Designing Degree Programmes for Bachelors and Masters in Information Security

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Abstract. The effectiveness of ensuring information security (IS) largely depends on the IS specialist's professional level. It is important to design the relevant degree programmes (DPs) for their training within the framework of academic education. This process involves the definition of initial data and the implementation of a certain number of interrelated stages. The peculiarities of national educational systems as well as inadequate coordination of educational activities at the international level are the main reasons for the lack of uniform requirements for the DPs' formation. A DP's design procedure, based on the experience of the international organizations engaged in the accreditation of individual DPs, is considered. The paper defines the typical DP's structure and the basic stages of its design for the example of the Bachelor's and Master's in IS DPs.

Keywords: information security; information security professionals; professional standards; competency; degree programme; Bachelors; Masters; design

1 INTRODUCTION

The effectiveness of ensuring information security (IS) largely depends on the professional level of specialists in the field. It is important to design the relevant degree programmes (DPs) for their training. A DP refers to a set of educational and methodical documents, which set forth the basic provisions relating to the implementation of the educational process of training professionals of a certain level.

Each educational institution develops its own DPs based on its experience, others' experiences, and various regulations adopted at the national or international level. The peculiarities of the educational systems of different countries as well as an inadequate coordination of educational activities at the international level are the main reasons for the lack of uniform requirements for the DPs' formation.

In this paper, a DP's design procedure, based on the experience of the international organizations engaged in the DP's accreditation, is considered. As a successful example of such activities, we examine the experience of the Agency for Accreditation of the DPs in the field of engineering, informatics, natural sciences and mathematics (ASIIN, www.asiin-ev.de). The Agency proposes and implements quality control at

the international level for the DPs. The core of the DP's accreditation criteria, regardless of the country in which an applicant (educational institution) operates, consists of the following:

- The orientation of the learning outcomes;
- The feasibility of the DP;
- The quality features associated with the professional community and labor market;
- The applicant's potential, including its quality management maturity;
- The accounting of the requirements of the European Association for Quality Assurance in Higher Education (ENQA) (set out in the "European Standards and Guidelines") and the European Quality Assurance Register (EQAR).

Thus, the paper proposes a generalized (typical) description of a DP's structure, based on the formulation of its key implementation goals, objectives and intended learning outcomes with their features, the development of its curriculum and the description of requirements for the education quality control and the resource support of the DP's implementation. The effectiveness of the proposed approach is confirmed by the NRNU MEPhI's experience in designing the DPs for Bachelors and Masters in IS.

2 TYPICAL DEGREE PROGRAMME STRUCTURE

The shared experience of educational institutions, which successfully passed the procedure of their DPs' accreditation in the organizations like ASIIN (presented at http://www.asiin-ev.de), allow us to describe a typical DP's structure (Fig. 1).

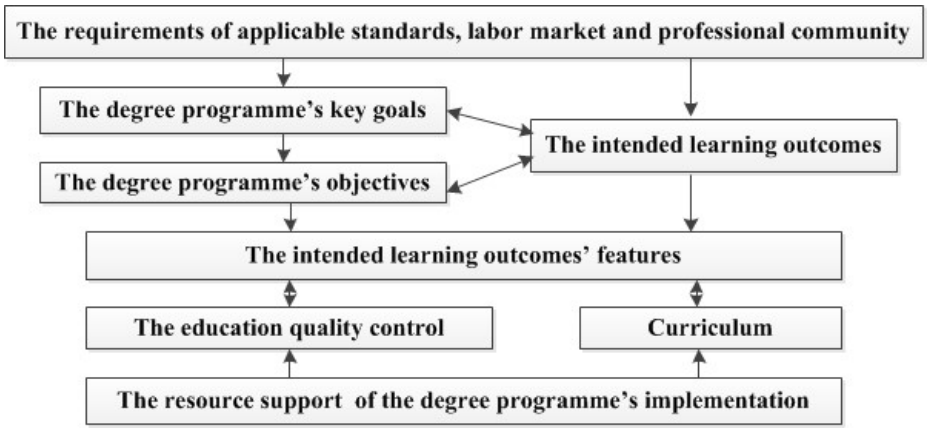

Fig. 1. Typical DP's structure

The educational and methodical documents relating to any DP should clearly describe all these structural elements. The DP's key goals and objectives, as well as the intended learning outcomes formulation should be guided by the requirements set

forth by the applicable standards, labor market and professional community (consumers of the educational institutions' graduates, etc.). [To simplify the presentation of our findings and in condition of limited paper size, the requirements resulting from general public interest, IS science itself, etc. are not discussed]. The intended learning outcomes should be described by the relevant features. The DP's curriculum content should be focused on the solution of problems formulated to achieve the key goals and intended learning outcomes. The education quality control should be ensured at all stages of the curriculum implementation. The resources supporting the DP should provide the necessary quality of curriculum implementation. Thus, all the components of a typical DP's structure are interrelated. These relations are causal, allowing the high-quality DP implementation to achieve the key goals of education. In this case, any DP can be regarded as a description of the professional training system with a certain level of operational quality. The optimization of the education quality is associated with an efficiency of management of this system.

3 PROCEDURE OF A DEGREE PROGRAMME's DESIGN

The DP's structure description and its elements' interrelations determine its design procedure, consisting of the following consequent steps:

1. Analysis of the requirements of the applicable standards, labor market, and professional community.
2. Selection of the DP type (for Bachelors/Masters).
3. Definition of the DP's key goals and objectives.
4. Formulation of the DP's intended learning outcomes.
5. Definition of the intended learning outcomes' features.
6. Development of the DP's curriculum.
7. Selection of resource support for the DP's implementation.
8. Selection of the education quality control measures.

For the quality of the educational process, it is important to embed the DP's design processes into the processes implemented by a professional training system in a particular field. Any educational institution is interested in improving the overall efficiency of these processes. Hence, the using the continuous process improvement model (called the Deming-Shewhart model or the PDCA cycle) is reasonable [1, 2]. The PDCA cycle is closely connected with quality management [3] where the process control and optimization are especially important. This model assumes a cyclic repetition of four steps. Plan (P): the establishment of objectives and the processes necessary to achieve them, the planning of activities for achieving the objectives and satisfying the customers, and the necessary resource allocation and distribution. Do (D): the planned activities' implementation. Check (C): the collection of information and control of the process implementation results based on the key performance indicators, the identification and analysis of deviations, and their causes. Impact, management, updating (A): the adoption of measures to address the causes of the deviation, and the changes in the planning and allocation of resources.

The application of the first PDCA cycle to the educational process is the first process implementation: P: the DP's design; D: the implementation of the DP's curriculum; C: the educational process's quality control in order to determine the level of the tasks solution set out above and the objectives' achievement degree, detection of abnormalities and their reasons' analysis; and A: the DP's adjustment, which involves the elaboration of measures to change the design process content.

The subsequent PDCA cycles correspond to the continuous improvement of the educational process. In this case, it is important to choose the intervals between the full cycles and to define the control procedures.

Taking into account the educational process's inertia (study duration) and its phasing (semesters, academic years) two options for its improvement are recommended. The *tactical improvement* is associated with the correction of the curriculum and resource support. This adjustment should occur after the educational year based on the DP's quality self-assessment. The *strategic improvement* is associated with the correction of all DP's components. This adjustment should occur after the completion of a full cycle of training on the programme (e.g. four years for a Bachelor's DP and two years for a Master's DP) based on the self-assessment and external audit of the DP's implementation quality. It is possible to associate the quality control with the processes of the DP accreditation.

We also consider an example of the design procedure for any Bachelor's and Master's DP in the field of IS that takes into account all the specific peculiarities and requirements (national and international) for education in this field. The general (non-technical) education requirements (e.g. in humanities, social sciences, etc.) are out of scope of this paper.

3.1 The requirements of applicable standards, labor market and professional community

The requirements of a separate segment of the labor market and professional community for the qualification of professionals who are capable of fulfilling the kinds of professional activity can be found in various national or international regulations. The documents developed in the USA, Australia, the Russian Federation, the European Community and the International Organization for Standardization (ISO) are the most interesting in the IS field.

The National Cyber Security Division of the U.S. Department of Homeland Security (DHS/NCSD) published the "Information Technology Security Essential Body of Knowledge: A Competency and Functional Framework for IT Security Workforce Development" [4]. NIST prepared the more specialized National Initiative for Cybersecurity Education (NICE) [5]. The Australian Government Information Management Office developed "Cyber Security Capability Framework & Mapping of IS Manual Roles" [6]. The European Commission approved the e-Competence Framework version 3.0 (e-CF 3.0) [7]. ISO has drafts of new standards. ISO/IEC 27021 covers "… [c]ompetence requirements for information security management systems professionals." Three parts of ISO/IEC 19896 describe knowledge, skills, general and effectiveness requirements for ISO/IEC 19790 testers and ISO/IEC 15408 evaluators.

The state-level requirements' formulation features in the documents of the USA, Australia, the European Community and ISO were analyzed in detail in [8].

In our research, we used the requirements of the generalized Russian labor market in the field of IS, combining government, industry and academia. The Russian Federation has developed a set of IS professional standards [9]. At the beginning of 2017 this includes the following professional standards: "Specialist in automation of information and analytical activity in the sphere of security"; "Specialist in security of computer systems and networks"; "Specialist in IS of automated systems (ASs)"; "Specialist in IS in telecommunication systems and networks" and "Specialist in technical information protection". The "Specialist in IS of ASs" professional standard has been approved at the state level. The remaining standards have a project status.

All these standards have a common methodology for forming the requirements. Each professional standard formulates the name of the professional activity; the key goal of the type of professional activity; the generalized job functions included in the type of professional activity; the specific job functions related to a certain generalized function, etc. In our research, we take all this information from the standard as initial data for the DPs and hence we do not show how key goals, learning outcomes and requirements are derived from one another.

Each job function relates to a specific professional qualification level (PQL). The graduates of the educational institutions on the Bachelor's DPs can fit on their qualification to the 6^{th} level (PQL=6); the graduates on Master's DPs, to the 7^{th} level (PQL=7). For each job description, the job activities that a professional with a specific PQL can perform are described and the necessary knowledge and abilities that he/she must possess are identified.

As an example, the main provisions of the "Specialist in IS of ASs" professional standard are considered.

The name of professional activity: IS ensuring for ASs.

The key goal of the type of professional activity: IS ensuring for ASs, which operate under the threats in the information sphere and describe the information and technological resources to be protected.

The generalized job functions, corresponding PQLs, work functions, positions held and the required levels of education: are presented for the Bachelor's and Master's DPs in Table 1 (where HPE means Higher Professional Education). Russia uses a three-tier HPE system: Bachelor (4 years), Master (2 years after Bachelor) or Specialist (5-6 years), Post-graduate school (3-4 years after Master or Specialist)). Bachelor graduates with or without work experience can perform a generalized job function B (PQL=6), occupying one of the positions listed in Table 1. Master or Specialist graduates without work experience can perform a generalized function D (PQL=7), occupying one of the positions listed in Table 1.

An example of job activities that can perform a professional, referred to a specific PQL, and the necessary knowledge and abilities that he/she should possess: Table 2 shows the "Administration of IPSs for ASs" job function (the generalized job function B; at the same time, he/she should complete a Bachelor's DP and have no work experience) and for the "Development of the design decisions for the AS's information protection" job function (the generalized job function D; at the same time, he/she should complete a Master's DP and have no work experience).

Table 1. The generalized job functions, corresponding PQLs, positions held and required levels of education from the "Specialist in IS of ASs" professional standard

Generalized job functions		*Work functions*	*Position held*	*Required level of education*
Code	*Name*	*Name*		
B (PQL =6	Ensuring IS for ASs during their operation	Diagnosis of information protection systems (IPSs) for ASs Administration of IPSs for ASs IS management for ASs Providing IPSs functioning in emergency situations Monitoring of information protection in ASs Audit of information protection in ASs	Information Protection Engineer Information Protection Specialist Software Engineer for Technical Information Protection Software Engineer	HPE, Bachelor
D (PQL =7)	Design of IPSs for ASs	Testing of IPSs for ASs Design decision development for the AS's information protection Development of the maintenance documentation for IPS for ASs Development of software and hardware IPSs for ASs	Leading IPSs' Development Engineer Leading Information Protection Specialist IPS's Development Project Head IPS's Department Head	HPE, Master, Specialist

Table 2. An example of job activities and the necessary knowledge and abilities from the "Specialist in IS of ASs" professional standard

	Basic education – Bachelor's DP	**Basic education – a Master's DP**
Job activities	Installing AS's software updates Protecting information, taking into account the requirements of the efficient AS's functioning Managing AS's users authorities Informing users about AS's operation rules, accounting the IS requirements Conducting training of personnel to work with AS's IPS, including the workshops with staff on models or in a test area Changing of operational documentation and organizational and administrative documents for AS's IPS	Developing the IS threats' models of and the intruders' models for ASs Developing the models of ASs and ASs' protection subsystems Developing the regulation drafts, regulating the information protection activities Developing the proposals on improvement of AS's IS management system
Necessary knowledge	The formation principles for IS policy for ASs Hardware and software IPSs for ASs The key cryptographic methods,	The guidelines and methodological documents of the authorized executive bodies on information protection The regulations and national standards for

	algorithms and protocols, used to protect information in ASs The methods of protection effectiveness control for information leakage via technical channels The criteria for evaluating the effectiveness and reliability of ASs' software protection The technical tools for monitoring the information protection measures' effectiveness The organization principles and structure of AS's software protection system The content and procedure of the personnel activities on operating the protected ASs and AS's IPSs The main information protection measures for ASs	licensing in the sphere of protection of state secrets and information protection tools' certification The principles of construction and functioning, examples of implementations of modern local and global computer networks and their components The information protection features in the automated technological processes' control systems The evaluation criteria for ASs' software protection effectiveness and reliability The organization principles and structure of AS's software protection system The main characteristics of IPTs against leakage via technical channels The formation principles for AS's IS policy
Necessary abilities - To	Create, delete and modify AS users' accounts Write an IS policy for AS's software components Install and configure operating systems, database management systems, computer networks and software systems to meet the IS requirements Use the cryptographic information protection methods and tools in ASs Register the events associated with information protection in ASs Analyze the events associated with information protection in ASs	Apply the existing regulatory framework in the field of IS Apply the regulations on countering technical intelligence Classify the protected information by types of secrets and confidentiality degrees Define the types of access subjects/objects to be protected Identify the access control methods, types and differentiation rules for the access objects to be implemented in ASs Select the information protection measures to be implemented in AS's IPTs Identify the kinds and types of IPTs, ensuring the implementation of technical information protection measures Determine the structure of AS's IPTs according to the requirements of the regulations in the field of IS for ASs

Our analysis of the "Specialist in IS of ASs" professional standard and its comparison with the results of similar analysis of the regulations of the USA, Australia, European Community and ISO standards' drafts [7] leads us to conclude that all these documents have their own peculiarities, reflecting the experience and specifics of the respective countries, and some terminological inconsistency.

However, they have common features: they contain the qualification requirements for IS professionals related to a separate type of work they can perform at a certain position. This information is extremely important for the educational institutions, which are developing and implementing the educational programmes for training IS professionals of a certain level. It allows them to define the key goals and objectives of training and to formulate the requirements for the intended learning outcomes.

3.2 Definition of the DP's key goals and objectives

Defining the DP's key goals and objectives must take into account the key goals and objectives set by the standards mentioned above, and the labor market's requirements. In our case, the DP's key goal can meet the needs of professionals who can do the types of professional activity in a particular segment of the labor market. An example of such a segment is the area of IS that requires professionals of a certain level (e.g. Bachelors or Masters). The types of their professional activities may include, but are not limited to: operation of IPTs or protected information processing systems; design of IPTs or protected information processing systems; management of systems ensuring IS or protected information processing systems; research in the field of IS; and pedagogical activities in the field of IS.

As an example, the definition of the Bachelor's and Master's DP's key goals and objectives for the "Specialist in IS of ASs" professional standard of the Russian Federation is considered.

The overall key goal of the Bachelor's and Master's DP: the training of professionals in the field of IS of ASs, which operate under the threats in the information sphere and protect information and technological resources.

The particular key goal of the Bachelor's DP: the training of professionals in the field of IS for ASs during their operation (as defined in Table 1, based on a generalized job function B).

The objectives of the Bachelor's DP: the training of professionals for the job functions which are defined in Table 1 (column 3, based on the job functions related to a generalized job function B).

The particular key goal of the Master's DP: the training of professionals in developing IPTs for ASs (as defined in Table 1, based on a generalized job function D).

The objectives of the Master's DP: the training of professionals for the job functions defined in Table 1 (column 3, based on the job functions related to a generalized job function D).

The definition of the DP's key goals and objectives directly influences the intended learning outcomes.

3.3 Formulation of the learning outcomes

When determining the requirements for the DP's implementation results, the DP's key goals and objectives should be taken into account, as well as the requirements of the labor market and professional community. These requirements can be found in various regulations of the national or international level.

The modern approach to their definition is based on the establishment of professional competencies of a professional's ability to solve given problems and to perform specific work within his/her sphere of activity [10]. As an example, the definition of the intended learning outcomes for the implementation of the Bachelor's and Master's DPs based on the requirements of the "Specialist in IS of ASs" professional standard of the Russian Federation. The professional competencies in this case can be formulated for each job function (Table 1) based on the determination of the job activities relating to this job function (Table 2).

The intended learning outcomes for the Bachelor's DP: the professional competencies that a Bachelor should have to perform for the "Administration of IPSs for ASs" job function (a generalized job function B). The Bachelor must be able to demonstrate (according to the job activities defined in Table 2) the ability to install AS's software updates; secure information, taking into account the requirements of the efficient functioning of the AS; manage the AS's user rights; inform the users about the rules of AS operation, taking into account the IS requirements; train personnel to work with the AS's IPS, including workshops with staff on models or in a test area; and change the operational, organizational, and administrative documents for the AS's IPS.

The intended learning outcomes for the Master's DP: the professional competencies, that a Master should have to perform for the "Development of the design decisions for AS's information protection" job function (a generalized job function D). The Master must be able to demonstrate (according to the job activities, which are defined in Table 2) the ability to develop the IS threats' and intruders' models for the ASs; the models of the ASs and the ASs' protection subsystems; the regulation drafts regulating the information protection activities; and proposals for improveing the AS's IS management system.

If a DP trains professionals to perform multiple job functions, then a set of professional competencies should be formulated for each job function.

The DP may also include general professional competencies, the formation of which is necessary as a basis for the subsequent formation of the professional competencies. This is especially true for the Bachelor's DPs.

3.4 Definition of the intended learning outcomes' features

Characterization of the intended learning outcomes is traditionally associated with a specific competency by combining observable and measurable knowledge (K), skills (S), and abilities (A) [10]. Knowledge is the cognizance of facts, truths and principles gained from formal training and/or experience. A skill is a developed proficiency or dexterity in mental operations or physical processes that is often acquired through specialized training; using these skills results in successful performance. Ability is the power or aptitude to perform physical or mental activities that are often affiliated with a particular profession.

In accordance with the recommendations of the "The European Qualifications Framework for Lifelong Learning" (EQF) [11], the definition of the learning outcomes' features in the form of requirements to the level of K, S and A depends on the DP's level: EQF level 5 for Bachelors and EQF level 7 for Masters in IS. When defining their features, the "Specialist in IS of ASs" professional standard for Bachelors and Masters (Table 2) were used. The EQF's recommendations were also considered.

The features of Bachelor's and Master's DP intended learning outcomes: The K, S and A are shown in Table 2, where job activities are equal to S.

All these data should be taken into account in the design of appropriate DPs' curricula.

3.5 Development of the DP's curriculum

The curriculum contains a list of training activities for the entire period of study. These activities include classes (C) and students' independent work (IW). As a rule, these activities are implemented within the framework of different curriculum elements: academic disciplines, internships, implementation, and protection of a Final Qualifying Work (FQW). The workload for each element is assessed in conventional units (CUs) or credits (Cs) correlated with the training hours (THs). For example, 1 credit is equal to 36 THs in Russia. The workload is distributed by semesters and study weeks. Each semester covers 18 weeks. Each curriculum element has its own knowledge progress testing (KPT): Exam (E) or Test (T).

The curriculum implementation workload for the Bachelor's DPs is more oftenusually valued at 240 credits. It corresponds to 8640 THs and 4 years (8 semesters) of study.

The curriculum implementation workload for the Master's DPs is usually valued at 120 credits. It corresponds to 4320 THs and 2 years (4 semesters) of study.

An example curriculum structure for a Master's DP is shown in Table 3. It is necessary to identify a list of disciplines, as well as KPT forms, workload (in credits and THs) and the distribution of THs by study weeks for each curriculum element.

Table 3. A curriculum structure's sample for a Master's DP

Curriculum elements	*KPT*	*Workload*				*Distribution by years, Hours per week (C/IW)*			
						1st year		*2nd year*	
		Credits, CUs	*Training hours*			*1st sem*	*2nd sem*	*3rd sem*	*4th sem*
			Total	*C*	*IW*				
Discipline 1	T	2	72	36	36	2/2			
Discipline 2	T	…	…	…	…	…	…	…	…
Discipline N	E	5	144	72	72		4/4		
Internship	3 Es	30	360	0	360	0/6	0/7	0/7	
FQW	E	30	360	0	360				0/20
Total		120	4320						

A programme for each curriculum element, the implementation of which is focused on the formation of specific competencies and intended learning outcomes, should be designed. A certain professional competence is formed by several disciplines [10]. In that case, all the curriculum elements should be combined into the separate training modules. For example, a Bachelor's DP curriculum can be designed based on four modules: General Educational, General Professional, Professional, Internship & FQW's Protection. The General Educational Module combines elements of the discipline; mastering it will create a basis for the students' mastering of disciplines to be included in the General Professional Module. It, in turn, combines elements of the discipline; mastering it will create a basis for the students' mastering of disciplines from the Professional Module. A Master's DP curriculum can be designed similarly based on three modules: General Professional, Professional, Internship & FQW.

The given structure separates the requirements for the intended learning outcomes for each module and expands the range of competencies that should have been formed

at the end of the educational process. Another positive effect of modular curriculum structure is the ability to support the mobility of students in passing their training, when the students can study the individual modules in different educational institutions (this is typical of the dual-diploma DPs).

The ASIIN's recommendations [12] can be used to describe a training module.

3.6 Selection of resource support for the DP's implementation

To implement any DP, the following resources are required: human resources, laboratories, educational and methodical resources, and financial resources. The faculty (their quantity and quality) forms the human resources. The required number of instructors depends on the workload and the number of students enrolled. The faculty's quality depends on the instructors' experience and professionalism (their educational titles, academic degrees, publication activity, etc.). Laboratory support is determined by the number and level of equipment of educational and scientific laboratories. Educational and methodological support is determined by the educational institution's library capacity, accessibility to different information sources, availability of textbooks and training manuals, design of a separate DP's implementation, etc. Financial support for the DP's implementation is based on the funds received from the students (paid training), from various organizations and funds (targeted training), and from the state (budget training).

The resource requirements for the provision of the educational process in the Russian Federation are formulated in the educational standards, and are developed and approved at the state level for each training direction (including that of IS).

3.7 Selection of the education quality control measures

Any educational institution implementing a DP for Bachelors/Masters should be a guarantor of the education quality based on continuous multilevel education in order to best meet the learning outcomes of all stakeholders. For that purpose, a Quality Management System should exist with the appropriate control measures in place. Their formation and development are based on global trends focused on the concept of Total Quality Management, the requirements of ISO 9001:2015 [3], the guidelines for Quality Assurance Agencies in Higher Education, etc.

4 CONCLUSION

The above design procedure has been tested at the Institute of Cyber Intelligence Systems of the National Research Nuclear University MEPhI in the development and implementation of the following DPs in IS: *for Bachelors*: "Automated Systems Security"; *for Masters*: "Cryptographic Methods for Cybersecurity", "Information Security of Crucial Objects" and "Information Security and Intelligence Analysis for Financial Monitoring". All these DPs have been successfully accredited in Russia, proving the consistency of our approach. In addition, these DPs are currently passing the international accreditation by ASIIN. Using our approach, we prepared the DPs' self-

assessment report as an initial data for this procedure. During this self-assessment, we found a few ASIIN requirements were not met (for example, in dividing DPs in training modules, the distribution of disciplines within the modules for the Bachelors' DP). We corrected the curricula to satisfy those requirements. One lesson we learned is that we needed to pay more attention to consumer's demand for graduates of our DPs and their expectations of graduates' knowledge, skills and abilities.

Currently, the third generation of students is being trained with a total enrollment of 105 students (15 Bachelors + 90 Masters). After every graduation year we reviewed and adjusted the curriculum of each DP due to the changes in the requirements and educational content.

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