questions asked by Cognitive Science are not new. Philosophers, Psychologists, Linguists, Neuroscientists, Anthropologists and Computer Scientists have all approached the basic questions posed by the nature of mental processes in their own ways as part of the broader endeavours of their respective fields. Cognitive Science is distinguished from these traditional disciplines by its highly interdisciplinary approach. Its defining technique is to bring expertise gained from the related disciplines to bear on a set of common questions: What are the basic components of cognitive processes? Are they subsumed by a common mental mechanism? What is the relationship between the physical apparatus and cognition? To answer these questions Cognitive Scientists engage in empirical studies aimed at assessing their formal and computational models of various aspects of cognition. The sorts of areas investigated include the information-acquisition and information-processing mechanisms underlying cognitive abilities like perception, recognition, information storage and information retrieval, language acquisition, comprehension and production, concept acquisition, problem solving, and reasoning. Its intellectual origins are in the mid-1950s when researchers in several fields began to develop theories of mind based on complex representations and computational procedures.

9.2 Representations and their background in cognitive science

Attempts to understand the mind and its operation go back to the Ancient Greeks at least, when philosophers such as Plato and Aristotle tried to explain the nature of human knowledge. In his well-known allegory of the cave (*The Republic. Book VII*), Plato already questioned the problem of representation. In this allegory, prisoners are bound in a cave in such a way that they cannot turn their heads or move around. They can only see a wall in front of them. The light of a distant fire behind them casts shadows on the cave wall of themselves and other people wandering around. The prisoners have been restricted to this perception since birth. Therefore, their only perception of themselves and their world is through the moving shadows to be the actual objects in the world rather than recognizing them as mere shadows of the 'real' environment. So the problem of representation is certainly not a new one but it took a long time to explore it explicitly. Since the Seventeenth Century, the development of a unified science of the mind has been frustrated by the fact that questions about perception, thought, memory, imagination, language comprehension, learning, and other mental phenomena fell under the purview of several distinct sciences, each with its own methodology, conception of explanation, and preferred set of explanatory models.

The study of mind remained then the province of philosophy until the nineteenth century, when experimental psychology developed. Wilhelm Wundt and his students initiated laboratory methods for studying mental operations more systematically. Within a few decades, however, experimental psychology became dominated by behaviourism, a view that virtually denied the existence of mind. According to behaviourists such as J. B. Watson, psychology should restrict itself to examining the relation between observable stimuli and observable behavioural responses. Talk of consciousness and mental representations was banished from respectable scientific discussion. Especially in North America, behaviourism dominated the psychological scene through the 1950s. Around 1956, the intellectual landscape began to change dramatically. George Miller summarized numerous studies which showed that the capacity of human thinking is limited, with short-term memory, for example, limited to around seven items. He proposed that memory limitations can be overcome by recoding information into chunks, mental representations that require mental procedures for encoding and decoding the information. At this time, primitive computers had been around for only a few years, but pioneers such as John McCarthy, Marvin Minsky, Allen Newell, and Herbert Simon were founding the field of artificial intelligence. In addition, Noam Chomsky rejected behaviourist assumptions about language as a learned habit and proposed instead to explain language comprehension in terms of mental grammars consisting of rules.

Until recently, most psychologists, philosophers, computer scientists, linguists, and neurobiologists have been content to pursue these questions in relative isolation. In the last two decades, however, the gradual emergence in each of these disciplines of some versions of the view that mental phenomena can be fruitfully understood as operations on symbolic representations and that the mind is thus, in some sense or the other, an information processor, has made a truly interdisciplinary approach possible that holds the promise of being the long sought unified science of the mind.

9.2.1 Methods in cognitive science

Cognitive science has unifying theoretical ideas, but we have to appreciate the diversity of outlooks and methods that researchers in different fields bring to the study of mind and intelligence. Although cognitive psychologists today often engage in theorizing and computational modeling, their primary method is experimentation with human participants.

People are brought into the laboratory so that different kinds of thinking can be studied under controlled conditions. For example, psychologists have experimentally examined the kinds of mistakes people make in deductive reasoning, the ways that people form and apply concepts, the speed of people thinking with mental images, and the performance of people solving problems using analogies. Our conclusions about how the mind works must be based on more than "common sense" and introspection, since these can give a misleading picture of mental operations, many of which are not consciously accessible. Psychological experiments that carefully approach mental operations from diverse directions are therefore crucial for cognitive science to be scientific.

Although theory without experiment is empty, experiment without theory is blind. To address the crucial questions about the nature of mind, the psychological experiments need to be interpretable within a theoretical framework that postulates mental representations and procedures. One of the best ways of developing theoretical frameworks is by forming and testing computational models intended to be analogous to mental operations. To complement psychological experiments on deductive reasoning, concept formation, mental imagery, and analogical problem solving, researchers have developed computational models that simulate aspects of human performance. Designing, building, and experimenting with computational models is the central method of artificial intelligence (AI), the branch of computer science concerned with intelligent systems. Ideally in cognitive science, computational models and psychological experimentation go hand in hand, but much important work in AI has examined the power of different approaches to knowledge representation in relative isolation from experimental psychology.

While some linguists do psychological experiments or develop computational models, most currently use different methods. For linguists in the Chomskian tradition, the main theoretical task is to identify grammatical principles that provide the basic structure of human languages. Identification takes place by noticing subtle differences between grammatical and ungrammatical utterances.

Like cognitive psychologists, neuroscientists often perform controlled experiments, but their observations are very different, since neuroscientists are concerned directly with the nature of the brain. With nonhuman subjects, researchers can insert electrodes and record the firing of individual neurons. With humans for whom this technique would be too invasive, it has become possible in recent years to use magnetic and positron scanning devices to observe what is happening in different parts of the brain while people are doing various mental tasks. For example, brain scans have identified the regions of the brain involved in mental imagery and word interpretation.

Additional evidence about brain functioning is gathered by observing the performance of people whose brains have been damaged in identifiable ways. A stroke, for example, in a part of the brain dedicated to language can produce deficits such as the inability to utter sentences. Like cognitive psychology,

neuroscience is often theoretical as well as experimental, and theory development is frequently aided by developing computational models of the behaviour of groups of neurons.

Cognitive anthropology expands the examination of human thinking to consider how thought works in different cultural settings. The study of mind should obviously not be restricted to how English speakers think but should consider possible differences in modes of thinking across cultures. Cognitive science is becoming increasingly aware of the need to view the operations of mind in particular physical and social environments. For cultural anthropologists, the main method is ethnography, which requires living and interacting with members of a culture to a sufficient extent that their social and cognitive systems become apparent. Cognitive anthropologists have investigated, for example, the similarities and differences across cultures in words for colours.

With a few exceptions, philosophers generally do not perform systematic empirical observations or construct computational models. But philosophy remains important to cognitive science because it deals with fundamental issues that underlie the experimental and computational approach to mind. Abstract questions such as the nature of representation and computation need not be addressed in the everyday practice of psychology or artificial intelligence, but they inevitably arise when researchers think deeply about what they are doing. Philosophy also deals with general questions such as the relation of mind and body and with methodological questions such as the nature of explanations found in cognitive science. In addition, philosophy concerns itself with normative questions about how people should think as well as with descriptive ones about how they do. In addition to the theoretical goal of understanding human thinking, cognitive science can have the practical goal of improving it, which requires normative reflection on what we want thinking to be. Philosophy of mind does not have a distinct method, but should share with the best theoretical work in other fields of concern with empirical results.

In its weakest form, cognitive science is just the sum of the fields mentioned: psychology, artificial intelligence, linguistics, neuroscience, anthropology, and philosophy. Interdisciplinary work becomes much more interesting when there is theoretical and experimental convergence on conclusions about the nature of mind. For example, psychology and artificial intelligence can be combined through computational models of how people behave in experiments. The best way to grasp the complexity of human thinking is to use multiple methods, especially psychological and neurological experiments and computational models. Theoretically, the most fertile approach has been to understand the mind in terms of representation and computation.

9.2.2 Representation and Computation

The central hypothesis of cognitive science is that thinking can best be understood in terms of representational structures in the mind and computational procedures that operate on those structures. While there is much disagreement about the nature of the representations and computations that constitute thinking, the central hypothesis is general enough to encompass the current range of thinking in cognitive science, including connectionist theories which model thinking using artificial neural networks.

Most work in cognitive science assumes that the mind has mental representations analogous to computer data structures, and computational procedures similar to computational algorithms. Cognitive theorists have proposed that the mind contains such mental representations as logical propositions, rules, concepts, images, and analogies, and that it uses mental procedures such as deduction, search, matching, rotating, and retrieval.

The dominant mind-computer analogy in cognitive science has taken on a novel twist from the use of another analogue, the brain. Connectionists have proposed novel ideas about representation and computation that use neurons and their connections as inspirations for data structures, and neuron firing and spreading activation as inspirations for algorithms. Cognitive science then works with a complex 3-way analogy among the mind, the brain, and computers. Mind, brain, and computation can each be used to suggest new ideas about the others. There is no single computational model of mind, since different kinds of computers and programming approaches suggest different ways in which the mind might work. The computers that most of us work with today are serial processors, performing one instruction at a time, but the brain and some recently developed computers are parallel processors, capable of doing many operations at once.

9.3 Theoretical approaches

Here is a schematic summary of current theories about the nature of the representations and computations that explain how the mind works.

9.3.1 Formal logic

Formal logic provides some powerful tools for looking at the nature of representation and computation. Propositional and predicate calculus serve to express many complex kinds of knowledge, and many inferences can be understood in terms of logical deduction with inferences rules such as modus ponens. The explanation schema for the logical approach is:

Explanation target:

- Why do people make the inferences they do?

Explanatory pattern:

- People have mental representations similar to sentences in predicate logic.
- People have deductive and inductive procedures that operate on those sentences.
- The deductive and inductive procedures, applied to the sentences, produce the inferences.

It is not certain, however, that logic provides the core ideas about representation and computation needed for cognitive science, since more efficient and psychologically natural methods of computation may be needed to explain human thinking.

9.3.2 Rules

Much of human knowledge is naturally described in terms of rules of the form IF ... THEN ..., and many kinds of thinking such as planning can be modelled by rule-based systems.

The explanation schema used is:

Explanation target:

- Why do people have a particular kind of intelligent behaviour?

Explanatory pattern:

- People have mental rules.
- People have procedures for using these rules to search a space of possible solutions, and procedures for generating new rules.
- Procedures for using and forming rules produce the behaviour.

Computational models based on rules have provided detailed simulations of a wide range of psychological experiments, from cryptarithmic problem solving to skill acquisition to language use. Rule-based systems have also been of practical importance in suggesting how to improve learning and how to develop intelligent machine systems.

9.3.3 Concepts

Concepts, which partly correspond to the words in spoken and written language, are an important kind of mental representation. There are computational and psychological reasons for abandoning the classical view that concepts have strict definitions. Instead, concepts can be viewed as sets of typical features. Concept application is then a matter of getting an approximate match between concepts and the world. Schemas and scripts are more complex than concepts that correspond to words, but they are similar in that they consist of bundles of features that can be matched and applied to new situations.

The explanatory schema used in concept-based systems is:

Explanatory target:

- Why do people have a particular kind of intelligent behaviour?

Explanation pattern:

- People have a set of concepts, organized via slots that establish kind and part hierarchies and other associations.
- People have a set of procedures for concept application, including spreading activation, matching, and inheritance.
- The procedures applied to the concepts produce the behaviour.
- Concepts can be translated into rules, but they bundle information differently than sets of rules, making possible different computational procedures.

9.3.4 Analogies

Analogies play an important role in human thinking, in areas as diverse as problem solving, decision making, explanation, and linguistic communication. Computational models simulate how people retrieve and map source analogues in order to apply them to target situations.

The explanation schema for analogies is:

Explanation target:

- Why do people have a particular kind of intelligent behaviour?

Explanatory pattern:

- People have verbal and visual representations of situations that can be used as cases or analogues.
- People have processes of retrieval, mapping, and adaptation that operate on those analogues.
- The analogical processes, applied to the representations of analogues, produce the behaviour.

The constraints of similarity, structure, and purpose overcome the difficult problem of how previous experiences can be found and used to help with new problems. Not all thinking is analogical, and using inappropriate analogies can hinder thinking, but analogies can be very effective in applications such as education and design.

9.3.5 Images

Visual and other kinds of images play an important role in human thinking. Pictorial representations capture visual and spatial information in a much more usable form than lengthy verbal descriptions. Computational procedures well suited to visual representations include inspecting, finding, zooming, rotating, and transforming. Such operations can be very useful for generating plans and explanations in domains to which pictorial representations apply.

The explanatory schema for visual representation is:

Explanation target:

- Why do people have a particular kind of intelligent behaviour?

Explanatory pattern:

- People have visual images of situations.
- People have processes such as scanning and rotation that operate on those images.
- The processes for constructing and manipulating images produce the intelligent behaviour.

Imagery can aid learning, and some metaphorical aspects of language may have their roots in imagery. Psychological experiments suggest that visual procedures such as scanning and rotating employ imagery, and recent neurophysiological results confirm a close physical link between reasoning with mental imagery and perception.

9.3.6 Neural Connections

Connectionist networks consisting of simple nodes and links are very useful for understanding psychological processes that involve parallel constraint satisfaction. Such processes include aspects of vision, decision making, explanation selection, and meaning making in language comprehension. Connectionist models can simulate learning by methods that include Hebbian learning and backpropagation.

The explanatory schema for the connectionist approach is:

Explanation target:

- Why do people have a particular kind of intelligent behaviour?

Explanatory pattern:

- People have representations that involve simple processing units linked to each other by excitatory and inhibitory connections.
- People have processes that spread activation between the units via their connections, as well as processes for modifying the connections.
- Applying spreading activation and learning to the units produces the behaviour.

Simulations of various psychological experiments have shown the psychological relevance of the connectionist models, which are, however, only rough approximations to actual neural networks. In recent years, computational models of the brain have become biologically richer, both with respect to employing more realistic neurons such as ones that spike, and with respect to simulating the interactions between different areas of the brain such as the hippocampus and the cortex.

These models are not strictly an alternative to computational accounts in terms of logic, concepts, rules, images, and connections, but should mesh with them and show how mental functioning can be performed at the neural level.

9.4 Philosophical Relevance

Some philosophy, in particular naturalistic philosophy of mind, is part of cognitive science. But the interdisciplinary field of cognitive science is relevant to philosophy in several ways. First, the psychological, computational, and other results of cognitive science investigations have important potential applications to traditional philosophical problems in epistemology, metaphysics, and ethics. Second, cognitive science can serve as an object of philosophical critique, particularly concerning the central assumption that thinking is representational and computational. Third and more constructively, cognitive science can be taken as an object of investigation in the philosophy of science, generating reflections on the methodology and presuppositions of the enterprise.

9.4.1 Philosophical Applications

Much philosophical research today is naturalistic, treating philosophical investigations as continuous with empirical work in fields such as psychology. From a naturalistic perspective, philosophy of mind is closely allied with theoretical and experimental work in cognitive science. Metaphysical conclusions about the nature of mind are to be reached, not by a priori speculation, but by informed reflection on scientific developments in fields such as computer science and neuroscience. Similarly, epistemology is not a stand-alone conceptual exercise, but depends on and benefits from scientific findings concerning mental structures and learning procedures. Even ethics can benefit by using greater understanding of the psychology of moral thinking to bear on ethical questions such as the nature of deliberations concerning right and wrong. Goldman (1993) provides a concise review of applications of cognitive science to epistemology, philosophy of science, philosophy of mind, metaphysics, and ethics.

9.4.2 Critique of Cognitive Science

The claim that human minds work by representation and computation is an empirical conjecture and might be wrong. Although the computational-representational approach to cognitive science has been successful in explaining many aspects of human problem solving, learning, and language use, some philosophical critics such as Hubert Dreyfus (1992) and John Searle (1992) have claimed that this approach is fundamentally mistaken.

Critics of cognitive science have offered such challenges as:

1. The emotion challenge: Cognitive science neglects the important role of emotions in human thinking.
2. The consciousness challenge: Cognitive science ignores the importance of consciousness in human thinking.
3. The world challenge: Cognitive science disregards the significant role of physical environments in human thinking.
4. The body challenge: Cognitive science neglects the contribution of the body to human thought and action.
5. The social challenge: Human thought is inherently social in ways that cognitive science ignores.
6. The dynamical systems challenge: The mind is a dynamical system, not a computational system.
7. The mathematics challenge: Mathematical results show that human thinking cannot be computational in the standard sense, so the brain must operate differently, perhaps as a quantum computer.

Thagard (1996) argues that all these challenges can best be met by expanding and supplementing the computational-representational approach, not by abandoning it.

9.4.3 Philosophy of Cognitive Science

Cognitive science raises many interesting methodological questions that are worthy of investigation by philosophers of science. What is the nature of representation? What role do computational models play in

the development of cognitive theories? What is the relation among apparently competing accounts of mind involving symbolic processing, neural networks, and dynamical systems?

What is the relation among the various fields of cognitive science such as psychology, linguistics, and neuroscience? Are psychological phenomena subject to reductionist explanations via neuroscience? Von Eckardt (1993) and Clark (2001) provide discussions of some of the philosophical issues that arise in cognitive science. Bechtel et al. (2001) collect useful articles on the philosophy of neuroscience.

9.5 Cognitive learning strategies

As already mention in the previous chapter there is a predominance of the behaviourist approach in educational methodologies used in schools of practically all levels. Theorists like Chi and Rees (1983), Gagné Glaser (1987), Mandler (1985), Shuell (1986), among others, support that there are reasons enough to believe in the possibility that the cognitive approach may be adopted as the model of learning. In recent years, some experiments have already been carried out in such direction, but they are embryonic studies and do not really represent a clear movement towards the adoption of the cognitive psychology of learning (Pozo, 1999). However, already Lakatos (1978) developed an application of the behaviourist theory of learning which attempts to conciliate the issues of conditioning and repetition as bases for scientific research as a learning factor (fig. 9.1).

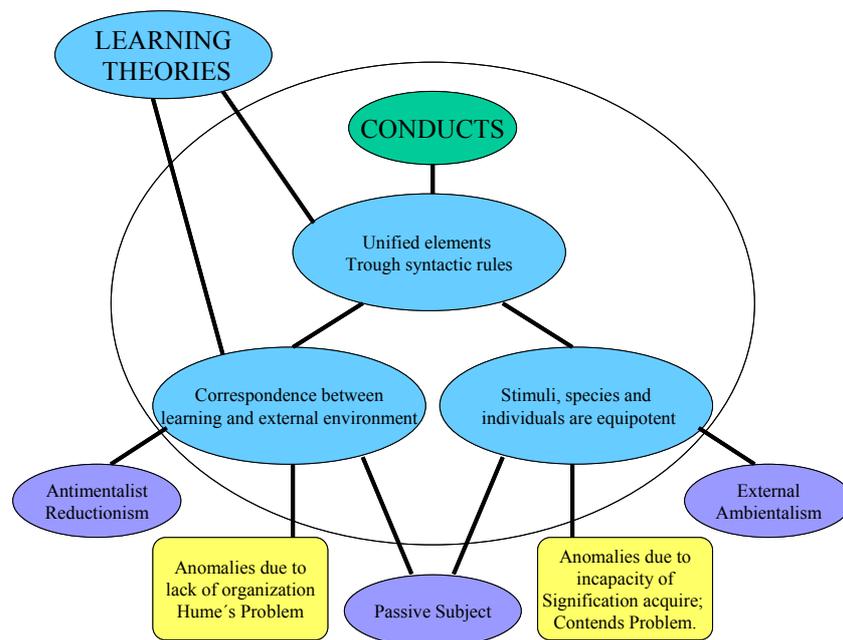


Figure 9.1. Behaviourism as a scientific research programme according to Pozo (1999)

One of the main criticisms to behaviourism is its incapacity to produce original theoretical responses. As a consequence, new programs are being elaborated, whose basic difference consists of a release of the behaviourist conceptual core, eliminating, mainly, the rejection of cognitive processes and increasing

information gathering (Pozo, 1999). The central concept of cognitive psychology, the basis of this new program, is broader than the concept of information processing itself.

According to Rivière (1987), "the most general and ordinary things we can say of Cognitive Psychology refers to the explanation of behaviour, mental entities, states, processes and definitions of mental nature, all which demand an unique level of speech". This means, therefore, that the actions of the individual are determined by his mental representations, according to some authors like Piaget and Vigotsky. Fig. 9.2, counter-pointing fig. 9.1, shows the strategy of scientific research according to cognitive psychology.

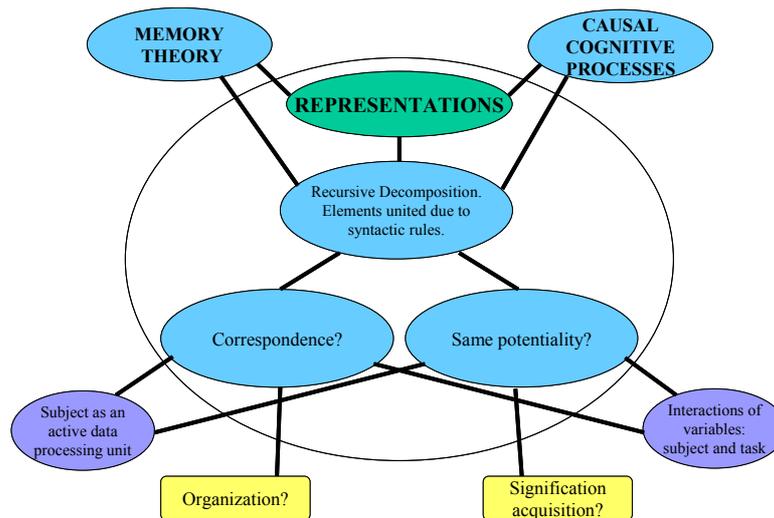


Figure 9.2. Information processing as a program of scientific inquiry according to Pozo (1999)

Thus, learning capacity would be determined by the way the individual represents his/her knowledge, together with his/her memory capabilities and his/her causal cognitive processes. To acquire these representations, the human being uses his/her mechanisms of assimilation as channels, understood here "as a broad sense of an integration to the previous structures" (Piaget, 1967) and uses, therefore, his senses as a door towards the perception of the external world together with the mental processes of information handling. The greater or minor effectiveness of this assimilation depends on learning factors, varying from person to person, and constituting learning strategies. These strategies take in account emotional, motivational, sensorial, and intellectual factors, or using a computer era terminology, logical-mathematical factors.

9.5.1 Emotional Factors

Goleman (1995), places the issue of emotional intelligence as a new type of ability, requiring a development of aptitudes natural to the "human heart". His theory appears in the context of a society with a rising increase of violence in practically all its forms (crime, suicides, drug abuse and other indicators of social distress); individualism, even as a consequence of social pressures, reaches an unprecedented exaggeration, causing, therefore, a growing competitiveness, mainly in the job market and academic

fields. This conjunction of factors brings the isolation and deterioration of social relations, generating a slow disintegration of community life and the need for self-confidence.

Placing this scenario under a learning perspective, it is inferred that emotional education - or, in other words, emotional learning - urgently needs to be rethought. The human brain has mechanisms to deal with emotions, but such mechanisms come from a biological evolution that goes back to the origin of life itself (Pinker, 1998). Our mental apparatus is prepared to face "wild" situations, as the ones experienced in a forest, but it has little power to confront rush hour traffic. Under the educator's point of view, it is important to be in harmony with the student's emotions and work the totality of the emotional repertoire. In our emotional repertoire, each emotion plays a specific function, as disclosed by its distinct biological signatures. Using new technologies that allow the exploration of the brain and the body as whole, researchers are discovering physiological details that enable the verification of how different types of emotions prepare the body for different types of responses:

In *anger*, the blood flows to the hands, making it easier to draw a weapon or to hit the enemy; the cardiac beats speed up and a wave of hormones, like adrenalin, among others, generate a pulsation, a strong enough energy for a vigorous performance.

In *fear*, the blood runs to the muscles of the skeleton, like those in your legs, facilitating the escape; the face is livid, since the blood is taken from there. At the same time, the body is paralyzed, even if for a brief moment, to perhaps allow the person to consider the possibility of, instead of reacting, running away to hide. Existing circuits in the emotional centres of the brain trigger the torrent of hormones that puts the body in general alert state, making it uneasy and ready to act. The attention is focused on the immediate threat, to better calculate the response to be given.

The feeling of *happiness* causes one of the main biological alterations. The activity of the cerebral centre is triggered, inhibiting negative feelings and favouring the increase of existing energy, silencing those that generate concern thoughts. But no particular physiological change occurs, except for a sense of tranquility, which makes the body recoup quickly from the stimulation caused by disturbing emotions. This pattern gives the body total relaxation, as well as energy and enthusiasm for the execution of any task and to achieve a great variety of goals.

Love, and the feelings of affection and satisfaction, implies parasympathic stimulation, which constitutes the physiological opposite that mobilizes one to "fight-or-run away" which occurs when the feeling is of fear or anger. The parasympathic standard, called "relaxation response", is a set of reactions that cover the whole body, causing a general state of calm and satisfaction, facilitating recovery.

The rising of eyebrows, in *surprise*, provides ampler visual sweepings, and also more light for the retina. This allows us to get more information on unexpected events, making it easier to perceive accurately what is happening, and to elaborate the best plan of action.

Around the world, the expression *repugnance* is similar and sends the same message: some thing is unpleasant to the taste or smell, either in actuality or metaphorically. The face expression of repugnance suggests, as Darwin observed, a primeval attempt to cover the nostrils to prevent a harmful odour or to spit out deteriorated food.

One of the main functions of *sadness* is to propitiate an adjustment to a great loss, like the death of somebody or some major disillusionment. Sadness causes a loss of energy and enthusiasm towards life's activities, in particular for diversions and pleasures. When sadness is deep, approaching depression, the metabolic speed of the body is reduced. It is possible that this loss of energy was caused to keep the vulnerable human beings in sadness state so that they remained close to home, where they felt safer.

This emotional diversity shown by Goleman demonstrates that there are moments and situations that propitiate more effective learning. An educational methodology that would provoke a feeling of happiness, or, at the very least, respect moments of sadness or anger, would have better conditions to form new mental structures and to more efficiently relate all acquired knowledge.

9.5.2 Motivational Factors

Motivation brings inlaid the concept of impulse for action and the maintenance of such action. Schank (1995) states that learning is a natural process that happens in the form of a "waterfall": first, the apprentice creates a goal, then generates a question and, finally, answers the question. This process brings implicitly the importance of motivational factors in learning: when there is a desire to learn to ride a bicycle, for example, a goal was created. During the process of "riding a bicycle", the apprentice will fall, loose balance or feel foolish, and all this will make him question exactly, even if internally, what he/she is doing wrong - why cannot he/she succeed in riding a bicycle? He/she will then look for answers to this questioning, and will learn.

However, Schank doesn't expose the initial motivational role: why would someone want to ride a bicycle? Also, following the same reasoning, why did the apprentice not give up when he fell for the first time? This motivation "to continue trying" is a consequence of the internal pressures generated by curiosity or challenge, both feelings of inadequacy. So, for the learning to occur entirely, a constant stimulation of the student's motivation is necessary.

To successfully keep the motivation, researchers develop new educational proposals, like self-orientation and personal effectiveness as educational goals (Barrel, 1995). This way, the students can make their own learning decisions, cultivating an existing desire in all human beings: independence (Goodlad, 1984). Another important motivational factor is the relevance of learning. Students learn more effectively when what they are being taught has direct relation to their reality, offering them a chance to become agents of their own lives (Freire, 1996). When professors add new information to the previous knowledge of the student, they activate his/her interest and curiosity, and apply their teachings with a sense of intention (Presseisen, 1995). It is not enough, therefore, to simply adopt the "natural waterfall" proposed by Schank. The teacher needs to show the student that it is good to get your feet wet, "to climb the waterfall".

9.5.3 Sensorial Factors

Senses are open doors to information in the world. All our knowledge comes directly from the mechanisms that we possess to absorb reality and to represent it. As a biological phenomenon, a human being has systems of perception capable of stimulating the brain to interact with the outside world, to

understand it or to modify it, as a way to guarantee the adaptation of the species. The quality of this perception varies from person to person, and from culture to culture. "To perceive is to know, through the senses, objects and situations (...) the act of perceiving can also be characterized by the limitation of information. It is perceived according to a perspective. The possibility of apprehending the totality of the object only occurs in the imagination, which constitutes, on the other hand, a form of organization of the conscience internally protected against error" (Greenspan, 1999).

Under this definition, there are some hidden basic aspects of learning. One of them is the limitation on the amount and the quality of information that can be perceived. This can easily be understood when we study, for example, Classic History. No matter how hard we read about the subject, no book will be able to transmit the feelings, the odours, the colours accurately, the social tensions and politics that existed at the time. Another aspect poses the question of perspective: one perceives what one wishes to perceive. In practical learning, this means that it is of little value to insist on teaching a pupil whose basis of knowledge differs from the professor's, since his/her perspective of the subject is another; it would be like trying to talk with a Chinese person without knowing how to speak Chinese. In this case, according to the concept of perception by Penna, there is no real perception of the object of study, but an inadequate mental construction that shelters the mind against error. In other words, "no human being (...) can dominate presented elements under a way not manageable by the nervous system" (Greenspan, 1999).

9.5.4 Intellectual Factors

For Piaget, all learning derives from mental relations of abstraction and balance. In other words, the human being is constantly seeking improvement of his/her higher reasoning capabilities. Thus, using mechanisms of assimilation, adjusting and adaptation, people learn through their mistakes and victories, analyzing them through mental operations and grouping relations. This process is what Piaget calls balancing mechanism.

It can also be included in the intellectual factors, the operations, the relations, the groupings, the construction of schemes and the structuring, all according to Piaget. In fact, such mental manipulations derive from the representation of reality that each one has. For Piaget, intelligence is constructed in continuous form, through processes of mental abstraction resulting from the relations between the individual and the object. These relations happen, in a higher form, as abstract operations that perceive reality associating mental structures and creating projects of assimilation of reality. That is where the denomination of intellectual factors comes from: its effectiveness depends on the logical-mathematical mental coordination, influenced by all the other factors, such as perception, emotion and motivation.

The importance of intellectual factors is as essential to determine the quality of learning as all other factors. Some educators tend to place too much emphasis on the intellectual aspects, forgetting, however, that these same factors depend upon a series of external circumstances (Antunes, 1998; Gardner, 1995). In other words, it is important to think, but the world is not only made of thoughts.

Learning, therefore, depends on a conjunction of dual factors, involving physical (sensorial and intellectual) and sensational (motivational and emotional) aspects, with complex relations between themselves and the external environment:

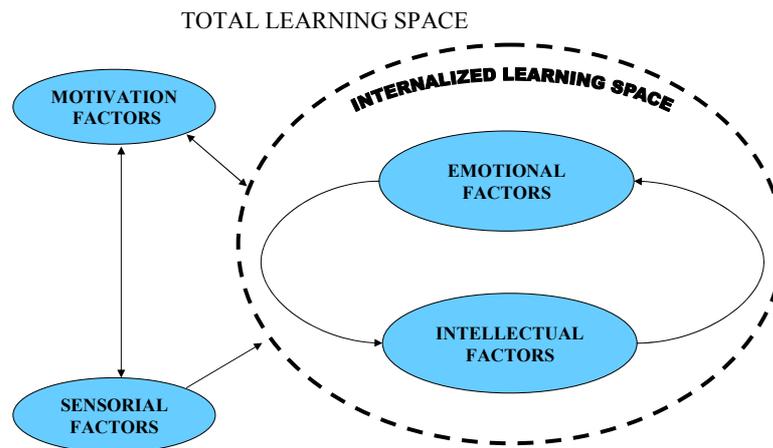


Figure 9.3. The interaction of factors in learning spaces according to Greenspan (1999)

Figure 9.3 considers the existence of two learning spaces: one that is internalized, where emotional and intellectual factors act more effectively; and a more general space, that allows more complex interactions between the individual and the environment, mediated by the motivational and sensorial factors. According to this reasoning, there is no learning without all the factors being involved, in greater or smaller degree, in the creation of knowledge (Greenspan, 1999).

Cognitive learning strategies can be understood as a conjunction of factors that define a variety of interactive ways responsible for the amplitude of an individual's knowledge. The knowledge of such factors (emotional, motivational, sensorial and intellectual) allows the educator to prepare all pedagogical content more efficiently and to offer his students, effectively, a much better learning process. These factors are also important in the creation of virtual environments. The experiences of Schank demonstrate the potential of a natural educational approach, but maintain the existence of these factors implicit.

The realization of their existence could define a new methodology of work in the construction of such environments, focused not only on natural learning, but also in the interaction between emotional, sensorial, motivational and intellectual factors in the formation of a permanent learning cycle, where the individual would be continuously motivated, moved, challenged, and sensorially interpellated, in a learning space full of stimuli and feedback.

Research in this area could find support in the theories of LeDoux, Goleman and Greenspan, regarding the emotional and motivational factors; in the Gestalt theories and in the biological foundations of the senses, for a more profound approach on sensorial aspects; in the studies of the cognitivists, like Piaget, Pinker and Pozo, about the intellectual aspects; and in the works of scientists on artificial intelligence, like Dennet, Schank and Minsky, among many others.

9.6 Representations and their debated status in cognitive science

Whenever a human cognitive system interacts with its environment, it is confronted with the highly complex, multidimensional, and dynamical structures of the world. The cognitive system has to solve a wide variety of tasks on different levels of complexity (e.g., from "simple" physical survival by searching for food to complex reasoning and problem solving in science). In other words, the interaction between a human and its environment can be described as the interaction between two complex dynamical systems; the goal is to establish some kind of stability inside the cognitive system (e.g., survival, epistemological and cognitive stability through successful predictions or manipulations of the environment, etc.) and between these two systems.

The topic of different forms of representation is not only interesting from a philosophical/epistemological and representational perspective, but it also touches on important issues in cognitive science, semiotics, and philosophy of science. Furthermore, it is highly relevant to many situations in modern natural sciences: every form of *visualization* or *graphical representation* (in physics, chaos theory, dynamical systems theory, chemistry, biology, computational neuroscience, geography, computer graphics, etc.) is an example in which different forms of representation are transformed into each other in order to facilitate the understanding or perception of a certain phenomenon.

Cognitive science and cognitive psychology (and, in fact, most approaches in epistemology) are based on the assumption that, in order to behave adequately in a given environment, the organisms must have some kind of *representation* of (at least) some parts of this environment. These representations are referred to as "internal representations", as it is postulated that they exist "inside the head". The common sense view of this claim suggests that the world (or parts of it) is represented in the form of symbols, propositions, sentences, mental images, semantic networks, etc. (e.g., Posner 1989; Newell et al. 1976, 1980; Kosslyn 1990, 1994) and an algorithm or some manipulation mechanism operates on these representations. These operations result in behavioural externalizations of the organism which then lead to the desired stabilities described above.

9.6.1 Definitions

One of the standard definitions of mental representations, which matches up with both philosophical traditional and current usage, was coined by Chemero (1998; 2000; Chemero and Eck, 1999).

According to this definition something is a representation if it shows one of the following three conditions (R1-3).

A feature R_0 of a system S (say, an organism) will be counted as a *representation for S* if and only if:

(R1) R_0 stands between a representation producer P and a representation consumer C (say, a part of the perceptual apparatus of S) that have been standardized to fit one another.

- (R2) R_0 has as its proper function to adapt the representation consumer C to some aspect A_0 of the environment, in particular by leading S to behave appropriately with respect to A_0 , even when A_0 is not the case.

- (R3) There are (in addition to R₀) transformations of R₀, R₁...R_n, that have as their function to adapt the representation consumer C to corresponding transformations of A₀, A₁...A_n.

Next to this, there are several features representations have: First, as mentioned above, since it requires a representation to have functions, it is *teleological* (R2). Second, it requires that the representation serves as a representation in the context of producing and consuming devices (R1). Combining R1 and R2, it can be said that something is a representation whenever it is one of several things that were designed to be used as representations by some agent (where 'agent' is intended to be neutral among humans, non-human animals, and machines). Third, it requires that a representation is part of a system of representations (R3). Agents must be able to represent more than one thing, else they should not be thought of as representing anything at all. Fourth, according to Millikan (1984) in focusing on the representation consumer in determining the content of a representation, it can be said that the content is the way the world would need to be for the behaviour caused by the representation consumer to be adaptive (R2). According to this definition of representation, *everything* that was designed to interact with its environment represents its environment. That is, one can argue that any system is representational, using the definition of representation outlined above, one that matches up with usage in cognitive science and philosophy.

In examining the emerging literature on internal/external representations three central characteristics can be abstracted, which can be considered as a useful analytic framework from which to explicate aspects of external cognition.

These are computational offloading, re-representation and graphical constraining:

1. *Computational offloading* - This refers to the extent to which different external representations reduce the amount of cognitive effort required to solve informationally equivalent problems.

For example, Larkin and Simon (1987) point to the greater efficiency in geometry problem-solving for diagrams over sentential forms through their ability to provide direct perceptual recognition of geometric relations. Explicitly representing the problem state in diagrams in this way enables solutions to be more readily 'read-off'. In contrast, solutions for the same problems represented as sentential descriptions typically are implicit and so have to be mentally formulated. This requires a greater computational effort.

2. *Re-representation* - This refers to how different external representations, that have the same abstract structure, make problem-solving easier or more difficult. For example, Zhang and Norman (1994) describe carrying out the same multiplication task using Roman or Arabic numerals. Both represent the same formal structure, but the former is much harder for people, used to working with the decimal system, to manipulate to reach the solution (e.g. LXVI11 x X is much more difficult to solve than 68 x 10).

3. *Graphical constraining* - this refers to the way graphical elements in a graphical representation are able to constrain the kinds of inferences that can be made about the underlying represented world. This characterisation is a term developed in recent work on the value of diagrams for solving formal logic problems by Stenning and colleagues (e.g. Stenning and Tobin, 1995; Stenning and Oberlander, 1995).

9.6.2 Research overview

Generally speaking it can be said that the term 'external cognition' is given to a range of different approaches which take as their central concern the relationship between internal and external representations. Within the last years there has been a move in cognitive science towards promoting the need to analyse the interaction between internal and external representations. This trend dates back to a special issue on situated action in the journal of Cognitive Science, in which Vera and Simon (1993) stress that, "A fundamental problem for cognitive modellers is to interleave internal and external states in order to achieve naturalistic behaviour" (p12). Norman (1988, 1993) has for several years been describing cognition in terms of 'knowledge in the head' and 'knowledge in the world'. Larkin (1989) has also shifted her thinking from Larkin's and Simon's (1987) earlier computational model of diagram use - that focused primarily on internal representations - to considering the role played by external displays in cognitive problem-solving. Reisberg (1987) was concerned with the functional differences between internal and external representations; in particular the computational power afforded by being able to externalise one's thoughts through writing them down and re-interpreting them. Hutchins (1995) discusses how various cultural artefacts that have become an integral part of work practices (e.g. specialised protractors for plotting positions on a navigational map) have evolved in such a way that they reduce the cognitive processing required by the operator to translate one form of external representation into another (e.g.. a numerical representation of a position into a point on a 2-D chart).

Others, like Cox and Brna (1995) have been examining specifically the cognitive effects of external representations in reasoning tasks. External representations, here, may refer to both linguistic and graphical forms. Scaife and Rogers (1996) also propose a new agenda for research on how different kinds of graphical representation are cognitively processed.

What most approaches have in common is an emphasis on the importance of external representations, and the goal of specifying in greater detail than previously how they are processed cognitively and how they offer support to problem-solving.

9.6.3 Various views

Within cognitive science there is currently a debate going on concerning the extent to which mental representations earn their explanatory keep. Fodor (1975), Clark (1997), and Markman & Dietrich (2000) (among others) have argued that representations are absolutely necessary. Brooks (1991), van Gelder (1995), and Keijzer et al. (2001) have argued that representations are an explanatory dead end.

In traditional cognitive science, most studies either exclusively focused on internal representations or, when taking external representations into account, often failed to separate them from internal ones. Thus, these studies often mistakenly equate external representations to internal representations, or equate representations having both internal and external components to internal representations (noted by Kirlik, Plamondon, Lytton, and Jagacinski, 1993).

A different view is that external representations are merely inputs and stimuli to the internal mind. In this view, even if it is the case that many cognitive tasks involve interactions with the environment, all cognitive processing only occurs in the internal model of the external environment (e.g. Newell, 1990).

Another approach emphasizes the structures of the environment and people's interactions with them without denying the important roles of internal representations. The situated cognition approach, for example, argues that people's activities in concrete situations are guided, constrained, and to some extent, determined by the physical and social context in which they are situated (e.g. Clancey 1993; Greeno & Moore 1993; Lewis 1991; Suchman 1987). In this view, it is not necessary to construct an internal model of the environment to mediate actions: people can directly access the situational information in their environment and act upon it in an adaptive manner.

As another example, the distributed cognition approach explores how cognitive activity is distributed across internal human minds, external cognitive artefacts, and groups of people, and across space and time (e.g. Hutchins 1995; Norman 1993). In this view, much of a person's intelligent behaviour results from interactions with external objects and with other people. For example Hutchins (1990 & 1995) showed that the cognitive properties of a distributed cognitive system consisting of a group of people interacting with complex cognitive artefacts (e.g. the cockpit of a commercial airplane or the control room of a military ship) can differ radically from the cognitive properties of the individuals, and they cannot be inferred from the properties of the individuals alone, no matter how detailed the knowledge of the properties of these individuals may be.

9.6.4 External vs. Internal representations

External representations are involved in many cognitive tasks, such as multiplication with paper and pencil, grocery shopping with a written list, geometrical problem solving, graph understanding, diagrammatic reasoning, chess playing, and so on. Within research it has become obvious that much can be learned about the internal mind by studying external representations. This is due to the fact that the structure of the internal mind is a reflection of the structure of the external environment (e.g. Anderson 1993; Shepard 1984; Simon, 1981). As argued by Zhang et al. (1993) external representations are not simply inputs and stimuli to the internal mind, rather, they are so intrinsic to many cognitive tasks that they guide, constrain, and even determine cognitive behaviour.

External representations can be defined as the knowledge and structure in the environment, as physical symbols, objects, or dimensions, (like written symbols or dimensions of graphs, etc.), and as external rules, constraints, or relations embedded in physical configurations (e.g. spatial relations of written digits, visual and spatial layouts of diagrams, etc.).

The information in external representations can be picked up, analyzed, and processed by perceptual systems alone, although the top-down participation of conceptual knowledge from internal representations can sometimes facilitate or inhibit the perceptual processes.

According to Zhang and Norman (1994) there are several properties of external representations. First, they provide information which can directly be perceived and used without being interpreted and formulated explicitly. Second, they can anchor cognitive behaviour. That is, the physical structures in external representations constrain the range of possible cognitive actions in the sense that some actions are allowed and others prohibited. Third, they change the nature of tasks. Tasks with and without external

representations are completely different tasks from a task performer's point of view, even if the abstract structures of the tasks are the same.

In contrast, internal representations are the knowledge and structure in memory, as propositions, productions, schemas, neural networks, or other forms. The information in internal representations has to be retrieved from memory by cognitive processes, although the cues in external representations can sometimes trigger the retrieval processes. An example of this would be multiplying 542 by 289 using paper and pencil. The internal representations are the meanings of individual symbols (e.g. the numerical value of the arbitrary symbol '5' is five), the addition and multiplication tables, arithmetic procedures, etc., which have to be retrieved from memory; while the external representations are the shapes and positions of the symbols, the spatial relations of partial products, etc., which can be perceptually inspected from the environment (Zhang & Norman. 1995). To perform this task, people need to process the information retrieved from internal representations in an interwoven, integrative, and dynamic manner.

According to Zhang (2000) external representations can be transformed into internal ones by memorization. However, this internalization is not necessary if external representations are always available and not possible if the external representations are too complex. In the same way, internal representations can be transformed into external ones by externalization.

9.7 Case study on external and internal representations in the 'Game of Set'

Virtual learning environments (VLE) were thought to become an important part of the strategy for delivering online and flexible learning. However, contrary to the expected breakthrough in learning strategies, relatively little use is made of those virtual learning environments. Therefore we carried out some case studies to examine the effects of PC game instruction techniques on training outcomes, which was defined as player's game performance after being exposed to various instructional methods.

The main focus was on examining which combination of instruction techniques resulted in a better performance in initial game playing and to investigate the effectiveness of the most common instructional methods currently used in VLE (such as text-based-, symbol- and audio instruction compared to java tutorial instruction).

We used the 'Set Game' for our research; a rather complex online available card game that combines several aspects of cognition such as perception, information processing and learning strategy.

9.7.1 The Game of Set

Set is also referred to as the family game of visual perception. It is a rather complex card game that combines several aspects of cognition such as perception, information processing, strategy, learning and time pressure.

Set is played with a deck of 81 cards, either alone or against other players; either with real cards or on the computer. For our study we asked test persons to play alone against the computer. As already mentioned above the crucial point about our research was that we had 4 groups of people which all received different kinds of instructions; varying in their instructional character:

Group 1	Static written text
Group 2	Audio-instruction read aloud
Group 3	Symbols
Group 4	Java tutorial

Figure 9.4. Representation groups

The Cards in Set have pictures made out of symbols on them that can be described by four attributes: colour, shape, filling and number. Each of the four attributes can have three possible values, blue, green and red for colours, rectangle, oval or squiggle for shape, solid, open or speckled for filling, and one, two or three for number.

The object of the game is to identify a 'Set' of three cards from 12 cards. In the game, twelve cards are dealt open on the screen. The player has 30 seconds to find a set of three cards; else the computer will uncover a set. A 'Set' has to satisfy the following rule: For each attribute, the three values that the cards have on this attribute are either all the same, or all different. That is to say, any feature in the 'Set' of three cards is either common to all three cards or is different on each card.

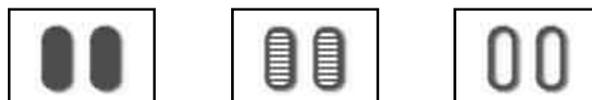


Figure 9.5. Example of a simple 'Set'

All three cards are red; all are ovals; all have two symbols; and all have different shadings.

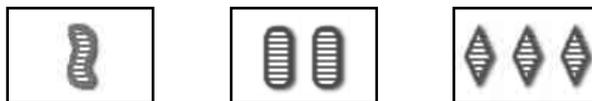


Figure 9.6. Example of a more complex 'Set'

All have different colours; all have different symbols; all have different numbers of symbols; and all have different shading.

9.7.2 Strategies in playing Set

First of all it has to be mentioned that one common experience among Set players is that there are easy and hard sets. Some sets seem to pop out as they are perceptually obvious, while others require extensive search to find. Easy sets are the sets that are perceptually similar: the sets in which three out of four attributes are the same. The hard sets are the sets in which all four attributes have different values. More precisely, we have three levels of difficulty: three, two, one or zero attributes the same.

Set players report that they use the following strategies in playing the game. The first strategy is a general method to find sets. In order to find a set, you first select two cards, and based on these two cards you determine what the third card should look like. For example, if the first card is one red solid oval, and the second card two red solid rectangles, then the third card has to be three red solid squiggles.

The second strategy is only applicable in specific situations. If there are many cards with the same attribute value, for example, eight out of twelve cards are blue, it is a good strategy to search for a set that consists of blue cards. The third strategy mirrors the second strategy: if there is only one card with a certain attribute value, for example a single red card, then search for a set with that card.

9.7.3 Brain functions involved in playing SET

As SET involves learning a rule of logic, players must invoke their 'left brain' thinking skills. Left brain thinking skills, such as logical thinking, are the ones predominantly taught in modern western society.

However, to find 'sets', players must examine the spatial array of cards and locate, in the overall pattern, the cards that satisfy the rule. To do this 'right brain' thinking skills must be used.

Right brain thinking skills are usually associated with spatial, intuitive thinking. These skills are usually underdeveloped. To effectively employ creative thinking the use of both left and right sides of your brain is required. Both right brain thinking skills and whole brain thinking receive little attention at school. They remain underdeveloped as we go through life because only a few occupations require them. Every time a 'set' is found, the whole brain of a person is used and his/her potential to be creative.

The main cognitive functions are attention, memory, language, mental imagery and executive functions. Actually the brain always has several functions working simultaneously (Lydia Kibiuk, 2003).

It requires:

- Complexity
- Diversity
- Variety

A task often calls upon attention, memory and language at the same time. To cope with complexity the brain has to combine a lot of information and simultaneously develop varied cognitive mechanisms.

Rapidity and accuracy are variable parameters depending on the person and task. Everybody has his own preferences, feels more at ease in some tasks and more efficient at others. This clearly shows that absolute performance is not significant. But most important, working on varied materials (words, numbers, pictures, objects) in various activities is what enables to really keep brain functions at the best possible

level. Finally, motivation and pleasure are fundamentals in acquiring an expertise or carrying out a successful mental work-out.

Variety is the best ingredient for your brain. This may not be very comfortable for some people, and may require some effort. The brain needs varied work to function at its best. Cognitive functions, and the psychological and emotional functions of people are constantly interacting. Thus, a person having a nervous breakdown will have less efficient cognitive functions.

The human brain has two hemispheres. Each brain hemisphere is divided into four lobes. The frontal lobe, located directly behind the forehead, is one of the four divisions of each hemisphere of the cerebrum. It helps control voluntary movement and aids higher intellectual functions, such as solving a math problem or planning an event. Damage to this lobe may alter a person's ability to execute plans and may make them inconsiderate or passive. It may also hurt movement. The temporal lobe is one of the four divisions of each hemisphere of the cerebrum. It is associated with speech, sound and complex visual perceptions. Damage to this lobe may result in an inability to recognize faces, even those of close family members. It can also result in dramatic hallucinations and loss of memory. The occipital lobe is one of the four divisions of each hemisphere of the cerebrum. It deals with vision. Damage to this lobe can harm eyesight, possibly even causing blindness. The parietal lobe is one of the four divisions of each hemisphere of the cerebrum. It plays a role in sensory processes, attention and language. Damage to this lobe may interfere with the recognition of touch and pain. It may also jumble knowledge of where the body is in space.

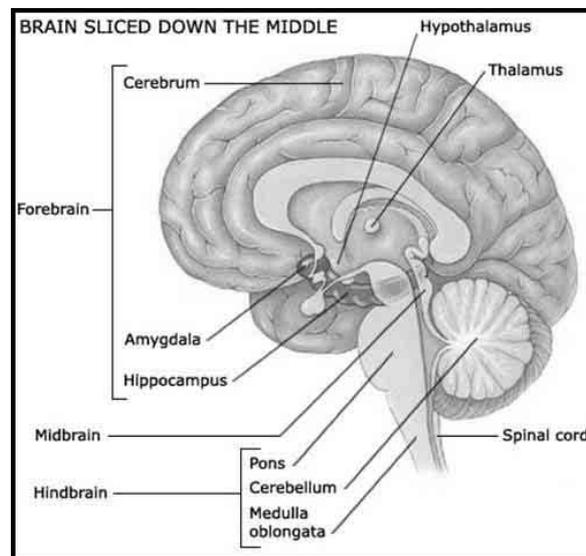


Figure 9.7. The main human brain areas according to Lydia Kibiuk (2003)

The forebrain carries out the highest intellectual functions, such as thinking, planning and problem-solving. The largest section of the forebrain is the cerebrum. The forebrain also includes the thalamus, hypothalamus, amygdala and hippocampus. The hypothalamus, a thumb-tip sized nerve cluster, performs more types of tasks than any other brain structure of its size. An essential coordinator of the central nervous system, it regulates body temperature and controls thirst and appetite. It also influences blood pressure, sexual behavior, aggression, fear and sleep. The amygdala, an almond-shaped nerve knot, is

involved with emotions. The sea horse-shaped hippocampus sits deep in the brain. It is involved in memory, learning and emotion. Damage to this area may result in memory impairment.

The cerebrum, the main upper mass of the human brain, fills the top of the skull. It is considered as the base of conscious mental processes. Resembling a giant wrinkled walnut, it makes up seven-tenths of the entire nervous system. The wrinkles greatly enlarge the amount of surface area that can squish inside the skull. If the surface layer of the cerebrum, termed the cerebral cortex, was smooth rather than wrinkled, the brain would inflate to the size of a basketball. The cerebrum is divided into two almost identical hemispheres. It is split lengthwise down the middle and connected deep down, near the center of the brain.

9.8 Measures

The data analysis of our study focused on the cognitive strategies followed by the users, their abilities in visual perception and logical thinking. To describe the mutualities and differences between these factors we applied the External Cognition framework (Scaife and Rogers, 1996). Using this framework we analysed how external representations, presented to users in various kinds of instructions, influenced the gaming task.

In order to understand the cognitive processing involved, it is critical to study the interaction between the information presented to the users and their internal representations. As already mentioned in previous chapters, works on graphical representation processing has emphasised the importance of studying the interaction between the internal and external structures as well as the cognitive benefits of different graphical representations.

Since graphical representations are a special case of external representation our approach was to apply the External Cognition framework for helping us understand the interaction in which we were interested. External Cognition refers to the cognitive interplay between internal and external representations; this refers to the process by which people integrate representations.

For example, reading and abstracting knowledge from a gaming instruction requires making connections between different elements of display in a temporal sequence, using both internal and external representations in concert. The framework allows us to identify the properties of external representations in terms of their 'computational offloading'. This refers to the extent to which different external representations reduce or increase the amount of cognitive effort required to understand or reason about what is being represented. High computational offloading is where much of the effort is offloaded onto the representation, requiring minimal effort on behalf of the user for a given task. In contrast, low computational offloading is where much cognitive effort is required by the user to perform his task. In our analysis we have identified two main forms of computational offloading.

These were:

- re-representation: this refers to how different external representations, that have the same abstract structure, make problem-solving easier or more difficult.

- graphical constraining: this refers to the way graphical elements in a graphical representation are able to constrain the kinds of inferences that can be made about the underlying represented concept.

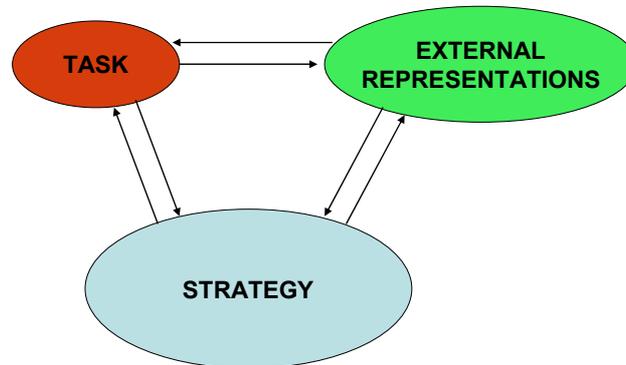


Figure 9.8. Model of the interaction between the users, their task and the external representations during the process of the case study according to Scaife and Rogers (1996)

9.8.1 Participants

Nine volunteers participated in the study. All of them were post-graduate students of the Danube University Krems at the centre of research and media, Austria. All of them were male, aged 33 to 47. The mean age was 42.07 with a standard deviation of 5.00. Therefore, the participants can be considered as a homogenous group.

Based on the literature reviewed on gender differences in video game performance (Sanchez-Ku and Arthur, 2000; Brown, Hall, Holtzer, Brown, & Brown, 1997), it was decided that only male participants would be included in the case study to prevent additional variance from gender differences on dependent measures. Results of the studies by Brown et al. indicated that male participants performed better in playing a video game than did the female participants with a comparable video game experience level.

All nine data transcripts were recorded, however due to missing sequences in the physiological data of one test person we had to drop out this candidate. In the following we will concentrate on the eight complete measurements. All test persons were teachers; according to their main subject four of them were maths teachers, three were English teachers and one was a computer science teacher.

9.8.2 Measuring procedure

Due to the exploratory nature of this study, we used observational methods with interviews, questionnaires and video recording. Both the interviews and the task performance were video captured. This approach, according to Pejtersen and Fidel (1998) proved effective for providing descriptive information about the participants' strategies in gaming. For recruiting persons the first essential criteria was that the game of Set was completely unknown to them; otherwise these persons were excluded from the study. Second, at the beginning of the data collecting process, we asked participants to fill in a PANAS (Positive and Negative Affect Scale; Watson, 1988). Then they were asked to consider their personal and usual learning strategies and to write them down for latter data evaluation. Afterwards, the

electrodes were applied to the test persons and the base line measures (1.30') started. Following these measurements, the test persons were given an instruction for playing Set.

Essential for our study was the subdivision of the test group into 4 subgroups according to instructional design, varying in its character:

- reading a text
- listening to text
- interpreting symbols
- java tutorial

All instructions were of same duration (2') and in English language.

After the specific instruction each test person was asked to transfer and explain its mental model concerning the rules of the game. Then the candidates were asked to play the online game against the computer. Finally, the candidates were once again asked to fill in the PANAS.

9.8.3 Physiological measurement

Different physiological measures have been found to be differentially sensitive to either global arousal or activation level, or to be sensitive to specific stages in information processing. The advantage of physiological responses is that they do not require an overt response by the operator, and most cognitive tasks do not require overt behaviour. Moreover, most of the measures can be collected continuously, while measurement is nowadays relatively unobtrusive due to miniaturisation.

Kramer (1991) mentions as disadvantages of physiological measures the required specialized equipment and technical expertise, and the critical signal-to-noise ratios. For the case studies we made use of electromyogram, electrodermal activity and temperature measurements. It can be stated that temperature rose during test time as expected and is therefore excluded from further analysis. The equipment used was from Thought Technologies Ltd.. Measurements took place at the Usability Lab of the Danube University Krems, Austria.



Figure 9.9 Usability Lab source DUK homepage (2004)

Generally, research related to processing demands as well as mental effort and the measurement of the electrical activity of task-irrelevant muscles (ElectroMyoGram, EMG) was previously directed towards limb-muscle activity, but is nowadays concentrated on the activity of facial muscles. Jaencke (1994) found no effect of emotionally charged stimuli on activity of the frontalis muscle. Compared with the

corrugator muscle, the frontalis muscle may for this reason be preferred for mental effort-assessment. The assessment of mental effort by facial muscle activity is a fairly recent development. The results cited above seem to indicate that facial EMG provides promising measures in the field of mental workload and was therefore one of the most important measurements used for our case study.

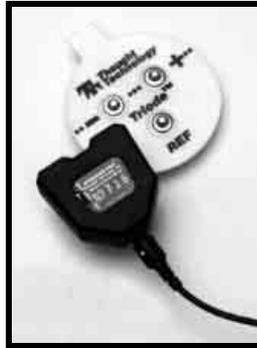


Figure 9.10. EMG-electrodes Source Thought Technologies Ltd. Homepage (2004)

Electrodermal activity (EDA) refers to the electrical changes in the skin. These changes are the result of ANS (autonomous nervous system) activity. In his review Kramer (1991) refers to several studies that show sensitivity of SCR (skin conductance response) to information processing. The main problem with electrodermal activity measures is a global sensitivity, or as Heino et al. (1990) state 'all behaviour' (emotional as well as physical) that affects the sympathetic nervous system (SNS) can cause a change in EDA. EDA was measured on the palm of the hand where SNS-controlled eccrine sweat glands are most numerous (Dawson et al., 1990, Kramer, 1991). Activity of these glands is sensitive to respiration, temperature, humidity, age, sex, time of day, season, arousal and emotions. The measure is therefore not very selective.



Figure 9.11. EDA-electrodes Source Thought Technologies Ltd. Homepage (2004)

9.9 Findings

We collected data from:

- 1) Questionnaires about positive and negative affects (prae and post gaming session)
- 2) Observational behaviour studies according to video recording

3) Learning and comprehension check.

First we summarise the information from the questionnaires. Following this, we will explain the main findings regarding the participants' cognitive strategies. Finally, we will highlight some of the problems and interpret them from the perspective of the external cognition approach.

All participants have shown themselves to be highly influenced by the External Representations presented to them. Therefore, the focus of our analysis is on the specific characteristics of the relationship between the internal representations and the external representations, and the cognitive processing involved. This is exactly the focus of the External Cognition framework.

As already mentioned, there were four subgroups of instructional design; the table below shows the effort of the candidates in relation to the varying instruction. As indicated in fig. 9.12 the worst gaming positions (white boxes) were taken by graphical constraining (symbols) and by java tutorial. Best ranks (dark grey boxes) were reached at the level of listening and java tutorial. Middle positions (light grey boxes) were held by reading and listening. The obvious contradiction was within the instruction of java tutorial, as results were among the best and the worst. However, it has to be mentioned that the emotional state of the test persons, their logical and perceptual abilities and the time of testing (morning vs. evening) may certainly influence the re-representational and gaming results.

instruction	position
	5
reading	3
	2
listening	4
	6
symbols	7
	8
java tutorial	1

Figure 9.12 Table of ranking according to instruction

The eight observed participants had different levels of education which were: college of education (white boxes), educational studies (light grey boxes) and post-graduate studies (dark grey box). It can be stated that the level of education did not influence the final result of the game, because lower educated participants were allocated among the best, the middle and the worst positions in gaming results.

position	education	score
1	4	14
2	6	9
3	5	0
4	4	-4
5	4	-4
6	4	-9
7	5	-9
8	4	-9

Figure 9.13. Table of ranking according to level of education combined with total game score

However, the candidates' fields of interest were of greater relevance for the result, as candidates in positions 1-4 were maths teachers. We attribute to maths teachers a better understanding of logic rules and of conclusion drawing.

Rank 5, 7 and 8 were held by English teachers. This was also relevant for the results, as all instructions were in English language. To complete the ranking it is to say that position 6 is kept by a computer science teacher.

According to the procedure of our case study, the next important aspect to consider was the comprehension check in which candidates were asked to recapitulate their internalized version of the instruction (external representation) received before. In doing so test persons received a blank sheet of paper and pencils in various colours.

comprehension	strategies	position
1	3	1
1	3	2
1	1	3
0	2	4
0	5	5
0	2	6
0	4	7
0	3	8

Figure 9.14. Learning strategies in combination to overall game comprehension and gaming position

The amount of cognitive effort required for understanding or reasoning about what was being represented differed among the instructional subgroups. We understood the comprehension check as an indicator for computation offloading. High computational offloading was where much of the effort was offloaded onto the representation; this was realised by the efforts of subgroups 'reading', 'listening' and partly by 'java tutorial'.

The different external representations mentioned, had the same abstract structure but obviously made problem-solving easier or more difficult. It can be concluded that the subgroup instructed via graphical constraining had the greatest difficulties in getting ideas about the underlying represented concept.

Figure 9.13 shows that the first three candidates were able to decode the external representation and to transfer their knowledge to the game of Set. All other participants failed in re-representation. The ranking of Set has to be considered as the result of the amount of computational offloading. For test person 4 to 8 it is to say that their most common strategy was mere trying around in order to find out the basics of the game. However, as indicated in figure 9.12, impulsiveness had a negative effect on total score.

When considering the answers on candidates' 'usual and personal learning strategies' it can be stated that those persons who had mentioned fixed and preferred strategies scored better, as they could better apply the information of the instruction to the gaming activity. Maybe this is due to the fact, that a person who is convinced of specified learning strategies acquires knowledge more easily.

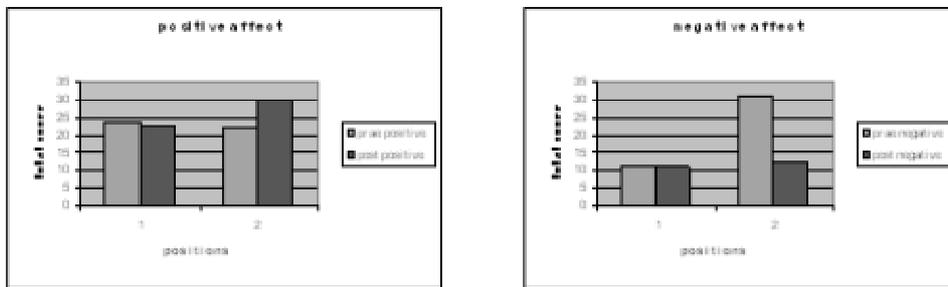


Figure 9.15. Table of ranks 1 and 2 according to pre and post measures of Panas

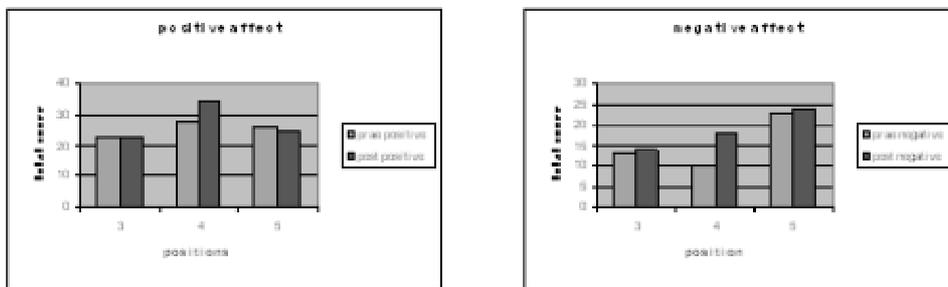


Figure 9.16. Table of ranks 3, 4 and 5 according to pre and post measures of Panas

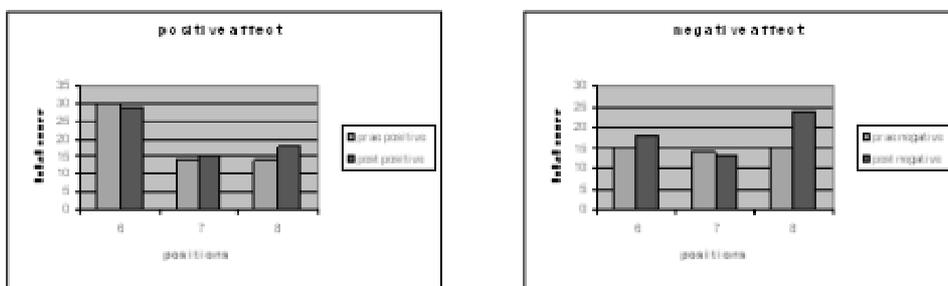


Figure 9.17 Table of ranks 6, 7 and 8 according to pre and post measures of Panas

As stated before we collected some psychological data with the Positive and Negative Affect Scale referred to as PANAS (Watson, 1988). This scale comprises two 10-item mood scales scored 1-5 to measure positive and negative affects during a given time period. Persons were asked to respond to given words describing emotions and feelings and to indicate to what degree they felt that way (1=very slightly, not at all; 2=a little; 3=moderately; 4=quite a bit; 5=extremely). Internal consistency coefficients range from .84 to .90. Test-retest reliabilities range from .39 to .71, with the higher coefficients reported for longer durations.

Relating to our case study, it was important to work on the totality of the emotional repertoire, as in this repertoire each emotion plays a specific function, as disclosed by its distinct biological signatures. Due to the fact that the PANAS enabled the verification of how different types of emotions prepared the body for different types of responses it was an important point of reference. Due to subjective impressions of the actual emotional state of the test persons and by combining subjective and objective emotional data, that is psycho-physiological measurements, it was possible to deduct some concrete ideas about emotional changes during the study task.

When focusing on various types of emotions that prepare the body for different types of responses, it can be said that persons in a rather negative pre-testing emotional state had relating low score results, while people in better emotional conditions were rather apt to form new mental structures and to relate all acquired knowledge more efficiently.

So in order to acquire representations, the human being has to use his senses as a door towards the perception of the external world, as mechanism of assimilation channels together with the mental processes of information handling. The greater or minor effectiveness of this assimilation depends on learning factors and constituting learning strategies. These strategies integrate emotional, motivational, sensorial, and intellectual factors.

Figure 9.13 to 9.15 show the PANAS results pre and post testing in direct relation for each person in its specific gaming position. Taking into consideration every single group no overall emotional tendencies can be concluded, as these vary from participant to participant.

9.9.1 Subjective and objective data according to instructional subgroups

In the upcoming instructions a comparison between objective emotional and mental data (physiology) as well as ranking is made. Similar to the subjective emotional results there are some convergences and differences in objective effort measurements according to the gaming (learning) process.

In the tables below we made use of following abbreviations, "b" referring to baseline measurement, "i" referring to instruction phase and "g" to gaming period.

a) Instructional design: reading - candidates 5 and 3 in ranking

Candidate 5 in ranking seemed rather cheerful at the beginning of the case study, but became increasingly tensed throughout the time of testing. During baseline he was relaxed. He had troubles with some words of the instruction, although he was highly concentrated. At the beginning of the gaming period he was

looking up help function although this was against the rules of the case study. He made the impression as he had neither got the point nor the rules of the game and was therefore rather frustrated.

The third candidate in ranking seemed rather relaxed and interested before testing. In the beginning of the relaxation phase measurement showed that he was rather nervous; but he quickly calmed down. During instruction he was attentive and concentrated, scrolling up and down the computer-based instruction. While playing the game he mentioned several times that he hated games with time pressure. As Set is a game involving the aspect of time pressure that allows each player only 30 seconds to choose a set out of the deck, the test person seemed rather tensed. However, he at the end of the game he seemed rather delighted with the total result.

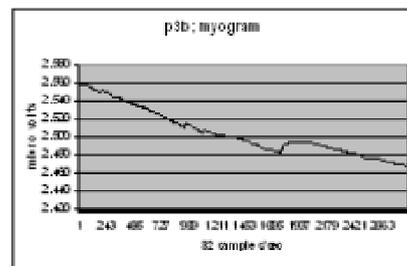
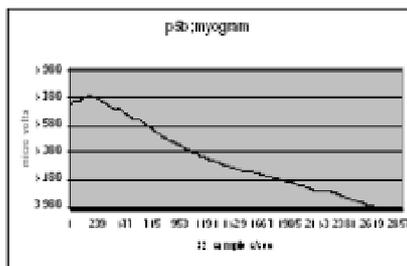
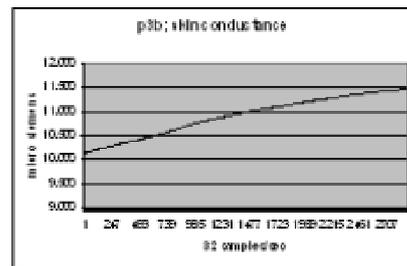
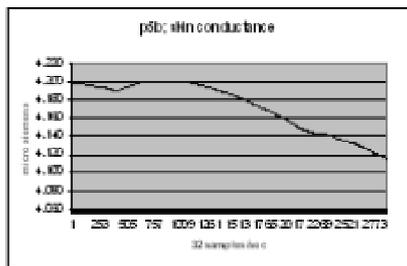


Figure 9.18 Instructional design reading during baseline

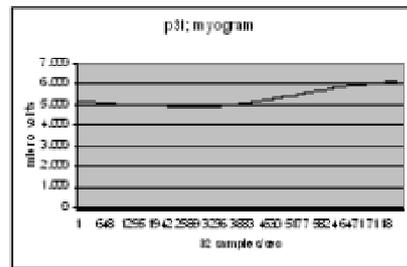
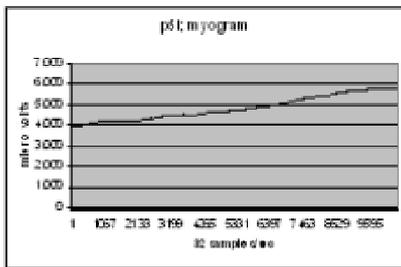
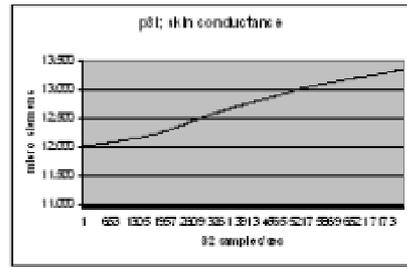
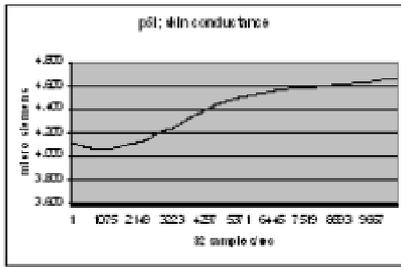


Figure 9.19 Instructional design reading during instruction

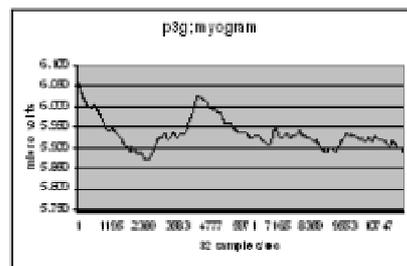
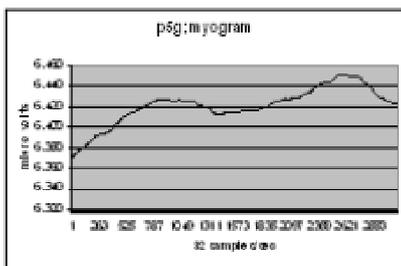
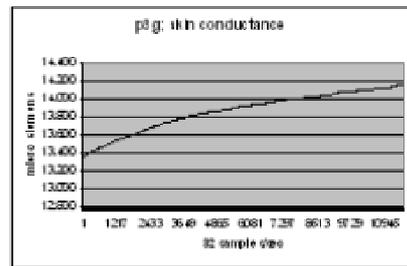
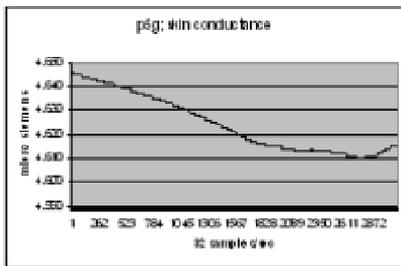


Figure 9.20 Instructional design reading during gaming

In subgroup one (reading instruction) only the instructional period is marked by emotional and mental correspondence as its values are increasing. In addition, the EMG of baseline and gaming measurement is corresponding.

b) Instructional design: listening – candidates 2 and 4 in ranking

Candidate 2 in ranking was calm and very serious. He was totally relaxed during baseline measurement. While listening to the instruction he was highly concentrated, thinking ambitiously and mentioned to have understood the game. His gaming phase is characterised by highly concentrated behaviour. The candidate gave himself some time to get the point of the game.

The sixth candidate proved to be well-balanced at the time of acquisition. The baseline period was marked by relaxation. During instruction he was very concentrated and serious. When playing the game he asked himself if he got the game instruction wrong. He commented his moves and questioned the moves of the computer.

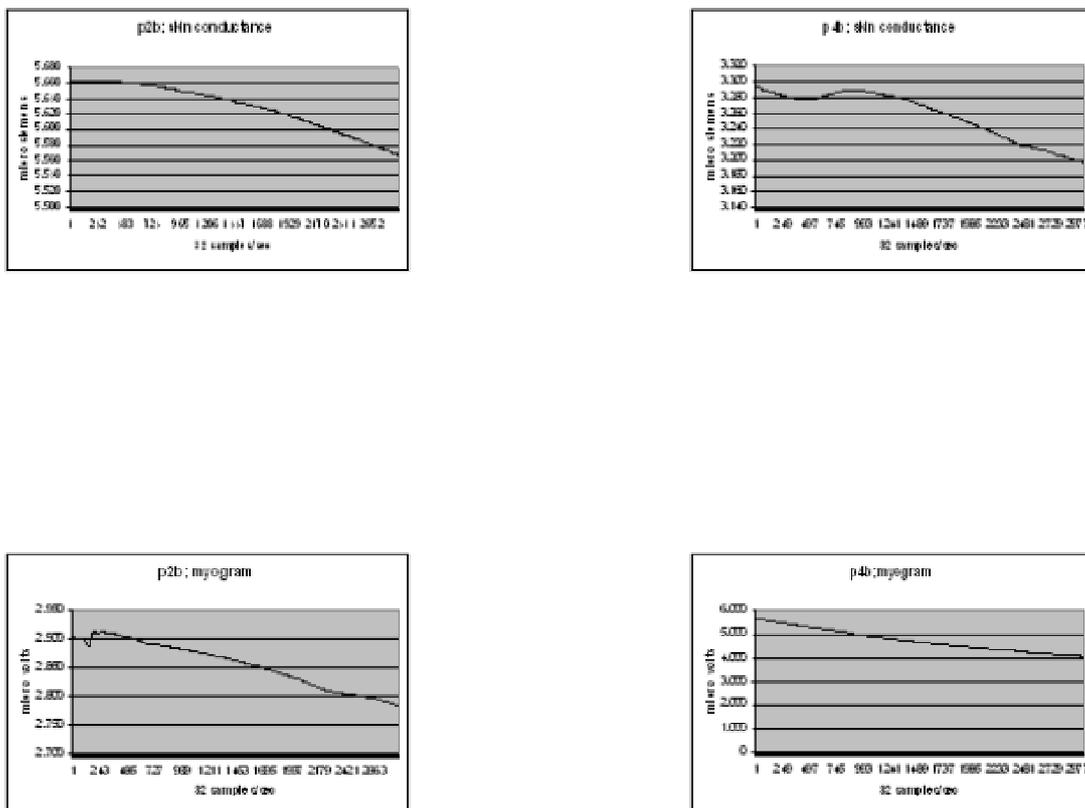
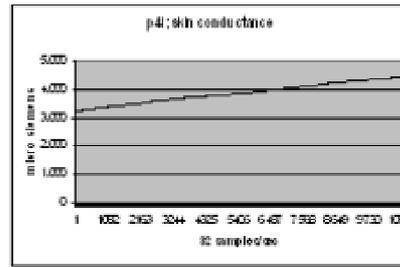
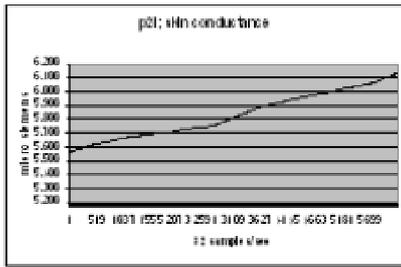


Figure 9.21. Instructional design listening during baseline



Test persons sharing listening instruction had convergent baseline measurements, as well as increasing data values concerning measured EMG data during instruction and gaming period.

c) Instructional design: graphical constraining - candidates 6 and 7 in ranking

Test person six seemed rather puzzled at the beginning of the case study. However, during baseline he was partly able to calm down. He observed the instruction in a rather concentrated manner, compared right to wrong sets and was thinking aloud. While playing the game he seemed rather desperate as the game was rather confusing to him. Like other bad performing candidates, he looked up help function, although this was against the rules.

Test person in final rank seven was rather expectant towards the case study. Baseline measurements showed him in a rather calm and relaxed state. He was rather attentive and thoughtful in trying to understand the instruction. Playing the game against the computer made him rather aggressive as he did not know what to do. He also tried to find out more about the game by looking up help.

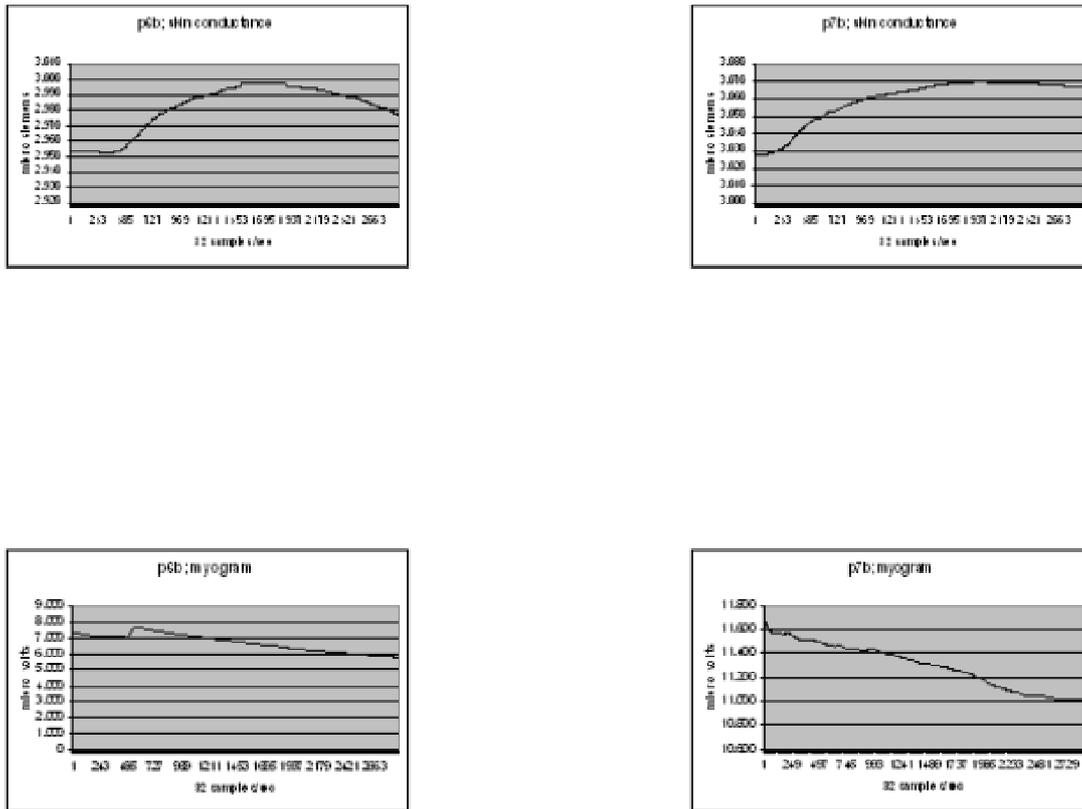


Figure 9.24. Instructional design symbols during baseline

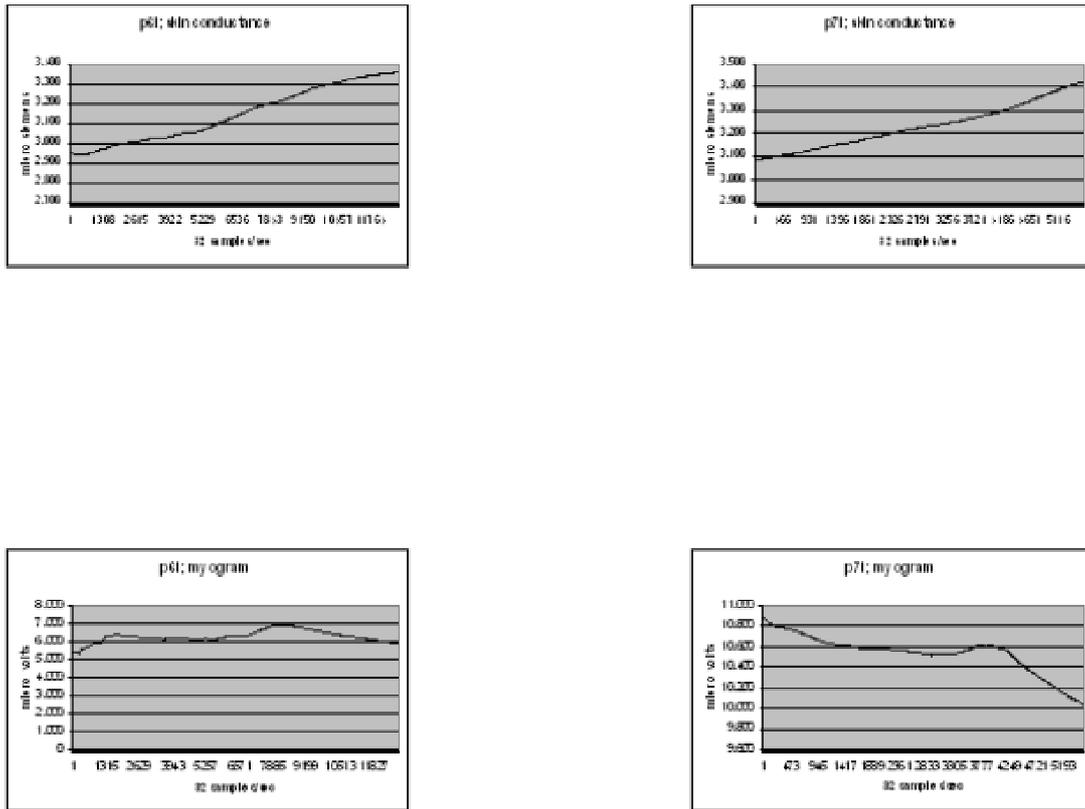


Figure 9.25. Instructional design symbols during instruction

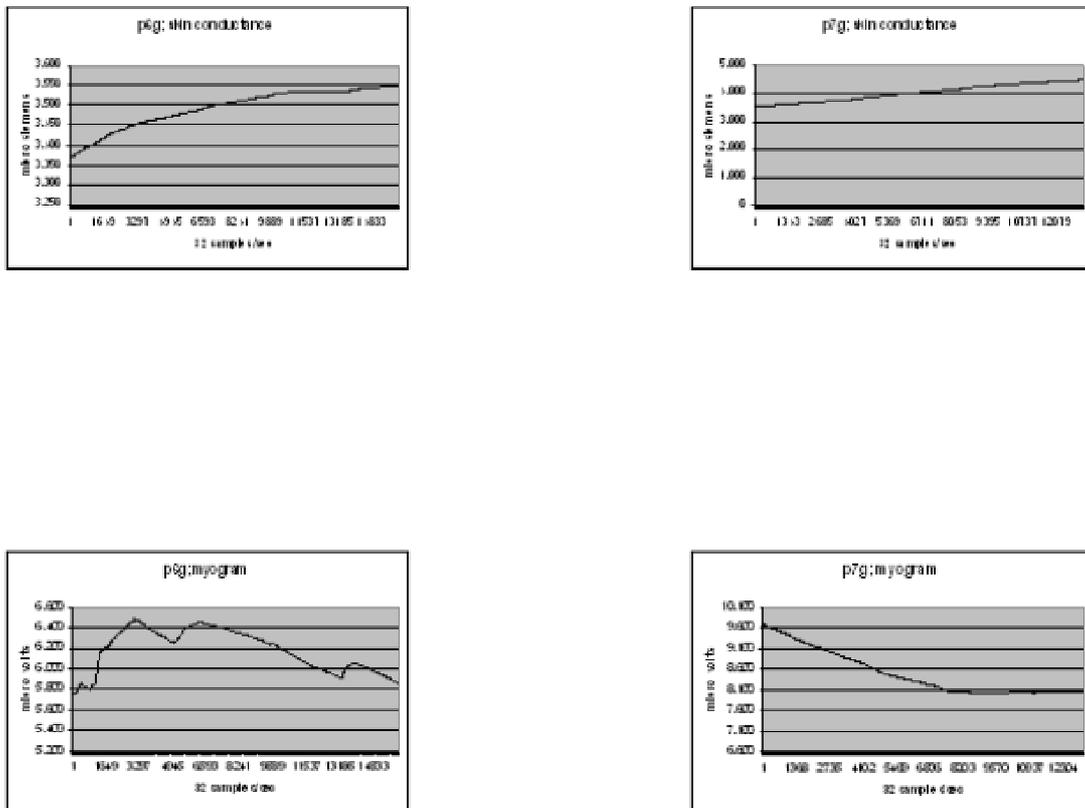


Figure 9.26. Instructional design symbols during gaming

Both candidates showed similar reactions according to baseline and EDA measurements during instruction and gaming.

c) Instructional design: java tutorial - candidates 1 and 8 in ranking

The best candidate in ranking seemed totally relaxed before and while testing. He was highly concentrated following the java tutorial. He made serious attempts in playing the game. The worst test person according to the total score seemed rather exhausted and tired. Baseline measurements showed him rather tired but relaxed. His lack of concentration prevailed in all measures. His behaviour can be described as rather frustrated and not motivated at all.

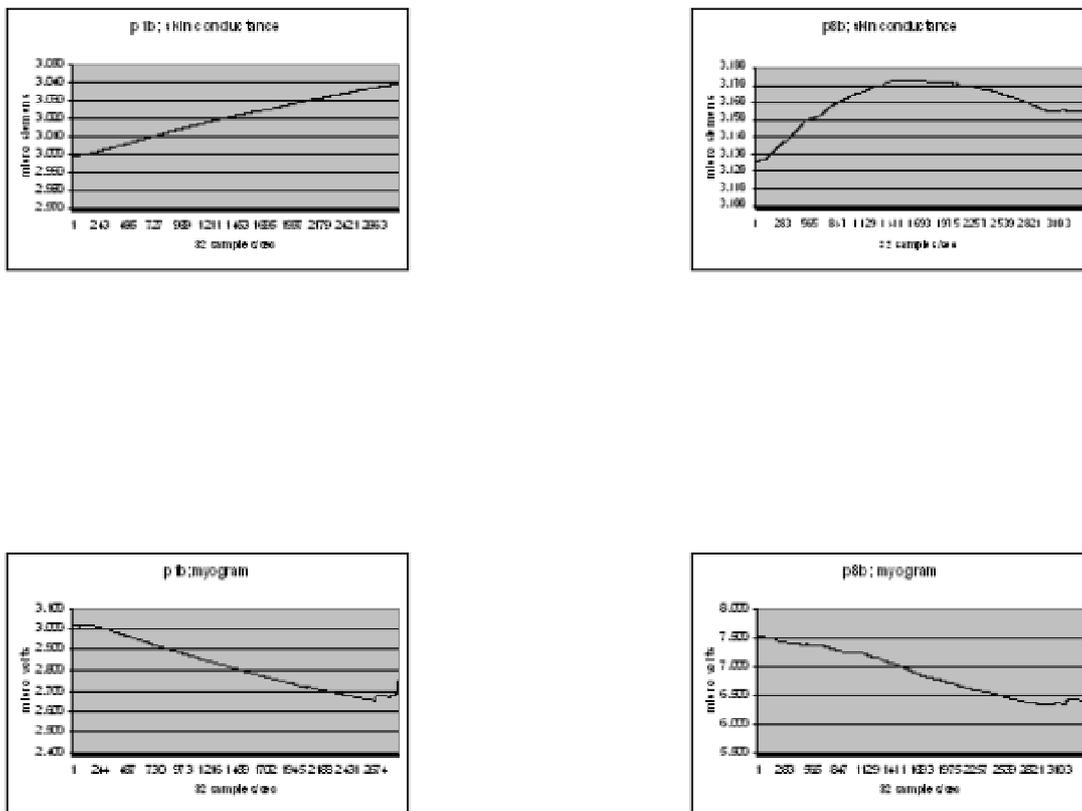


Figure 9.27. Instructional design java tutorial during baseline

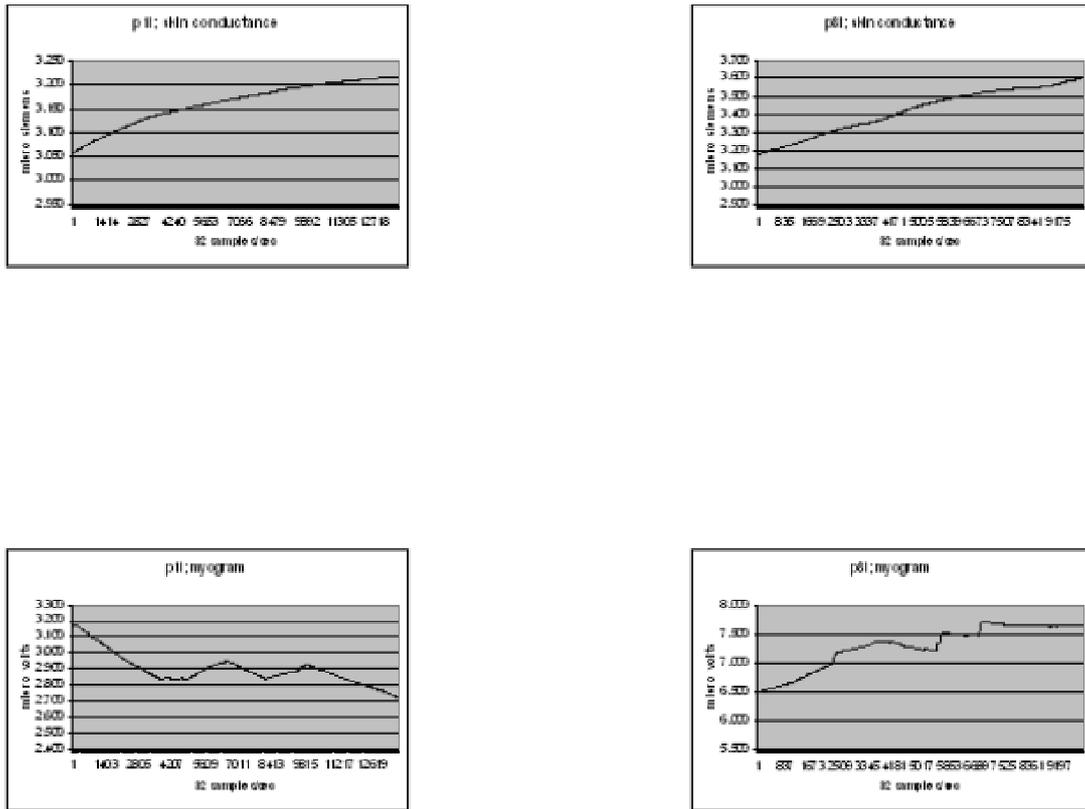


Figure 9.28 Instructional design java tutorial during instruction

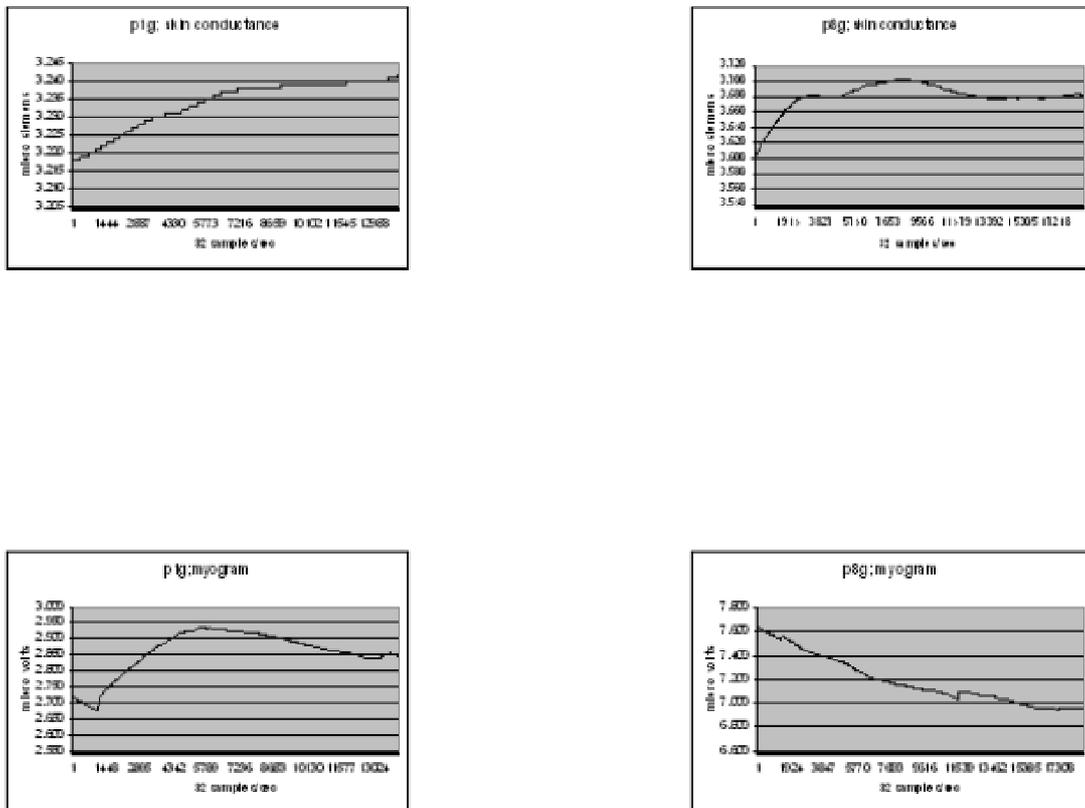


Figure 9.29. Instructional design java tutorial during gaming

Candidates showed a similar baseline as well as increasing values of EDA during instruction and gaming phase.

Overall comparison of three subgroups (listening, symbols and tutorial) showed an increase in EDA. This can be seen as an indicator of emotional reactions evoked by fear of failing, tension, pressure and scepticism about oneself. In addition growing EMG activity is within the framework of the case study obviously accompanied by better understanding and followed by high game scores. This interpretation is valid for all candidates but one (rank 2).

9.10 Conclusions

Summing up it can be said that the subjective and objective data proved helpful in reporting emotional and cognitive changes during re-representation and graphical constraining. Specifically we have found that the cognitive strategies developed by candidates depend on the various kinds of instructions. It can be stated that different instructional techniques seem to be effective in different ways. It can be said that only for candidate 1-3 in ranking computational offloading was realised. While for all other test persons, external representations presented to them did not lead to computational offloading.

The analysis guided by the External Cognition approach has proved to be useful in the analysis of the interaction between the participants' internal representations and the external ones.

We can not really recommend one of the four instructional techniques, because when they are used in solitude none really proved better than the other. In that sense multi-representational instruction certainly leads to the best internal representations. As can be deduced from our study listening and reading instructions certainly lead to good results, this implies for the participants of the relating instructional group that they were able to capture the underlying rules of the game in a more comprehensive way. Their strategies in finding a set were more elevated.

What is even more, the emotional state of persons certainly influences learning results. Higher cognitive functions of people may vary and are not evaluated enough. The time of the day also contributes to a good or bad attentional state, as people tested in the afternoon had lower results because of lacking receptivity.

The conclusion we drew from the physiological part of the study revealed that overall comparison of three subgroups (listening, symbols and tutorial) showed an increase in electrodermal activity (EDA). This can be seen as an indicator of emotional reactions evoked by fear of failing, tension, pressure and scepticism about oneself. In addition, growing electromyogram activity (EMG) is among the best test persons accompanied by better understanding and computational offloading.

A case study can only be seen as an indication of tendencies and interrelations and it should bring impulses for further research. For a more complex study of internal and external representations several further aspects should be included, as eye-tracking, thinking aloud, pretest of cognitive functions and visual pattern recognition as well as an extended physiological measurement like heart rate, electroencephalogram and breathing rate. Further research is needed to investigate in more detail cognitive strategies applied by test persons.

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CHAPTER 10: Case Study: Analysis of LEGO RoboLab Programming Environment in the Light of Different Representations

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Abstract. In this case study analysis of RoboLab programming environment will be made, in the light of methods and guidelines presented in Chapter 1. RoboLab is an iconic programming environment for programming LEGO Mindstorms RCX bricks, developed in cooperation between Tufts University, National Instruments and LEGO Educational Division. It is based on National Instruments LabVIEW™ software, and it targets groups of children in their classroom environment and in after-school activities. RoboLab itself is a very complex multimedia environment, allowing for programming on several levels of difficulty and including different instruction and inspirational material. This makes it a very interesting case-study for evaluating strengths and weaknesses of different external representation modes.

10.1 Introduction

Constructivism, pioneered by Dr. Piaget, states that knowledge should not be simply transmitted from teacher to student, but actively constructed by the mind of the student, as noted in (Mindel et. all, 2000) "Learning is an active process in which people actively construct knowledge from their experiences in the world", as Resnick states in (Resnick 1997). Seymour Papert, co-founder of MIT Media Lab, extends it to what he has termed the "constructionist" approach to learning (Papert 1980). Constructionism adds the idea that people construct new knowledge with particular effectiveness when they are engaged in building projects that are personally meaningful. Students construct their own knowledge effectively while building creations that interest and excite them, and encourage them to learn.

LEGO Company, the lead world manufacturer of plastic building bricks for children, accepts this learning philosophy while developing both toys and educational materials for children. All LEGO products are designed with belief that:

- Children learn best by doing or making, and
- Learning should be an enjoyable, as well as an educational, experience.

Thus, in close cooperation of LEGO Company and MIT Media Lab, LEGO Mindstorms RCX programmable brick was developed as a central part of a robotic construction set, and put on the market in 1998.

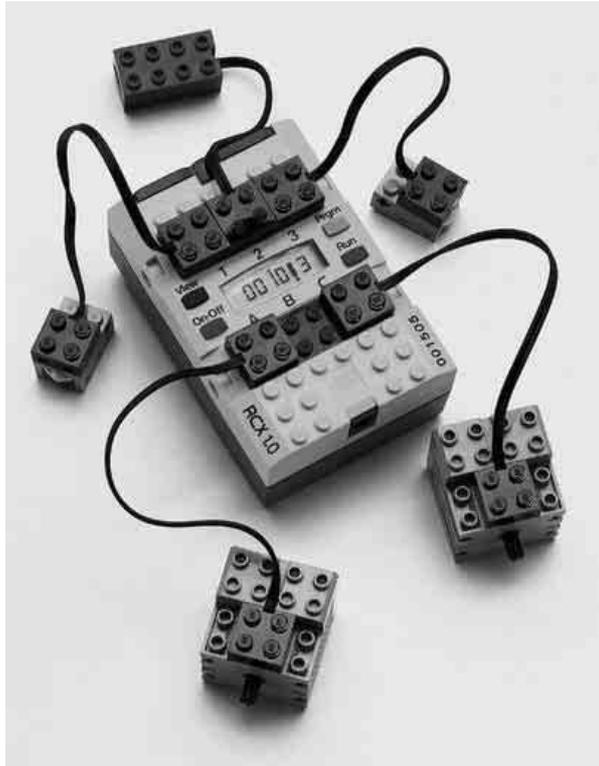


Figure 10.1. RCX programmable brick together with motors and sensors

The “brain” of LEGO® robots is a programmable brick, RCX. The RCX brick is a programmable microcomputer that can control up to 3 motors and take input from up to 3 sensors, when it executes a program made on a personal computer. LEGO offered two environments for programming RCX brick – Mindstorms, mainly for individual home use, and RoboLab, mainly for collaborative use in classroom environment or after-school activities. LEGO hobbyists, students and teachers throughout the world developed several other ways to program RCX, using specifically tailored languages like NotQuiteC, or general-purpose languages like C++ and Java.

This case-study will consider only RoboLab programming environment. Based on LabVIEW™, from National Instruments, Texas USA, the RoboLab Software uses an icon-based, diagram building environment to write programs that control the RCX.

The big idea in developing RoboLab was to empower elementary school children, as young as possible, to do some programming and engineering activities, otherwise not graspable for them, thus boosting their interest in technology and natural sciences. With RoboLab's customized user interface, designed for student users ages 8 and up, LEGO was aiming to bring the best values of constructionist learning approach to children and their teachers.

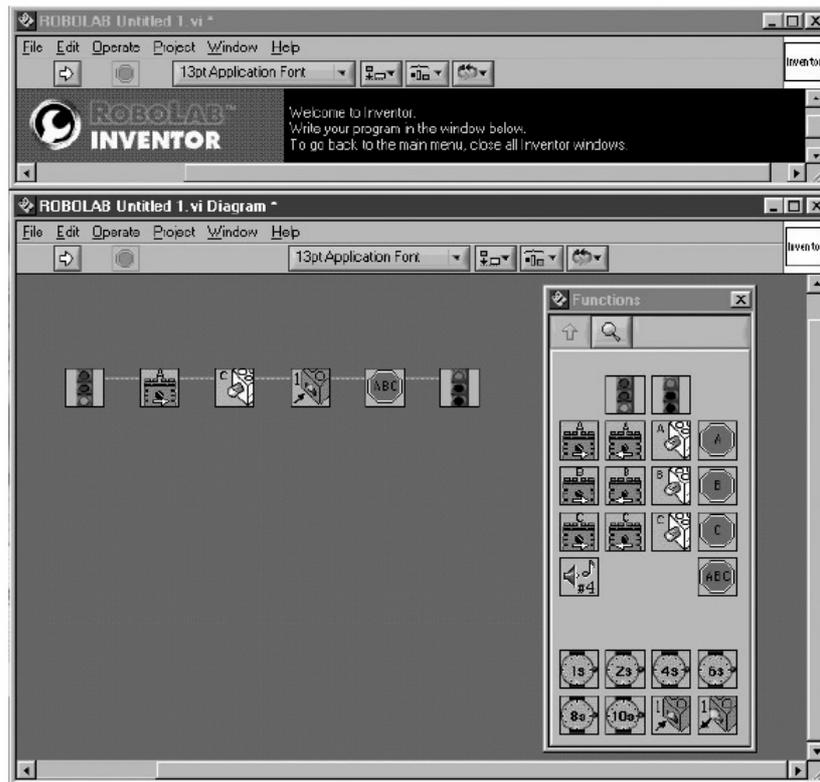


Figure 10.2. A sample screen of RoboLab programming environment

The workflow while building and programming robots using LEGO bricks and RoboLab programming environment is like:

- Users first build their invention using the RCX and the LEGO elements included in the LEGO sets.
- Then they create a program for their invention using ROBOLAB
- The program has to be downloaded to the RCX using a special Infrared Transmitter.
- Their fully autonomous creation can now be tested in direct interaction with the environment, and eventually modified/improved, starting again from the first or second bullet point.

This is very much in line how LEGO formulates its learning philosophy: "4C's" – Connect, Construct, Contemplate and Continue:

- Whenever some new challenge needs to be resolved, it is useful to **Connect** with some previous experience;
- Than users need to **Construct** the solution;
- While testing the solution, users should **Contemplate** what happened and why – it's not only about what went right and what wrong, but why happens what happens;

- Then the users should be empowered to Continue solving same or different tasks, but this time from the broader perspective, taking into account what they have just learned in the described process.

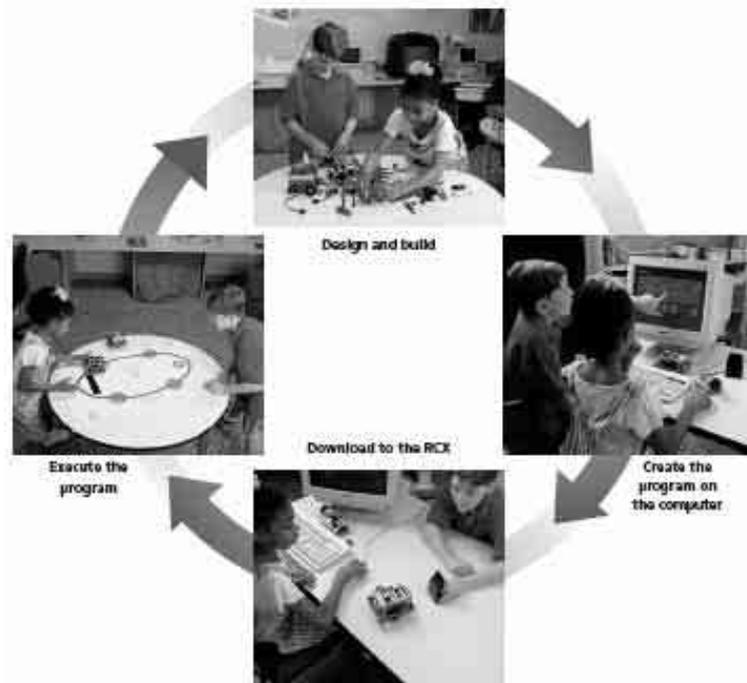


Figure 10.4. Workflow with LEGO RCX and RoboLab

RoboLab encourages this incremental-loop learning style, as it has progressive programming phases that allow the programming level to match the student's knowledge and skills.

PILOT is a basic environment where programs are built using a click-and choose interface. INVENTOR provides a more open-ended, icon-based environment. ROBOLAB INVESTIGATOR uses PIOLT and INVENTOR programming to incorporate data collection into projects.

Training Missions are also included in RoboLab environment. They are interactive audio and video tutorials for students and teachers to become more familiar with ROBOLAB programming. In addition, a detailed teacher's guide is available, in a form of a book or a PDF file on a CD.

10.2 Multiple representations in general in RoboLab

As said in Introduction, RoboLab is a programming environment for children, aimed to teach them some basic, and not only basic, constructing and programming skills. The idea is to connect programming with some immediate real-world feedback, thus giving children additional inspiration and motivation to go on with their natural curiosity to figure out how technology works. This connection of programming environment and real world object makes LEGO Mindstorms / RoboLab one of the most complex children toys ever – or, instead of “children toys” we could also say “multimedia learning object”, and be

true to the nature of the product. While both in a typical computer game and in a typical multimedia educational material the type of feedback system provides for users is in the best case restricted to simulation, in the LEGO's case consequences of working in virtual environment become visible in real world, giving more "tangible" meaning of what happens on computer screen.

The question which can be asked considering LEGO Mindstorm robot: is it an external representation (stands for something else – e.g. could be transcended to whole classes of robots or programmable objects) or is it an object itself (i.e. stands for itself only, without generalizations or transcending). Both views could be reasonable to accept, but probably with different consequences.

What is not questionable is that the whole Mindstorms constructing/programming environment is a multimedia one, including tactical, mechanical, textual with rich variety of textual representations, graphical, visual, audio, etc. In fact, it is very difficult to find some aspect of external presentations that is not, one or another way, present in LEGO Mindstorms / RoboLab constructing/programming environment.

This wealth of different presentations is exactly the cause of problems for users – where to start from, what to understand / learn first, how and where to proceed...

As said before, RoboLab is very rich multimedia environment, and all forms of external representations mentioned in Chapter 1 (section 1.1.3 External representations (ERs)) could be found somewhere in RoboLab environment.

Here are some of the examples of different representational codes used in RoboLab:

- textual;
- written text;
- speech;
- pictorial;
- animation;
- simulation;
- arithmetical;
- instructor-side generated;
- learner-side generated;

10.3 Description of the representation

10.3.1 The represented world

Represented world, in the RoboLab case, is a LEGO robotic construction itself, together with actual motors, sensors and a programmable brick, and with some behavior (program) downloaded to the programmable brick.

10.3.2 The representing world

Representing world is iconic-based graphical programming environment, supplemented with extensive and detailed help functions, as well as with simulations and films of real world LEGO robots.

10.3.3 Representational codes used

Literally all representational codes mentioned in Chapter 1 are used somewhere in RoboLab environment. For the programming itself, iconic programming language is used - graphical icons could be manipulated on screen. For help functions, combination of text, graphics and animation is used. For training missions (introduction how to use the system), film combined with narration and simulation is used. To indicate success/failure with communicating with physical robot, different audio feedback is utilized. There is also a digital camera included in the system, so the system also supports some basic picture analysis and modification. Some elementary music creation is also supported via combination of an interactive pictorial representation of a keyboard, 5-lines musical notation and audio feedback both from computer and the robot.

10.3.4 Modalities used

Aural and visual modalities of interaction with computer are widely used in RoboLab environment. Interaction with real robot (while downloading programs or adjusting mechanical construction to be able to make more convenient program) call for tactile modality too.

10.3.5 Aspects of the represented world being represented

RoboLab presents only behavioral part of the whole robotic construction. How is the robot actually constructed (i.e. how motors, sensors and special bricks – wheels, gears, etc. are connected together to make the robot) is not represented at all. Thus, if a program that controls actions of three motors is downloaded to a robot with two motors and one lamp, the lamp switching on/off will be controlled by commands for the motor to run or stop. This is in fact one of the most significant problems in the whole RoboLab environment.

10.3.6 Aspects of the representing world which are doing the modelling

Every active brick that can be part of a real robot (motors, sensors, lights, loudspeaker, digital camera, RCX bricks) has its iconic representation(s) in the programming environment. Icons can be connected in different structures. Timers, several events, interrupts... also have their icons. More abstract, non-physical objects, such as loop counters and containers for values measured by sensors (variables) also have iconic representation. Graphical design for some of icons has been questioned by users. Thus, main modeling tool in RoboLab are static graphical icons which could be manipulated and connected on the screen.

In training missions, robot's behavior is simulated and presented in film. For audio cover, narratives are used. While the usage audio is agreeably positive, it is questionable is the narrative representation the best for the given context.

10.3.7 Correspondence between the two worlds

This is a hard point in RoboLab programming. It needs to make correspondence not between two, but in fact between three worlds – real robot on the floor, program on the computer, and a user's idea how the robot should behave. As none of these worlds is complete representation of another, some message or meaning could be lost at any point, causing difficulties to proceed.

10.4 Types of representations to be used by students

All theoretically different representations mentioned in Chapter 1, namely:

- Concrete (pictorial imagery);
- Pattern imagery (depicting relationships);
- Icons or symbolic elements (numbers, expressions and formulae);
- Kinesthetic (manipulable) imagery (involving some kind of manipulation or activity);
- Dynamic imagery (including animations and also static representations structured so to express motion or transformation);

in one or another way exist somewhere in RoboLab environment. Only one example will be discussed here, others will be presented later in text, when they become important for theoretical issue discussed.

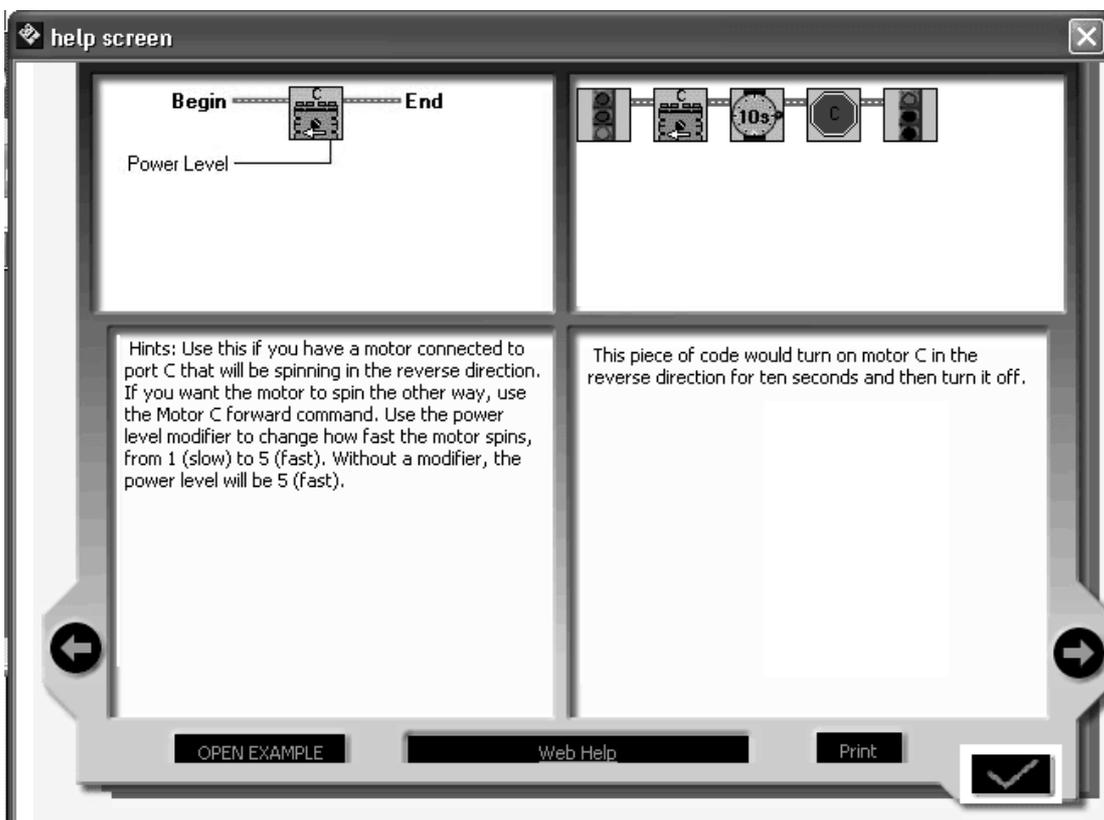


Figure 10.4. Using different types of representations in RoboLab Help

Figure 10.44 shows a nice example of using multiple representations in Help functionality of RoboLab. Picture in the upper left corner replicates the icon needed to be explained. Upper right corner gives a pictorial example of a small, but complete program where the icon could be used. Lower left part textually explains several possible usages of the icon, and lower right part textually explains the given example program. Black buttons with green text/images are action buttons – for scrolling help forwards and backwards, for opening the example in the programming environment, so it could be downloaded and tested on a real robot; for looking for more help on the web (linking to default LEGO Educational web page on <http://www.lego.com/eng/education/mindstorms/default.asp>); for printing the help and for exiting this window. In RoboLab environment there is additional form of action, not existing in computer-only multimedia environments. It is downloading the program to actual robot and testing on real system. We could agree that testing on actual system is not representation, it is the reality. But the physical process of downloading the program to the RCX has its graphical representation with visual/audio feedback on computer – and this process is often confusing for users, thus it is calling for appropriate representation.

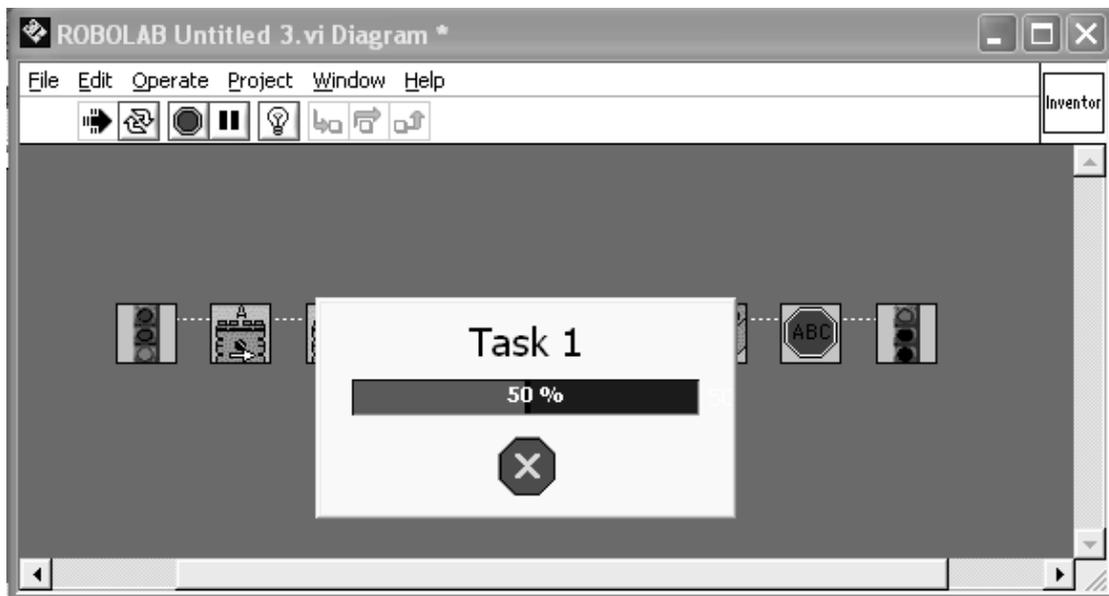


Figure 10.5. Dynamic slider to indicate progress of the program downloading process from PC to RCX

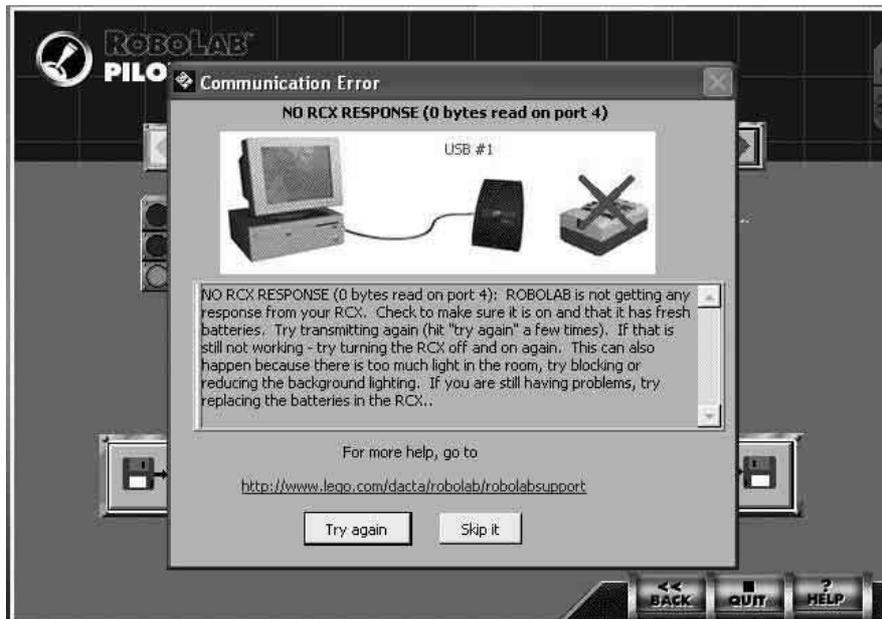


Figure 10.6. Representation of downloading failure – combining picture, text and sound

Downloading progress is dynamically represented with animated slider, which shows the percentage of the program code transferred to RCX. End of successful download is marked with an audio signal. Download failure is marked with another signal, and graphical/textual warning and some help how to proceed.

10.5 Equivalence of representations

There are both non-equivalent and equivalent representations in RoboLab environment. Obviously, representing different aspects of environment (instructions, actual programming, help functions) call for different, informationally non-equivalent representations. Graphical, iconic, representations for same actions on different complexity layers of RoboLab are different – being examples of informationally equivalent representations.

10.6 Affordances (roles) of the representations

There are different affordances (roles) that the representations in RoboLab are expected to provide:

10.6.1 Describing a given text

Opposite, in RoboLab environment text is used to explain pictorial icons and their connections.

10.6.2 Summarizing the available information

Help functionality, together with numerous examples, is an example of a trial to organize needed programming knowledge.

10.6.3 Structuring the reasoning activity

This is what iconic programming environment is trying to do for users, who are not expected to know anything about programming before they start to work with RoboLab. Lots of different icons are grouped according to their functionality. While experimenting with icons from one group the users should become aware that they are dealing with a certain class of activities. When they feel a need from an icon from another group, that should be an indicator that now a different action is performed.

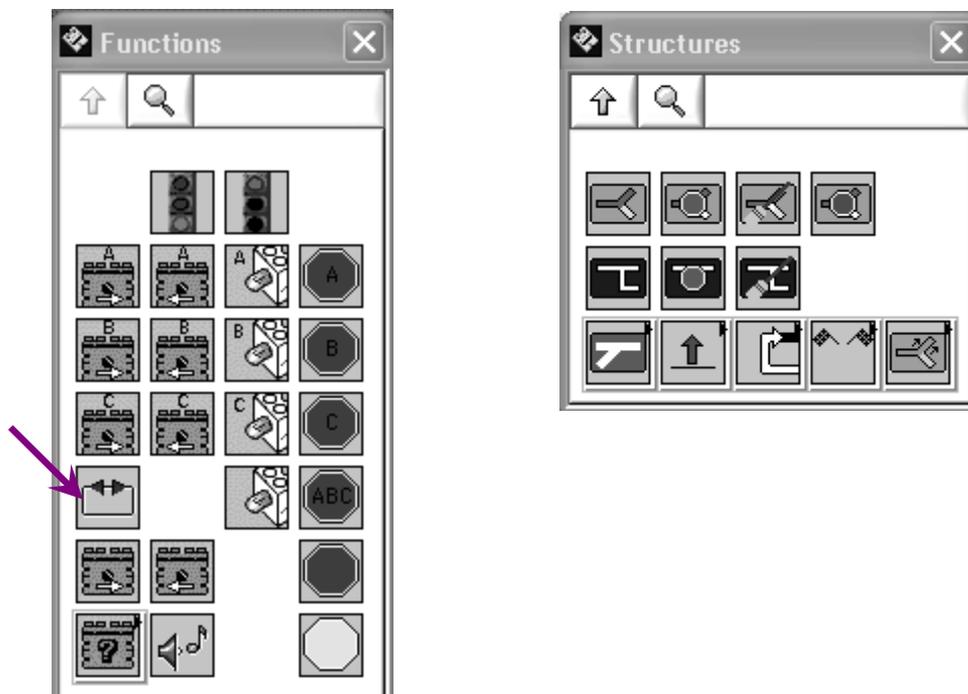


Figure 10. 7. Examples of different groups of programming icons - function icons which start or stop certain activities, and structure icons, which control the program flow

Figure 10. 7, while illustrating structuring the reasoning activity by grouping presentations for different actions into different groups, also points to one of concrete weaknesses of the actual realization. Look at the icon marked with a purple arrow. It belongs to a function group of icons, and in fact it is a functional icon – it causes the motor after which it is attached to reverse its direction – but with its line-arrow-like appearance it looks like a structural icon, thus providing a visual confusion for the users. The conclusion should be that while creating any representation, the designer should be very careful not to give the wrong clues.

10.6.4 Unblocking the mental activity of weaker students during problem solving

RoboLab Help, with its textual and graphical presentations, as well as concrete small programs which could be downloaded and tried, is an excellent example in this field. See Figure 10.4.

10.6.5 Supporting Conjectures

Built-in examples of functioning programs that could be downloaded and tried on real-world objects, as well as having the freedom to test immediately whatever is written, should boost this activity. In fact, the whole LEGO Mindstorms / RoboLab idea is based on learning by doing, by trial and error and on paradigm "hands on – minds in".

10.6.6 Supporting the construction of proofs

This is not the area RoboLab environment is meant to be. Everything is about empirical results.

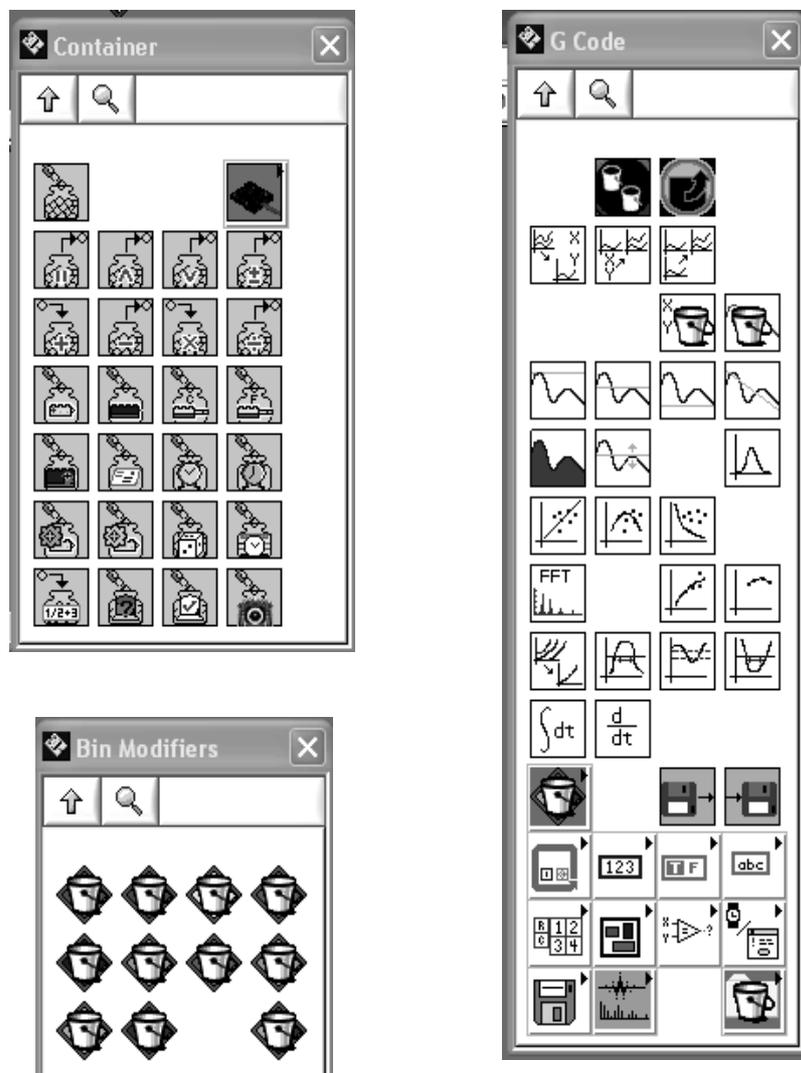


Figure 10.8. Icons for abstract objects - containers for measured sensor data. Values in different containers can be compared, or different arithmetic operations could be performed on them

10.6.7 Limiting abstraction

This is the area where RoboLab tried to make a significant contribution. First, very abstract mental activity such as programming is made possible even for very young children by using iconic graphical language instead of textual one. There are reports of meaningful usage of RoboLab even for 6 years old children, (Kearns et al, 2001). On lower Pilot levels, just a few programming icons are available, only those that are absolutely needed for basic motions, thus making it impossible to construct a program that does not function at all – it is possible that the program will not do exactly what the child wanted, that is the worse that could happen. As user’s experience and knowledge grow, more and more of programming tools are exposed to him, on higher Inventor and Investigator levels. On the highest level, practically the full power of LabView, complete professional programming environment for adult professionals, is revealed for the user.

Another example where RoboLab tries to limit abstraction and make concrete graphical representations for abstract object is data manipulation in Investigator. It is known that graphical representation of functions is something not quite intuitive, and that children age 10-12 have difficulties to understand it on mathematics classes. RoboLab offers concrete representations for data – containers for setting variable values, and buckets for sets of data loaded from sensors. Collected sensor data could be manipulated later on. See Figure 10.8 for iconic representations of containers and buckets. The sample program for data logging is on Figure 10.9.

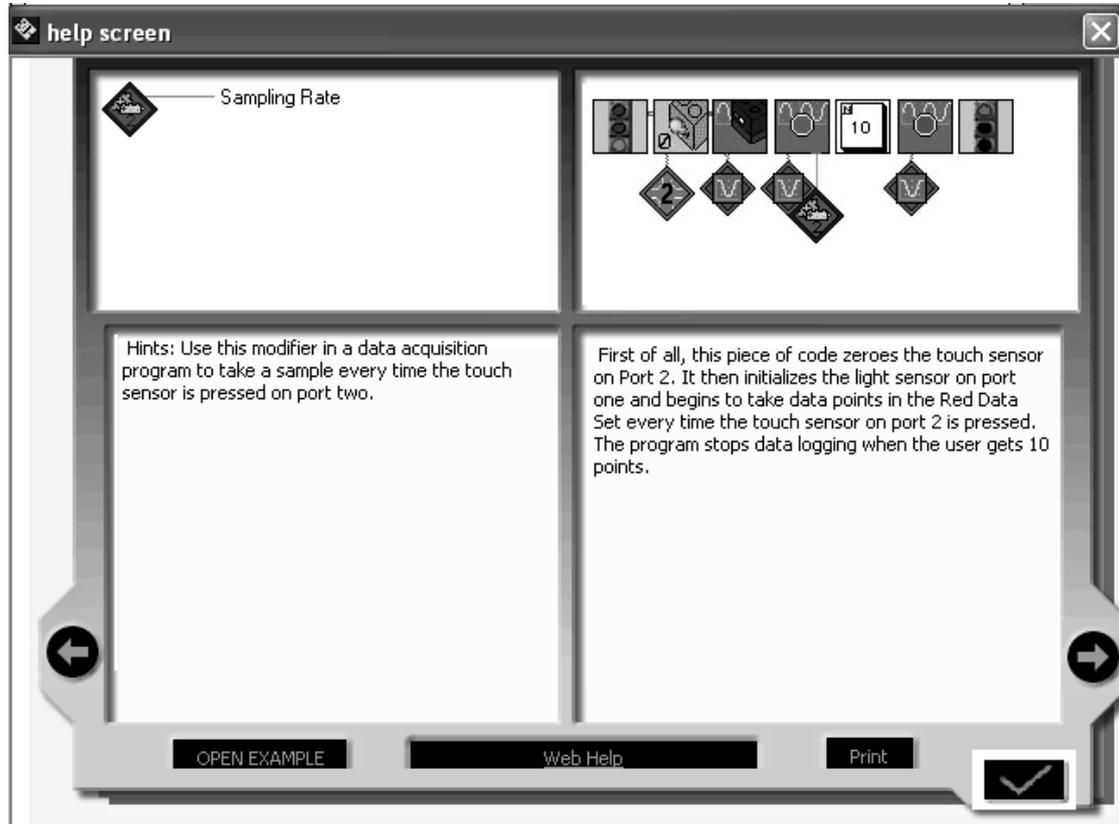


Figure 10.9. Representation of a program which collects data from the light sensor

Screen for dealing with collected data is presented on Figure 10.10, and available ways of graph representation on Figure 10.11.

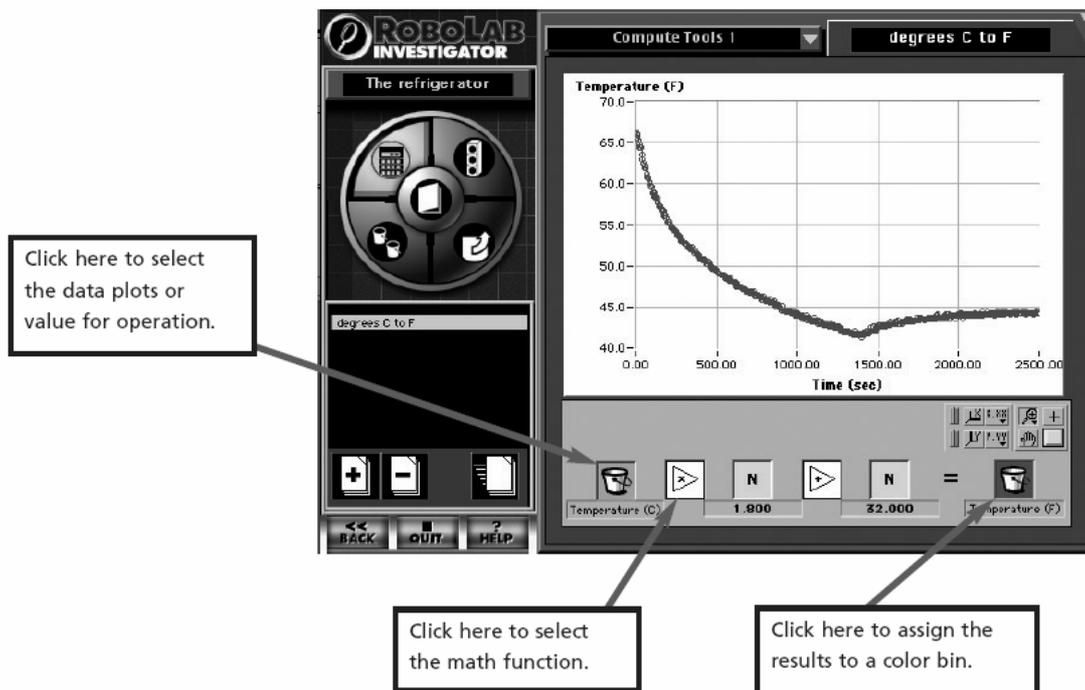


Figure 10.10. Processing data collected in a green bucket, and drawing data from a violet bucket

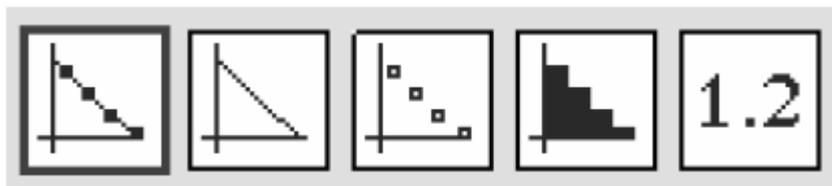


Figure 10.11. Icons for different ways of plotting graphs. Value "1.2" on the last icon indicates textual, numerical representation of gathered data

Another powerful feature of Investigator layer is ability to draw data while they are being logged, thus allowing for real-time construction of a graph. It is also possible to draw phase graphs of several measured data, as well as do mathematics operations like differentiation, integration or different mean values. Figure 10.8 and Figure 10.10 should give an idea what is possible.

There are several physics /chemistry / biology curriculums developed around this environment for middle high schools (for example, Erwin 1998). They report increased level of learning and, of course, great student's satisfaction, enthusiasm and fun during the process. However, this is still an activity where teacher's help and guidance is needed, in spite (or just because of!) of all the wealth of multimedia presentations used.

10.7 Reasons for using representations of a real system

None of theoretical reasons to use representations of real system mentioned in Chapter 1 in fact implies to RoboLab. RoboLab uses the real system as the object of control. It uses graphical representation of programming activity, because programming is too abstract for children. By using icons for different programming actions, simulations, text and graphic for help and inspiration materials, we hope to make this very abstract mental activity more available to children capabilities and interests. Thus, we could say that in RoboLab representation is used as an educational approach to empower the users to perform activities otherwise out of their abilities.

10.7.1 Most significant reasons for using simulations

Again, none of mentioned theoretical reasons to use simulations applies to RoboLab. However, RoboLab is using simulations in its Training Missions (simulating the ways certain programs could be developed), for training users how to use the system. Thus it could be said that simulations are used as guidance for users in absence of a real, human instructor.

10.8 Dimensions of representations:

10.8.1 Perspective

Programming environment is presented in event-based paradigm, not the now prevailing object-oriented one. It is an open topics for discussion is the adopted representation better to deal with control of real-life objects, or some effort should be made to somehow gently introduce children to basics of object oriented programming in iconic programming environment.

10.8.2 Precision

Description is precise, as a subset of a precise abstract system (microcontroller programming language) is represented with another precise abstract system, iconic programming language.

10.8.3 Specificity

Graphical iconic language, especially for children, requires that anything what needs to be represented could be converted into a single action (or a group of actions) that can be represented with a single image. An ordered sequence of these images, together with images that allow for structural changes of flow (forks for parallel actions, conditional loops, etc) is everything that can be represented in RoboLab.

10.8.4 Complexity (granularity, generality, and scope)

A trial has been made in RoboLab to guide the users gently through programming environment, thus dividing it into three layers, or modes, complexity wise. Those layers are called Pilot, Inventor and Investigator, and each of them is additionally divided into several levels.

The Pilot layer comprises a series of templates that have a fixed format associated with them. This was done in order to introduce the logical sequencing of icons to users. It is impossible to modify any of the templates to create a program that fails. The program might not do what is expected, but it will run each time, and undertake the exact command sequence listed.

The Inventor layer, as a difference to Pilot, has windows-based menu user interface, including extended help, bigger and more flexible graphical window, and another, much larger, set of programming icons than Pilot. Even the icons that exist in Pilot have slightly different graphical design. In practice, this has proven to be a problematic choice, causing lots of confusion among users.

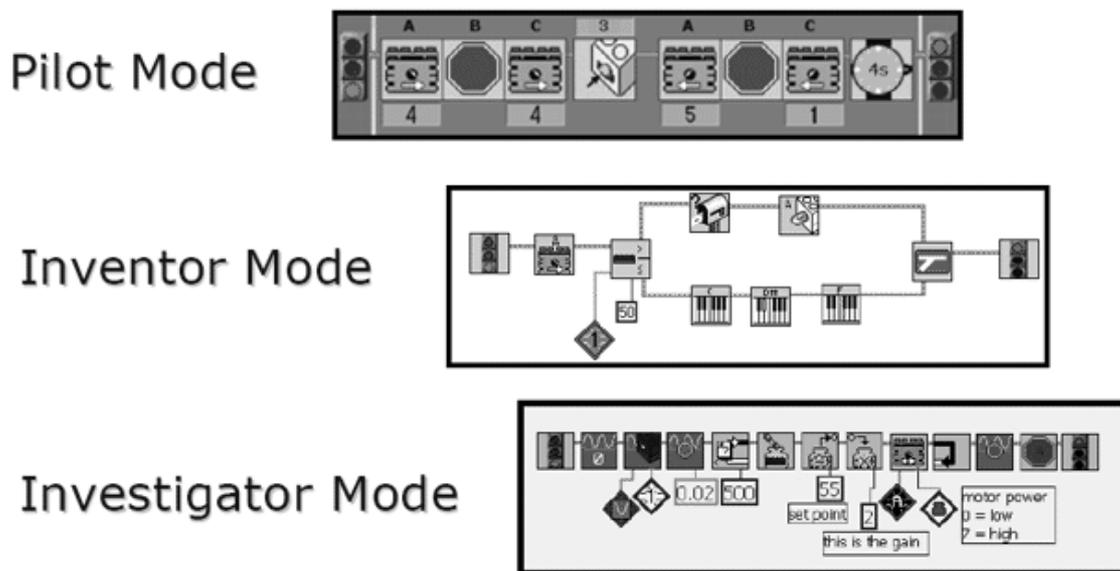


Figure 10.12. Typical programs on Pilot, Inventor and Investigator layers

In addition, there are several more command icon options added as the user moves up through the levels, ending with more than hundred icons on the highest level. On the highest Inventor level, lots of complicated LabView functionalities are exposed to user. Inventor is set up in a less structured way, allowing the powerful LabVIEW™ capabilities to be used as desired by the programmer. This flexibility, combined with the different levels, can be confusing for lots of users. Thus, hints and techniques for working in the Inventor phase are given both in electronic Help, and in the written User's guide, that comes with the product.

Investigator layer is a project-based interface for both robotic programming and scientific exploration through gathering data. Investigator uses the same command icons as Inventor. The project environment allows students to design, build and program their own science and engineering experiments, view, analyze, and manipulate the data, and write about it in a journal section.

10.9 Dynamic representations

Dynamic representations (speech, films, simulation) are used through Training Missions – in instruction material how to use RoboLab (see Figure 10.13). In RoboLab environment itself, basically static representations are used. However, in higher Investigator levels, it is possible to make a program which reads data from a prescribed sensor in prescribed intervals, and do with that data whatever user wants – present them in any form of dynamic time-dependent graph or time-singular representation like a speedometer. This opens possibilities to teach users about time-dependant functions using static or dynamic presentations – graph can be dynamically updated during the process of data-logging, and/or constructed later, when all data are available.



Figure 10.13. Training mission sample: Film is shown on the bigger part of the screen, with narrative audio layer for relevant information; texts and iconic buttons exist only in the lower part of the screen, for navigation purposes

10.10 Theoretical considerations

10.10.1 Computational effectiveness

This has been a specific concern while designing RoboLab graphical language. It is argued that for novice programmers, including non-programmers and children, graphical, iconic representation of a program code is significantly easier to understand and utilize.

10.10.2 Dual coding

This is done mostly in two areas – during Training missions a combination of speech and film (or simulation) is used, and for Help functions a combination of graphical program examples and written text is used, combined with possibility to download example piece of program to a real robot and really check what happens.

10.10.3 Cognitive load theory (redundancy hypothesis & Split attention effects)

Findings from the large number of studies which have reported superior learning results when visual text in multimedia instructions was replaced with spoken text were respected during Training Missions design – spoken language is used there. But, as narrative style is used as a speech mode, there is significant number of users who find Training missions simply boring. However, in Help functions, there is written text together with pictures. It is an open question would speech increase usability here, which might be considered in future versions.

10.10.4 Multimedia design theories

All multimedia design theories mentioned in Chapter 1 have been taken into account while developing RoboLab environment, for example:

- To support different ideas and processes - this is one of core ideas of constructionists approach to learning, and RoboLab environment strongly encourages it.
- To constrain interpretations - program icons, together with help functionality, serve as guidance through otherwise even more open general programming languages.
- To promote deeper understanding – similarly with the first point, allowing experiments, both with programming and mechanical construction is the core of constructionists approach, and this is foundation upon which RoboLab was developed.

However, as with all practical realizations of any theoretical framework, it is questionable how successful and usable all mentioned theoretical issues are implemented in RoboLab.

10.11 Cognitive Models

10.11.1 A cognitive model based on dual coding

The usage of dual coding is apparently noticeable during Training missions, where simulations and film are combined with audio narratives (see Figure 10.13), as well as in Help functions, where graphical iconic representation is combined with explanatory text (see Figure 10.4 and Figure 10.9). It is done with clear intention of supporting the *Selection, Organization, and Integration* of the information. However, in practical realization, although taken into consideration, the design principles of Contiguity, Modality, Redundancy, Coherence and Personalization, have not always been fully respected.

The example of violation of contiguity principle is illustrated in Figure 10.14. The intention was good – to provide some brief textual explanation of available icons, while the user is hovering with the mouse above them, to help the right choice. But the problem is that the text is too far from the actual icon, placed centrally and in bold letters above everything, thus appearing more as a title for the whole menu than the explanation of the particular icon. The result is that this information is often overlooked by users.

However, modality principle is basically respected, especially during Training missions. I would argue that Help functionality (see Figure 10.44 or Figure 10.9.) is not a violation of modality principle,

although it uses visual channel for both graphics and text. Student needs to understand what is meant by certain icon, so moving attention several times between icon and text should promote this understanding. Having the third representation here, i.e. ability to download a sample program and try it immediately in the real world, adds new modality and boosts understanding and learning.

There are no significant redundant representations in RoboLab, nor is coherence principle violated. Concerning personalization, maybe it is even overdone in Training missions. Narrative is direct, in a second-person singular, sometimes strengthening too much how the things should be easy for the user, and congratulating for certain actions, even without reliable feedback. If the user during Training missions gets confused from whatever reason,, this could result that he/she feels even more confused and patronized.

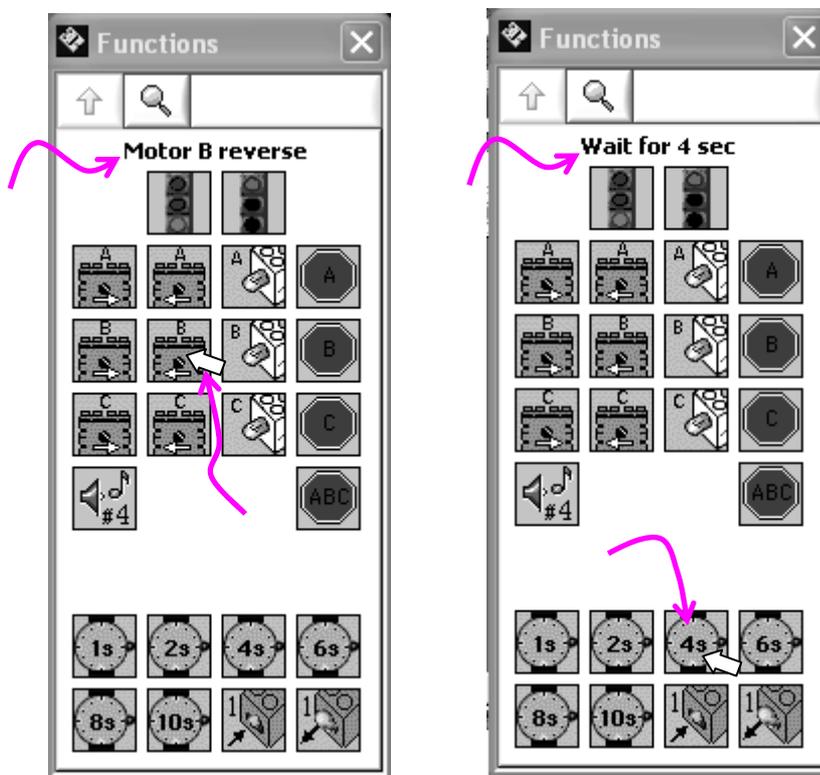


Figure 10.14. Example for violation of contiguity principle

10.11.2 A cognitive model promoting the notion of structural mapping

Analysis of RoboLab environment in the light of Schnotz & Bannert (2003) cognitive model for multimedia learning presented in Chapter 1 is a challenging and open-ended task. This is especially true for following two statements:

- Pictures can also have negative effects because a picture may interfere with mental model construction.
- It must be asked whether the form of visualization used in the picture supports the construction of a task-appropriate mental model.

For example, one could ask whether the model of a container-icon in the form of a glass-jar is appropriate for variables representation, and the model of a bucket is good enough for measured sensor data representation (see Figure 10.8).

The model of sequential program flow could also be discussed here. What the program on Figure 10.15 does is:

- Run both motors A and B in the same direction for 4 sec;
- Then run motor A in reversed direction and light lamp C, and do that until somebody presses a touch sensor.
- After the touch sensor is pressed, stop all actions and exit the program.

What happens is that motor B runs in its original direction the whole time until the touch sensor is pressed, as there is nothing to tell it to stop after 4s. Thus, although the program seems to be sequential and all the icons appear to be of the same nature (their graphical design, with the same rectangular shape and background color suggests it), the truth is different: motors A and B are turned on simultaneously, then the achieved state is kept for a certain amount of time, then a couple of other actions are performed, until some other event (pressing the touch sensor in this case) happens.

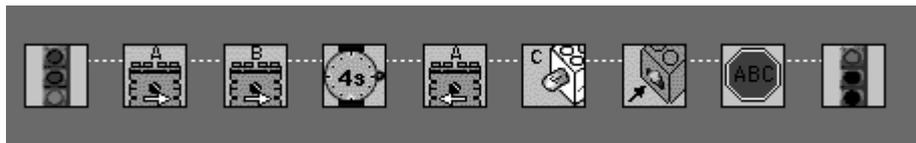


Figure 10.15. A sequential sample program

However, it is open for discussion what would be better representation to construct more task-appropriate mental model, if the task is general programming of sensor-equipped robots for non-programmers. There are different solutions in LOGO-environments, as well as in professional software like MATLAB and SimuLink, so what is needed is a careful analyses of benefits and problems with each solution – exactly in the light of Bannert study which emphasizes that in the design of instructional material including texts and pictures the form of visualization used in the pictures should be considered very carefully.

10.12 Purposes of using multiple representations and the resulting benefits

As stated before, multiple representations are used in several ways in RoboLab environment:

- different modalities for explanatory/learning purposes (film & speech for Training missions, icons & text for Help functions);
- different graphical iconic representations for the same functionality, on different complexity levels of the program (e.g. Figure 10.18)
- presenting numerical data using different function plotting manners (see Figure 10.10 and Figure 10.11)

It can be easily argued that multiple iconic representations for the same action, like on Figure 10.18, are chosen to express limitations on certain layers, minimize needed manipulation costs for users on lower

levels, thus allowing the users with different needs and capabilities to use the same applications. However, the real usefulness of this particular solution is still a matter of open discussion (see paragraph 10.132).

It is also correct that multiple representations were used when one representation is insufficient for showing all aspects of the domain. For example, although icons should be intuitive, it is very difficult to guess and memorize meanings for all of them – so the textual explanation is beneficial. Also, for lower levels of RoboLab programming, some aspect of domain were hidden from user on purpose, in order not to overwhelm him/her with all the complexity – so on higher levels some representations needed not to be only added, but also changed.

As different learners exhibit preferences for different representations, RoboLab environment tried to offer something for different types of learners. Together with programming of mechanical functions of robots, there is also support for basic composing of tunes robots could play, and analyses of pictures robot can capture from camera while moving around (see Figure 10.16 and Figure 10.17)

There are reports of children, apparently not interested in mechanical robot programming, who used Piano Player and icon for sending messages from one RCX to another, who programmed their own orchestra playing polyphonic tune – they programmed a tune, and then requested each of RCX-es to play it with a different delay. Also, picture analyzing software could be used to trig different robot behaviors, if an object of special color or shape enters specified region of the picture.

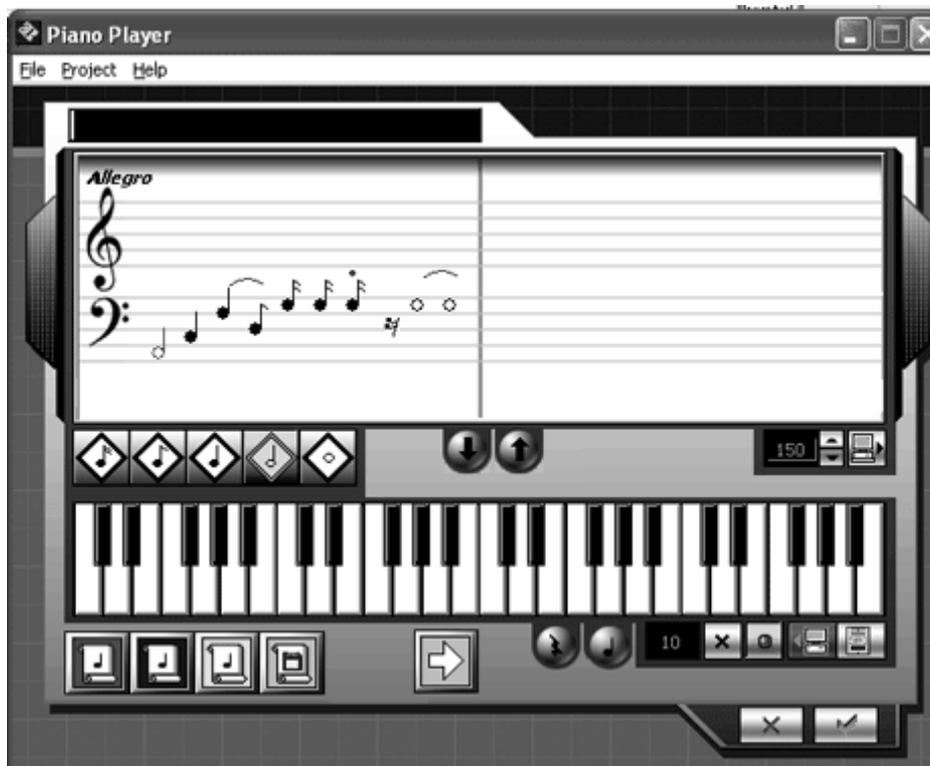


Figure 10.16. "Music composing" part of RoboLab



Figure 10.17. A simple robot for gathering visual data using digital camera, and the screen to process captured image

Using multiple representations when the learner has multiple tasks to perform is the obvious choice for different tasks in RoboLab (programming, figuring out how to program something, downloading, composing the music or analyzing the picture...) - as mentioned through the document.

There are also examples for using particular properties of representations to strengthen the message – for example the film to show how to make experiments with some robots and how exactly they should perform, or grouping property of graphical icons to differentiate between different programming tasks.

Using multiple representations to show the domain from different perspectives is not the main strength of RoboLab. In fact, it guides the user through one particular (sequential event-based) metaphor of robot programming.

However, multiple representations were used to vary the precision of the domain, as well as domain complexity - tools offered by Pilot, Inventor and Investigator being the best example for this.

Looking at general real-time programming languages as an unfamiliar representation, it could be argued that RoboLab is a representation which constraints interpretations of general-term programming language into something graspable for non-programmers, including children. It represents and thus reveals only the needed programming essence to users, broadening the borders at higher Inventor and Investigator layers.

Also, using multiple representations to promote abstraction is noticeable especially in Inventor, with different ways of dealing with /representing measured sensor data. This also belongs to category of using multiple representations to make it possible to manipulate variables

10.13 Problems with multiple representations

Using multiple representations in the same application, independently of modality of representation used, can cause some usability problems. The most noticeable problems in RoboLab environment are:

10.13.1 Understanding the syntax

This is especially evident while moving from Pilot to Inventor layer. For example, look at examples from Figure 10.18. All three pictures represent the same action "Run motor attached on port A with power level 3". However, not only different graphical representations are used on different levels in RoboLab, but the user needs to perform different actions in order to achieve identical tasks. It is not sufficient to find an icon for a motor. Introducing modifiers for particular motor ("A", "B", or "C") and power level (1-5) requires that the user should open another functions menu, find and wire appropriate modifiers.

There are reports that the leap between Pilot and Inventor is so troublesome for children that some teachers abandoned using Pilot at all, and start immediately with Inventor, to avoid problems with different representations.

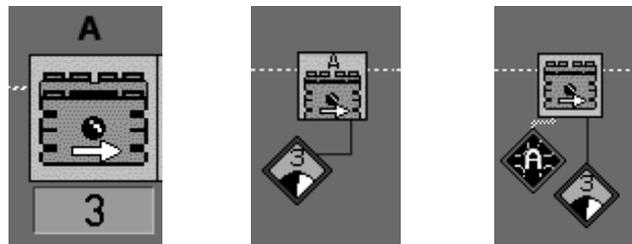


Figure 10.18. Icons for representing action "Rotate motor A in one direction with power level 3" in Pilot, Inventor Level 2 and Inventor level 3

10.13.2 Understanding what is represented

This is the problem especially in Investigator. For example, concepts of data sets and bucket manipulation are hard to grasp without teacher's help (see Figure 10.8 and Figure 10.10).

10.13.3 Relating the representations

Children do not seem to have problem with this. For them, virtual and real world seem to be very united, and they can move seamlessly between them. However, this causes confusion in introductory material – it is not easy to figure out what are the instructions and simulations of activities only, and what are the real actions.

10.14 Types of support

Automatically performed translation between representations is not according to RoboLab design. Either several representations are shown simultaneously (like film and speech, or graphical icons and text), or the user has explicitly to chose the next action, resulting with something new being performed, whether on computer screen, or in reality (downloading & running the program to real robot). Thus, it could be argued that the representations are presented sequentially to discourage attempts at coordination.

It has been taken special care to provide the users with representational system that has features that explicitly correspond to the entities and processes that underlie the physical phenomena being taught.

This has been done throughout the RoboLab application, as well as using multiple, linked representations in the context of collaborative, authentic, laboratory experiments (see Figure 10.9 and Figure 10.10 for illustration of one of possible experiments).

Also, the core goal of RoboLab environment is to engage students in collaborative activities. As a proof of fulfillment of this goal, there are data that RoboLab is constantly getting more and more popularity both in school curriculum and for after-school activities (LEGO clubs or computer club houses). Also, every year more and more teams get involved in world-wide robot building competition FIRST LEGO League (see <http://www.firstlegoleague.org>) – in 2003 more than 45.000 children worldwide participated in this competition.

10.15 Representations and collaborative learning

Collaborative learning is important aspect of RoboLab environment, probably because of its complexity and lots of different tasks which need to be fulfilled to complete any project – so it is much easier and funnier to do that with friends than alone.

10.15.1 Collaboration as a tool to improve individual processing of the external representation

There are always children willing to explain what they just understood (even if that might be wrong), and then in open discussion better learning emerges.

10.15.2 External representation as a product of collaborative processes

Users are encouraged to write a joint project journal, reporting obstacles and solutions they were dealing with.

10.15.3 Using external representation to facilitate collaboration and collaborative learning

As said before, RoboLAB environment, together with programmable RCX brick, physical motors and sensors and lots of "ordinary" plastic bricks is simply inviting for collaborative play (and learning, as inevitable consequence).

10.16 Degrees of freedom in interacting with the external representation

RoboLab is mixed environment concerning degrees of freedom for the user. It is even possible to find enforcing functions in Training missions. What is happening there is in fact simulation of a user interacting with environment, but the user is anyhow asked to perform a certain action. Although it seems that the user can do whatever he wants, only enforcing action is accepted. This was found to be highly

confusing, because at that point it is really difficult for the average user to differentiate between the interaction with the system and simulation of this interaction.

Iconic programming language on several layers is pretty well balanced, providing "freedom within constraints" – in a very similar manner as real, plastic LEGO bricks could be connected in practically unlimited number of combinations, but only within the well-defined system of constraints.

Functionality of Investigator is pretty open, just providing affordances for the user – with all mathematics and graphing and programming possibilities, as well as freedom to define non-LEGO sensors and new icons, the user is only limited with his imagination, time and interest to proceed.

10.17 Conclusion

Performed analysis of representations used in RoboLab multimedia programming environment supports the statement from Chapter 1 that the use of external representations for learning in multimedia environments is not a simple issue, as representations do possess various properties, serve different roles, appeal to diverse learners' capabilities and function in multiple ways towards the provision of an effective and efficient learning environment. Some positive properties of certain representations might be negative (overwhelming or confusing) to users, if analyzed from another point of view.

Thus significant care of multimedia designers needs to be paid to every single representation and implementation detail, in order to assure benefits for their users.

Acknowledgements

Majority of pictures included are taken from Using RoboLab, LEGO Mindstorms for schools, By LEGO Company. Others are screen shots of RoboLab environment.

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CHAPTER 11: Motivation and Representation in Educational Games

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Abstract. This paper concerns the domain of educational games (in this paper called EduGames). It does not concern computer (or video) games in general, although many parallelisms are made throughout. Core point in this work is the fact that computer games, in general, are very popular, while it cannot be argued the same for educational ones. So, the main question to be addressed concerns some of the main directions current research deals with, which domains are missing or underrepresented (in contemporary research) and finally to pinpoint some interesting questions, not yet addressed or underestimated. Through this study, the motivational factor emerges as an important factor as regards to the representations used. A case study has been performed; the results are presented and discussed. A clear result is that the use of animations and sound as the main means for representations is highly motivating for the children, however a concrete and careful design of the educational parameters must be performed at the design stage, in order not to diminish its educational value.

11.1 Part I - Contemporary Research and Core Questions on Educational Games

11.1.1 Introduction

There is already adequate evidence in the domain of computer or video games. Journals, such as ACM's Computers in Entertainment (<http://www.acm.org/pubs/cie.html>), or focused conferences, such as the workshop «Games And Social Networks: A Workshop On Multiplayer Games», to be held during the 18th British Group HCI 2004 annual conference at Leeds¹⁸ are not yet common, nevertheless they cover satisfactorily a domain, which however should be more turbulent, in our opinion.

In addition to this, some deliverables from EU funded research programs exist as well, such as the detailed report on the domain from the KITS consortium (Leemkuil et al., 2000). This study examines the theoretical analyses and empirical results from research in the area of instructional use of games and simulations. It mainly focuses on approaches taken in designing game (-like) learning environments and distils a list of characteristics of games from the instructional theory. It also tries to find evidence concerning the appropriate learning approaches and measures, which can optimize the learning effects of games and simulations.

These sources are a good starting point, however one would wish a broader coverage of the domain, considering the great consensus on the value of EduGames in the instructional procedure. Under this point of view, current research is not intensive enough, results are far from sacrosanct, and the technological progress far from satisfactorily.

¹⁸ Details at <http://www.dcs.gla.ac.uk/~barry/gamesworkshop/> and at the HCI 2004 website <http://www.bcs-hci.org.uk/hci2004>

So, in this work it is attempted to pinpoint some interesting research directions, while some core questions are stated, which are believed to offer enough initiatives for further research.

11.2 Research Directions

11.2.1 Application of EduGames in practice

In contemporary research, major point of concern is the application of EduGames in the classroom, or, more generally expressed, in the instructional procedure. This research direction represents the majority of the published research. A close enough estimation of this percentage could be 75%. A great deal of research focuses on computer literacy and basic programming skills.

Playing computer games is a popular recreational activity for young people. Not surprisingly, many of these enthusiasts dream that one day they will develop computer games themselves. So why not use game design as a vehicle to teach youngsters computer science? Developing computer games involves many aspects of computing, including computer graphics, artificial intelligence, human-computer interaction, security, distributed programming, simulation, and software engineering. Game development also brings into play aspects of the liberal arts, the social sciences, and psychology. Creating a state-of-the-art commercial computer game is an incredibly difficult task that typically requires a multimillion-dollar budget and a development team that includes 40 or more people. But simpler alternatives - ones within the reach of students and hobbyists - exist. Budding game developers can have fun creating variations on Pac-Man, Space Invaders, or simple platform games (Overmars, 2004).

Logo (www.logosurvey.co.uk) and its many variants provide the classic example of a programming language aimed at creating interest among youngsters. Primarily seen as a language to make drawings, with Logo, the user steers a virtual turtle to draw shapes onscreen. Even the basic program can make fancy drawings this way, while modern versions extend Logo's possibilities considerably. For today's users, spoiled by console and computer games, Logo is no longer flashy enough, however. Steering a virtual turtle can't possibly compare with steering a real robot, which probably accounts for much of Lego MindStorms' success (www.legomindstorms.com). With the admittedly limited software that comes with this system, users can create and program their own robots. Fortunately, third-party developers have written complete programming languages for these robots, most notably NQC (<http://bricxcc.sourceforge.net/nqc/>). The main disadvantages of using robots to learn programming are their expense and limited programming possibilities. On the other hand, robots do provide great vehicles for explaining concepts such as parallel tasks.

However, all these educational approaches support more or less the persistent public image of computing as a field of programmers. In other words, many people believe computer science is only a technology field without much science and engineering (Denning, 2004). To reverse this myth, stands on the same vehicle with the challenge to apply educational toys beyond programming: perceptive, psychological (mainly motivational) and personal factors play a major role, and are discussed later.

11.2.2 Benefits and Harms

Another focus theme in contemporary research is the discussion concerning benefits and harms of the use of games by young people, in the classroom or in private. Several arguments are commonly cited for the use of games in the computing classroom. Among others, Walker (2003) states as advantages:

- A. *Motivation*: (a) Some students find games very motivating, and (b) Many students have prior experience with a variety of computing games, so using games in courses may connect with students' background.
- B. Fancy graphics can *capture students' interest and imagination*.
- C. Games are often *easy to understand*, so developing programs that play games can highlight problem solving, data structures, classes/methods, and other high-level skills.
- D. Games provide *options for creativity* in assignments, possibilities for extensions, and opportunities to develop projects through a sequence of assignments.
- E. Games allow *assignments to be described in layers*, where a moderate level of functionality is required for a "C", additional features constitute a "B", and extensive refinements yield an "A".
- F. Games provide opportunities for *the early introduction of elements of modern technology*, such as client/server computing, concurrency, and object-oriented programming.

While games have various constructive elements within the classroom, various reports suggest that many positive elements also have counterbalancing negatives. Here are some commonly cited problems for the use of games. (Numbering is keyed to the points in the list of positives.)

- A. *Motivation*: (a) Some groups, particularly women and other underrepresented groups, are often turned off by competitive games. Students in these groups often want an emphasis on socially constructive applications. (b) An emphasis on games may reinforce the popular misconception that video games represent a major component of computer science. (c) Games and game playing can be quite addictive, so emphasizing games in the classroom can reinforce anti-social behavior. (d) Assignments utilizing games can encourage distractions during class sessions, as students show off their programs.
- B. *Graphics*: (a) Much class and/or student time can be devoted to graphics and I/O. If there is not a corresponding emphasis on HCI, game interfaces could focus on personal idiosyncrasies rather than principles and analysis. (b) Extensive time devoted to I/O can limit time available for such fundamentals as algorithms, data structures, and software engineering.
- C. *Extensions and Creativity*: (a) Encouragement to add features may undermine a sense of writing to specifications and considering actual customer needs. (b) Options for extended functionality may encourage program bloat and unnecessary complexity.
- D. When grades depend on multiple levels of functionality, *true beginners* (who often are students from underrepresented groups) can be at a significant disadvantage for the best grades and building self-confidence.

11.2.3 Classification

Some research also attempts to classify games, in general, and EduGames in specific. Games encompass many styles and subjects. For example, games may be competitive or cooperative, be played by individuals or groups, and touch on numerous themes, such as adventure, education, social interactions, science fiction, violence, and sexual circumstances. Simulations sometimes are considered games as well. Leemkuil et al. (2000) argue that games as learning environments are closely related to simulations, microworlds, adventures and case studies. The definitions of these environments partially overlap. For instance, the distinction between simulation and games is often blurred, and many recent articles in this area refer to a single "simulation game" entity.

11.3 Interesting Questions

This work aims to extend itself to questions addressed by current research and propose directions and further interesting questions, not yet addressed. Under this point of view, following research questions extend the above presented.

11.3.1 EduGames are underrepresented

If the benefits of using games in the instructional procedure are so clear, why then are they not yet a vital part of contemporary education? While gathering comparable statistics is challenging, there is one estimate of the relative size of the computer gaming industry. The Interactive Digital Software Association reported "2001 U.S. sales of computer and video games grew 7.9 percent year-on-year to \$6.35 billion, ..." (See <http://www.idsa.com/2001SalesData.html>). Also, the Information Technology Association of America combines information and communications technology (ICT) products and services within its definition of the information technology industry and reports that "U.S. spending in ICT has increased almost 70 percent since 1992, to almost \$813 billion in 2001." (See <http://www.itaa.org/news/gendoc.cfm?DocID=120>). Putting these numbers together, computer and video games made up 0.78% of total IT sales for the year 2001. This number is obvious far from satisfying, taking into account that these facts represent games in general and not only EduGames. An explanation here could be that designing an educational game is fraught with difficulties beyond those normally associated with writing a "normal" educational software program, as there are conflicts between educational and entertainment goals (Moser, 1997). In realizing the problem, big enterprises are seeking solutions. Microsoft has sponsored a "Games-to-Teach" project at MIT, which is building games for learning difficult concepts in physics and environmental science on the X-Box and Pocket PC (<http://cms.mit.edu/games/education/index.html>). Lucas Arts has lesson plans on its website to help teachers use its games to teach critical thinking (<http://www.lucaslearning.com/edu/lesson.htm>). A UK study by TEEM (Teachers Evaluating Educational Multimedia) has shown that particular off-the-shelf games can help youngsters learn logical thinking and computer literacy (<http://www.teem.org.uk/aboutteem/press/article?nid=92>). And the Liemandt Foundation has designed a contest in which college and graduate students create learning games to teach middle school subjects, competing for a \$25,000 first prize (<http://www.hiddenagenda.com>).

Given the almost perfect overlap between the profiles of gamers and military recruits, the US Military uses over 50 different video and computer games to teach everything from doctrine, to strategy and tactics (<http://www.dodgamescommunity.com>). One of these, "America's Army: Operations," a recruiting game released for free in 2002, now has almost 2 million registered users, with almost a million having completed "virtual basic training" (<http://www.americasarmy.com>).

So after all, why are educational games underrepresented in the instructional procedure? Some possible reasons could be suboptimal application scenarios, or lack of motivation. Prensky (2003) also states that despite all the findings, research, and cries for help from the kids in school, many parents and educators still tend to think of video and computer games as frivolous at best and harmful at worst. The press often encourages this with headlines about "killing games", when in fact two-thirds of all computer and video games are rated "E (everybody)", and 16 of the top 20 sellers are rated either "E" or "T (teen)".

There are however, many more reasons for this phenomenon, which research has to find out.

11.3.2 Does the "ZPD" play an important role in EduGames?

The zone of proximal development (ZPD) as described by Vygotsky (1930, 1978). Most of contemporary research argues that the application of educational games is of benefit to the learner, however, extremely low percentage emphasizes the aspect that, in fact, the educational game is the scaffolding factor, which aids the learner to the crossing of the ZPD. So, an interesting question in this direction is the mapping between the principles of the ZPD-theory with those of the educational theories, using the educational game as a catalyst.

An optimized view of the application of ICTs in the classroom argues that contemporary research in learner-centered design is developing new technology, curricula and professional development materials that integrate desktop and handheld computers into classrooms to support activities as diverse as story writing, scientific field experiments and online research (Lee et al., 2004). Educational design recognizes that learners have unique needs – such as a lack of background knowledge and a lack of motivation – that need to be addressed in the design of educational software tools (Quintana et al., 2003). When using educational technology, learners' needs arise both from the tool and from the activity. For example, in order to use a word processor to write a cover letter for a job application, learners must understand both how to create and edit a file using the word processor (a need arising from the tool) and what content and format is required in order to create a good cover letter (a need arising from the activity). To address learners' unique needs, educational technology practitioners often incorporate additional supports or "scaffolds" into their educational software. Scaffolds are temporary supports that assist learners in engaging in an unfamiliar task (Bransford et al., 2000). In software, scaffolds often appear as part of the user interface, providing support and guidance throughout the activity.

11.3.3 The factor of motivation.

Prensky (2003) states that a *sine qua non* of successful learning is motivation: a motivated learner can't be stopped. Almost every paper dealing with educational games refers to the term "motivation" somewhere in the text; however the term itself is seldom defined, neither is it adequately explained as

regards of the motivational parameters underlying the context of its use. An aid here could provide the four-factor theory of John Keller (Keller, 1983). According to this researcher, motivation can be analyzed into four distinct factors:

- i. *Interest & curiosity* refers to whether the learner's curiosity is aroused and whether this arousal is sustained appropriately over time
- ii. *Relevance* refers to the learner's perception of personal need satisfaction in relation to the instruction, or whether a highly desired goal is perceived to relate to the instructional activity.
- iii. *Expectancy* refers to the perceived likelihood of success, and the extent to which success is under learner control.
- iv. *Satisfaction & outcomes* refers to the combination of extrinsic rewards and intrinsic motivation, and whether these are compatible with the learner's anticipations.

According to this theory, vague claims, such as "students find games very motivating", can be analyzed in more detail, as «they have prior experience» (the *relevance* factor) or «women are often turned off by competitive games» (the *expectancy* factor).

Moser (1997), in attempting to answer the question why learning to program is so difficult, argues that it is merely computer- and knowledge-centered than human-centered. He argues that programming is a multi-layered skill, it is unrelated to much day-to-day experience, it is learned in a single context, it is boring and it is intimidating. In an attempt to optimally facilitate knowledge acquisition, most educational software encloses more or less all of these pitfalls as well. So, the question of the motivational factors that must be present in any EduGame is still to be addressed.

Malone (1980a, 1980b) also studies the question "what makes things fun to learn?" and gives a *taxonomy of intrinsic motivation*, according to three categories, *challenge*, *fantasy*, and *curiosity*. He concludes in a list of heuristics, as follows: A *goal* whose attainment is uncertain (subdivided in several corresponding conditions), *fantasy* involvement (also subdivided in extrinsic and intrinsic fantasy, as well as emotional aspects of fantasy), and *curiosity* (also divided in sensory and cognitive curiosity). There is obviously a matching between these parameters to the four Keller's factors of motivation, which in its turn implies that research based on this theory is on good track.

11.3.4 The factor of addiction

In contrary to this, the issue of addiction is, by so far, not studied enough. In a recent survey on how computer games affect students' school performance, Messerly (2004) states that in fact (games) ruin the social and scholastic lives of many students. He pinpoints role-playing games as most addictive, because players create characters and alter egos in cyberspace, living out their personal fantasies, usually by adopting the traits they believe they lack in the real world. In extending the above question, one wonders, *why some games are so addictive, while none educational is*. Is it the good graphics factor, the close-to-reality and sophisticated game play, the compelling environment, the escapism from reality or what? And why can't designers of educational games implement these features in EduGames? This could maybe be proved to be the most important factor, if it comes to practical considerations. Prensky (2003) argues that the amount of time today's young people spend playing computer and video games, estimated at 10,000

hours by the time they are 21 – often in multihour bursts – belies the “short attention span” criticism of educators. And while years ago the group attracted to video and computer games was almost entirely adolescent boys, it is now increasingly girls and all children of all ages and social groups. If designers of educational games could implement some of these “addictive factors” to their games, then the EduGames would greatly be augmented in terms of motivation. However, a very critical question emerges here, which is the ethic of the whole approach, namely to implement *a hidden psychological factor* to enhance the use of the product, even it is for a good purpose, as it is the fact in an educational game. On the other hand, one could argue that entertainment industry, which is profit-oriented, does it. And, after all, if players can develop alter egos in cyberspace with features they lack in real lives (as Messerly (2004) argues), isn't it the talk about an educational parameter worth to investigate and, under circumstances, to exploit? Nevertheless, this issue is from many perspectives very interesting.

11.3.5 Do underrepresented groups have a disadvantage?

The issue of the representation of women or other underrepresented groups in the technology-enhanced instruction is another important factor, when it comes on the use of ICT in the classroom. Negative perspectives by women of computer games are discussed in several articles in the Women and Computing special issue of the SIGCSE Bulletin inroads, June 2002. There is also interesting discussion in Educational Foundation Commission on Technology, Gender, and Teacher Education, Tech-Savvy: Educating Girls in the New Computer Age, American Association of University Women Educational Foundation, 2000. However, no clear results or even guidelines on how to confront this problem and aim these users during their work with ICT are broadly known or acceptable. In other words, this is a permanent and nagging question.

11.4 Discussion

This chapter by so far does not give answers. It only states questions, together with multiple hints to deal with. Current research, although present, misses the core point to address psychological factors which could motivate young people to use EduGames beyond the classroom, extending the instruction to the sphere of entertainment, realizing thus the term Edutainment, which is, at present, marginally successful.

There are on the domain many interesting questions, as well as interesting answers and counter-arguments, such as the development cost of an EduGame that could compete popular commercial games. However, there can be discussion on it: let's outsource the EduGame to one of these «commercial» companies, because EduGames are constructed once to be used forever. For example, a historical conquest game could be used repeatedly in schools over the world, and simultaneously played at home teaching children while amusing them. Under this point of view, cost and complexity are no more determinant factors. Our lack of knowledge on the psychological parameters and our unwillingness are more important.

The scope of the software covers a broad spectrum of lessons taught at primary school. Below we present only some of them with a brief description.

Arithmetic and Mathematics

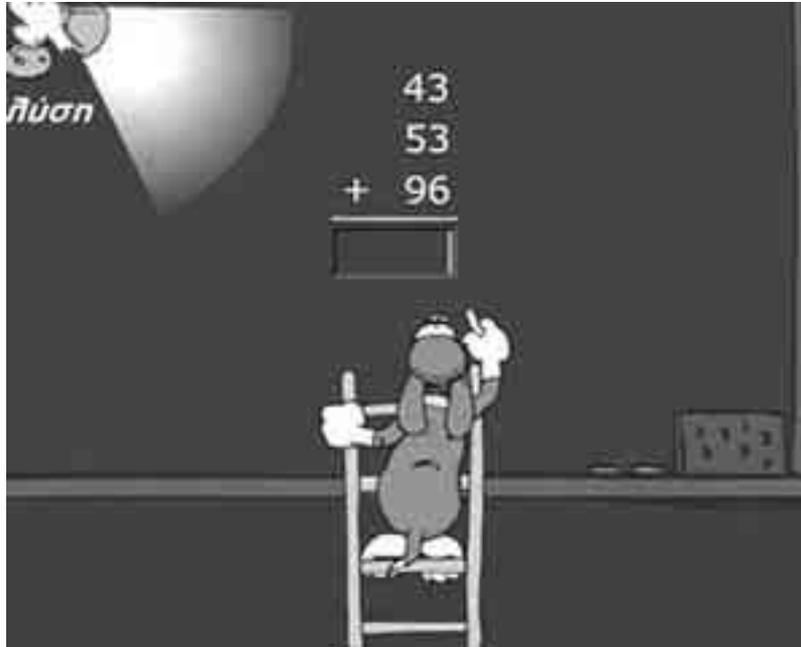


Figure 11.2. Addition

Basic skills in arithmetic. The difficulty grade is adjustable; the solution is presented by activating the light on the top left.

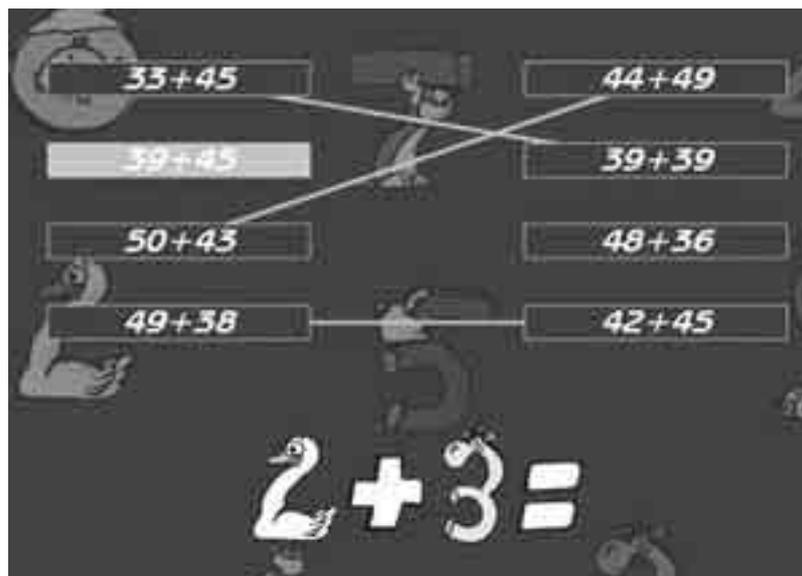


Figure 11.3. Matching of the sums

Matching the additions. The pupil has to use his/her mind, as there is no noting facility. Not an easy task at all. It enhances memory skills as well as the arithmetic ones.

Geometry

The pupil needs here to calculate the area of the square. Note the „chalkboard“ at the lower of the screen. It is to make calculations, while the sponge on the right initializes (erases) it.

The light on the left unveils the correct solution.



Figure 11.4. Geometry

Geography

Figure 11.5. European geography

There are plenty of exercises; here is one presented where Perry is trying to identify Belgium among 4 presented countries. Difficulty is also adjustable, interaction trough clicking.

Language

There are plenty of activities here, such as word spelling, or verbs.

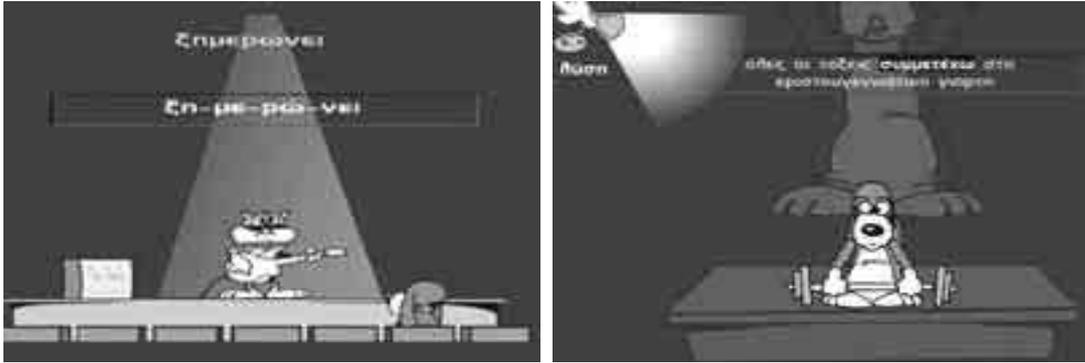


Figure 11.6. a and b: Word spelling and verb usage

Time

For the first classes, time practice is important. The pupil can interact with the watch, which animates accordingly.



Figure 11.7. Time

Matching

Representations of the real world (through images) and matching to words with vocabulary.



Figure 11.8. Matching of images and words



Figure 11.9. Crossword

For the greater classes, crosswords combine knowledge from different domains, geography, history etc., with wording and spelling skills. It is considered to be a higher level matching activity.

11.5.2 Feedback

Feedback occurs in all exercises with animation and sound, positive and negative with a „try again“ prompt. For example, in a problem solving activity, the correct answer brings the bus to Perry, who is waiting at the bus stop, while the wrong answer results the passing of Katia in a car, splashing the waiting Perry with mud.

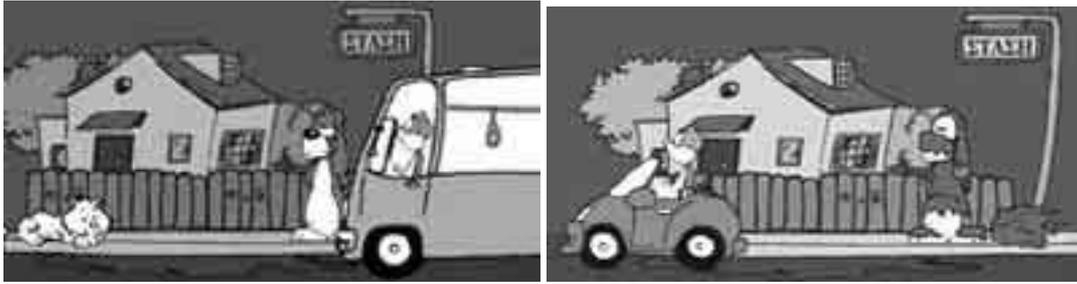


Figure 11.10. Positive and negative feedback

In another exercise (multiplication), the correct answer makes Perry smile, while the wrong drops him from the chair.

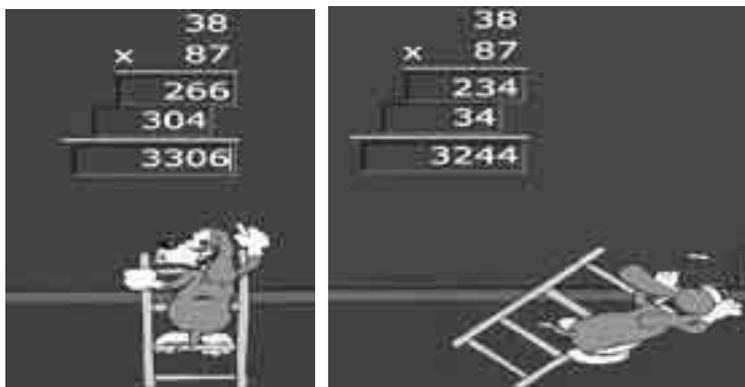


Figure 11.11. Another positive and negative feedback

This software is more or less representative of the majority of the used educational games; this is also the reason why it has been chosen as a case study. There are of course many exceptions, however as regards to the representations used this software belongs to the majority. The main characteristics of the representations are described subsequently.

11.5.3 Characteristics of the representations

It must be emphasized from the beginning that the animations and sounds are mainly used to motivate the pupil than to represent cognitive aspects to be dealt with. This is the case in other EduGames as well, as multimedia elements are used rather as decorative and stimulating elements than as vehicles to transfer and manipulate the offered knowledge. On this notification will later be based the discussion on the motivational parameters of the environment.

So, the utilized here representations provide following characteristics:

- *Multiple representations.* Animation (which embodies image representations) and sound constitute 90% of the used representations.
- *Code and modality.* The navigational elements (shown clearly in Figure 11.7 at the left hand and the right hand side) are all animated icons. They (the representing world) depict a navigational

structure (the represented world), which is usual in educational environments: next, previous, home, exit, repeat and help. The rest of the representations occur where interaction with the user is possible. A narration prompts the pupil to act and provides help on it. So, we are talking in both cases of *depictive* and *non-equivalent* representations, which are however *multimodal*, as they employ aural, visual and tactile modes to interact with the user (the user is often asked to type something). Although, from a usability perspective it could be debatable in how far the used navigation icons are intuitive to a novice user of this age, the application of the software showed that children can easily overcome such burdens with little or not at all help. The exploratory nature of a child permits it to explore the interface and discover its capabilities. Important is here the "prevent errors" usability factor, so as to hinder fatal errors an exploring user could cause. Such occurrences did however not happen during the use of this software.

- Animation seems to provide potency for *dynamic* and *kinesthetic* (manipulable) types of representations. However, in the particular case, only *concrete*, *pattern imagery* and *symbolic elements* are represented. As already stated, the majority of the animations concerns navigation or feedback actions on the interface. Animation for feedback is considered here to belong to the pattern category, as it only informs the user on the correctness or not of his/her action. As it is obvious, we are dealing here with *depictive feedback* (if it is correct or not) and not with *constructive feedback* (in what direction one should seek for the correct solution).
- *Affordances*. Rarely the visual representations in this case study provide concrete affordances, as it is the case of Geometry (Figure 11.4) or Crossword (Figure 11.9), where they help to visualize the information. In this sense, they help to structure the cognitive activity and provide patterns for experimentation. In most other cases animations and sound cues are used as feedback or as a helping facility (explaining narration).
- As regards to the *dimensions* of the used representations, it can be argued that this aspect is here not applicable, as it does not concern depictive modes, such as the crossword or the time representation, which are more or less an "information container". The scope of these representations is relative broad, as they are abstract enough to be applicable in almost all corresponding situations. In other words, the crossword representation suits for all wording exercises, while the watch representation (with the embodied interactivity) provides additionally a detailed granularity, corresponding to the one of the real world. In this sense, all used representations in the particular software piece are *time-singular* instances, according to the classification by Ainsworth and van Labeke (2004).
- Concerning the underlying theoretical support, the theories of *dual coding* and *cognitive load* seem to be implicitly employed in the design of the system, however there are not clear indications that the authors intended to do so. Dual coding theory is de facto implemented in any multimedia environment, and its ultimate purpose is to reduce cognitive load, so it can be argued that the use of multimedia animations intends to benefit from these theories. In contrary, *multimedia design* theories seem to be explicitly employed in the design and construction of the interface. Image, text, animation and sound are extensively used and extensively perceived by

the children who used the software, as the application showed. It was observed that older children equally paid attention on all modalities, while younger children showed a clear preference to aural feedback and hated to read or write the text.

- As regards the *cognitive modeling* support, it is not apparent in the designers' intentions, although the overall interface does not provide any problems on it. Children could easily work in the interface, without any hindering. One remark must be stated here, concerning the *redundancy* principle and the claim "avoid presenting verbal information in both textual and narrative form especially when graphics are presented at the same time", which is in accordance to our observations, and a claim stated by Juul (2000) that "it (the game) must not contain narration; everything must happen in the now of the playing". It is already stated that there has been observed a clear preference of the narrative form instead of the text for younger children. Besides, there is an open question whether narration and textual information presented together can assist young children in their first steps in literacy.
- At this point, the provided *degrees of freedom* must be discussed. The overall environment can not be characterized as a constructivist one, as most of the exercises are already known to the pupils from school and must be performed in a pre-defined way. The environment simulates the school environment, as it is apparent in figures 11.2 and 11.11 (addition and multiplication) or the real world, as in figures 11.7 (the watch) and 11.9 (crossword). So, it can be argued that the used representations significantly reduce the degrees of freedom, while they provide only limited affordances.
- Direct results of the above are two effects; one (positive) concerns the problems of the presentations, which are now diminished, and a second (negative) that no collaboration activities are implemented. The syntax is clear and consistent through the whole set of CDs, translations between the representations are coherent and reasonable. On the other hand, the environment is used as a stand-alone application and the participating children worked in it one after the other, with no option to collaborate, besides the questioning and answering between them on the presented activities.

As a result of the above presented, it can be elicited that no clear purpose on resulting benefits due to the use of the particular representations has been set by the designers. From an educational perspective, the software only mimics the school duties and represents them in an electronic form. It does not base on any specific educational theories, or targets to achieve some special results, due to the use of the representations.

However, the particular software is very popular to children, and is used and developed since three years. The children referred to it as "to play with Perry and Katia", indicating that the playing parameter is perceived to dominate over the educational one. So, the emerging question is what makes the environment so popular and stimulates the children to use it.

We believe that the explanation lies in the examination of the motivational factor.

11.6 The motivational factor

11.6.1 Overall Concerns

Although the extensive use of animations provides a fruitful background for simulations, it is rarely the case in EduGames, or the simulations are limited to a low percentage of the software. This has its reasons, as the high complexity of simulation environments, the design and construction difficulty and the bad cost/performance factor. So, the emerging question is "why then to use animations?" This is number 6 question in table 1.1. in chapter 1 of this work ("Reasons for using representations of a real system"). It seems that designers of EduGames see the animation rather as a motivational and stimulating factor than as a possibility *to represent a real system in another way*.

So, the issue of motivation emerges here and must be discussed.

In chapter four it is stated (and backed up with adequate literature review) that "students like to watch animation even if they do not really get any substantial learning benefits". So, designers implement animations mainly to activate students to deal with the environment, in other words to motivate them.

Which are the parameters of motivation. According to the already stated theory of the four factors, following parameters have been examined during this case study:

1. *Interest and curiosity*. It has already been stated, "fancy graphics can capture students' interest". As a cartoon-based software shows a very fancy and colorful screen, the factor of interest is here well served. The children equally attempt to give correct and wrong answers, just to see the reaction of Perry (or Katia). An important parameter of *interest* is, that it must be maintained over time. So, in this particular case study, animations prove to fulfill this requirement. A second parameter to preserve *curiosity* is to provide learners with unexpected and unpredicted events. As every animation is different in any context, this parameter is maintained perfectly.
2. *Relevance*. Cartoons are, by default, relevant to the children's nature. They consume a lot by TV watching and they learn also through the stories displayed. So, the cartoon animations in this software are very relevant to the children's' interest. Through the case study, children were able to notice every new figure emerging on the screen and characterize it correctly ("Look! Perry as a fireman!"), even if the (adult) observer failed to.
3. *Expectancy*. No such factor was apparent in this case study. Expectance of success was observed only in cases where the correct answer was difficult to achieve, and the resulting animation was not revealed. However, it was observed that children loosed quickly interest and proceeded to the next exercise, as there are plenty available on the 7 CDs. So, it can be argued that a certain failure in the educational parameter is stated, as there was a clear locus by the children only on the entertaining one.
4. *Satisfaction and outcomes*. There was no clear aiming to achieve any target, as the entertainment orientation of the software dominated. Satisfaction was also granted through the flexible navigation structure, as the completion of one exercise was not prerequisite to go further on. So the children could repeat favored exercises and neglect more "difficult" ones, as it was observed during the case study. On the question "why don't you like this exercise", the answers varied

from "it is difficult" to "Perry behaves stupid here". In conclusion, the option to neglect an exercise and repeat another seemed to stimulate the children at most.

11.7 Conclusions

The use of animations as the main means to represent is proved to be a very substantial part of the software, especially regarding the motivational factor. However, not all representations in the studied software were animations. Sound, text and images also contributed to motivate the young users. As already stated, sound seemed to be a substantial part, especially for younger children. Representations of other aspects of the world, such as the watch, seemed familiar (factor of relevance) and supported transparency of the interaction with the environment.

As a final conclusion it can be stated that, although the educational value of such an EduGame is underrepresented, its motivational potency is very high, providing thus a good starting point. This case study has shown that the extensive use of animations and sound as the main vehicles of representations can help children to interact *transparent* and *intuitive* with the educational environment. So, a more careful and precise educational design is highest insisted, if one wants also to implement a high educational value to an already highly stimulating environment.

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