Analytical Review of the Current Curriculum Standards in Information Technologies

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Abstract. The article provides us with an analytical overview of the current state (the beginning of 2018) of the curriculum system for undergraduate and graduate programs in computing (computing is the academic name of the field of Information Technology or IT), inter alia it considers: definition of the concept of curriculum, modern architecture of the curriculum system, construction principles and content of relevant curricula of the last decade, including the following documents: CC2005, CS2013, CE2016, SE2014, GSwE2009, IS2010, MSIS2016, IT2017, CSEC2017. The article provides a comparative analysis of curricula in terms of methodological solutions in describing educational content and learning objectives, highlighting the minimum required part of the curriculum knowledge (core), composition and methods of using didactic parameters for describing pedagogical emphasis on curricula and learning outcomes. The article will be useful for methodologists-developers of curricula and educational standards, in particular for comparing the domestic educational regulatory and methodological base with international experience in standardizing curricula in the field of training IT personnel. The information presented in the article can also be useful to students and graduate students to understand the international structure of the methodological foundations of the modern IT education system.

Keywords: Curriculum · International educational standards · Computing · IT-education

1 Introduction

The authors have been following the process of developing curriculum standards in the field of computing for many years (computing is the academic name of the field of Information Technology or IT) [1–7]. This approach is not new; it has long celebrated its half-century anniversary. The draft of the first curriculum standard for Computer Science (CS) was published by ACM in 1965 [8], and in 1968, after being finalized, it was published in its final form, known as Curriculum 68 [9]. The history of the curricular standardization of computing is described in detail by Perekatov V.I. [10, 11].

First of all, let's clarify what is meant by the term "curriculum". This is a teaching material in the form of a teacher's manual, designed to develop curricula in specific areas of training, which includes determining the set of expected characteristics of graduates and the requirements for pre-training for applicants to the curriculum, a description of

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the architecture of the body of knowledge of the curriculum, a detailed specification of the elements of the code knowledge, determination of learning outcomes/competencies, and also includes teaching materials with recommendations on methods for training programs, practices and laboratory work, the requirements in the final work, adapt to different institutional environments, etc. As a rule, another important component of such guidelines is the description of examples of curricula and examples of training courses implemented by well-known universities. Unfortunately, the authors cannot offer the term Russian language adequate to this concept. Therefore, we are forced to use the English term.

The goal of the activity under examination is to standardize at the international level the curricula of the IT education system in various areas of IT staff training. Curriculum standardization proved to be the most important methodological tool which contributed to the creation of a modern IT education system. The relevance of standardization of educational programs of IT education, due to the processes of globalization of the world economy and the widespread spread of IT with universal digitalization, is constantly growing.

It is the development of international standards/recommendations in the field of IT education, which have a high level of consensus in the professional environment and serve as a guideline for universities and universities, provides an opportunity to systematize and unify the practice requirements for relevant educational programs and for university graduates, and timely take into account the achievements and trends in the development of science and technology, to generalize and use the best educational practice, to increase the effectiveness of developing current educational programs and thus makes it possible to create a common space in the field of IT education, to provide high mobility of IT specialists. The leading international professional organizations such as the Association of Computer Engineering[1] and the Computer Community of the Institute of Electronics and Electrical Engineers[2] have responsibility for solving the problem of forming such guidelines-recommendations in the form of standardized curricula or curriculums.

Since the beginning of this century, the process of curriculum standardization has taken a systemic, continuous character. By the middle of the first decade of the current century, a holistic approach to building a curriculum standards system was developed, as it was reflected in Computing Curricula 2005 (CC2005) [12], and a set of curricula was created that describe typical curriculum models for the main profiles/areas of IT training. In subsequent years, as part of this process, all the curricula of the first five years were revised and published in new editions. The frequency of revision of curriculum standards is approximately five years.

The article considers the current state (at the beginning of 2018) of the curriculum system for undergraduate and graduate programs, in particular, the content and principles of constructing relevant curriculums of the last five years are examined, their comparative analysis is given in terms of methodological solutions, educational characteristics, and the use of didactic parameters.

[1] Association for Computing Machinery, http://www.acm.org.
[2] IEEE Computer Society, http://www.computer.org.

1.1 Systematic Approach to Curriculum Development

The main conceptual document of the curriculum system for IT education is the document SS2005 [12] mentioned above, defining the architecture of the curriculum system and describing the most important methodological principles underlying the curriculum approach.

In particular, CC2005 includes:

- a description of the curriculum system architecture and professional characteristics of the basic profiles/areas of training;
- a description of the characteristic areas of activity for different basic training profiles using a graphical model of the task space;
- a comparative analysis of basic profiles on the thematic content of training using a scaled tabular form for key technologies common to all profiles;
- a description of the outgoing professional characteristics of graduates of basic profiles;
- general principles for the development of the curricula, ensuring their conceptual integrity, etc.

An important outcome of CC2005 is the differentiation of the main areas of training IT specialists in accordance with the nature of their activities, as well as the definition of the appropriate architecture of the curriculum system. In particular, the following basic profiles are defined (SS 2005 also calls them as subdisciplines):

- Computer Science – CS;
- Computer Engineering – CE;
- Information Systems – IS;
- Information Technology – IT;
- Software Engineering – SE.

Figure 1 illustrates the architectural model of the curriculum system defined in CC2005. The figure demonstrates that this model is open, i.e. it can expand if new IT training profiles are developed. One of the candidates for expanding of this model was the Cybersecurity direction after the Curriculum Guidelines for Post-Secondary Degree Programs in Cybersecurity appeared in 2017 [20]. A distinct feature of this curriculum is that it determines the amount of knowledge and competence for the preparation of bachelors in cybersecurity, while it is assumed that this body of knowledge is the development of one of the main training profiles. This curriculum will be considered in more detail below.

Of the principles of curriculum development defined in CC2005, we note two aspects:

- the emphasis on the design, systematization and structuring of relevant collections of knowledge (explicit or implicit, through competencies), as well as the design of the associated learning outcomes/competencies system for various areas of training IT specialists,

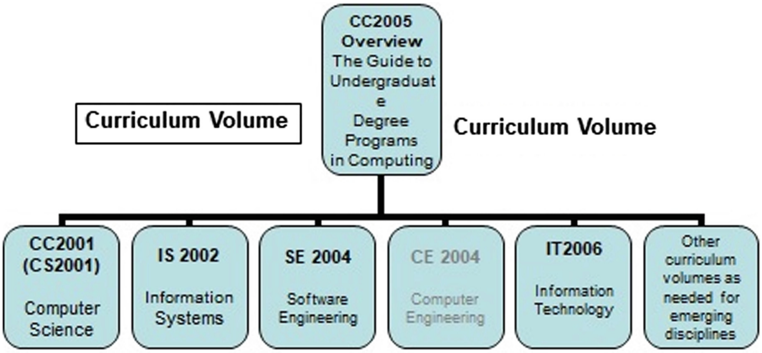

Fig. 1. Architectural model of the curriculum system defined in CC2005.

– the concept of the core of the body of knowledge - the allocation in the body of knowledge of the minimum necessary content (and the corresponding learning outcomes/competencies) for all curricula of a particular profile in the interest of supporting the integrity of the educational space, student mobility, guaranteeing a given level of quality of basic training.

The contents of this document were considered in more detail in previous works of the authors.

In the last five years, almost all the curricula for the above training profiles have been revised and released in new editions.

The modern stack of computing curricula for the training of bachelors and masters, including the main methodological document CC2005, consists of the following documents:

1. Curricula Computing 2005 (CC2005) [12];
2. Computer Science 2013 (CS2013) [13];
3. Computer Engineering 2016 (CE2016) [14];
4. Software Engineering 2014 (SE2014) [15];
5. Graduate Software Engineering 2009 (GSwE2009) [16];
6. Information Systems 2010 (IS2010) [17];
7. Global Competency Model for Graduate Degree Programs in Information Systems (MSIS2016) [18];
8. Information Technology. Curricula 2017 (IT2017) [19];
9. Cybersecurity. Curricula 2017 (CSEC2017) [20].

Figure 2 shows the architecture structure of a modern curriculum system.

Let's look at the main content and characteristics of the above current curriculum standards for each of the basic profiles (areas of training) with an emphasis on the principles of building a Body of Knowledge and CBoK core, as well as determining the learning outcomes and the ones used for them descriptions of didactic parameters.

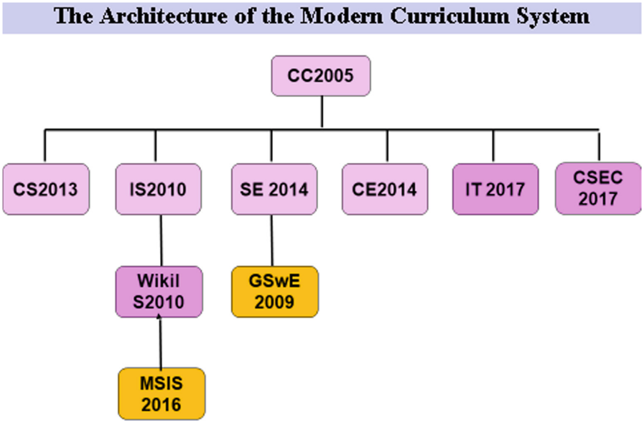

Fig. 2. The architecture of the modern curriculum system.

2 Actual Curricula of Undergraduate and Graduate Programs. Key Features

2.1 Profile Computer Science (CS)

For the CS profile, the latest version of the curriculum standard is CS2013: Curriculum Guidelines for Undergraduate Programs in Computer Science 2013 - a comprehensive revision of the previous edition of the curriculum (CS2008). CS2013 is designed to develop undergraduate CS-programs.

The main attention in the preparation of CS2013 was given to the following points: a thorough review of the body of knowledge, rethinking the core of the body of knowledge, clarification of the characteristics of graduates of CS programs, methodological aspects of training computer scientists in various institutional contexts. CS 2013 also includes a description of examples of CS programs and a significant pool of descriptions of the courses themselves for individual computing disciplines. The document contains more than 500 pages.

Let's take a closer look at CS2013.

In CS2013, the entire amount of top-level professional knowledge is divided into the following 18 subject areas:

- AL Algorithms and Complexity
- AR Architecture and Organization
- CN Computational Science
- DS Discrete Structures
- GV Graphics and Visualization
- HCI Human-Computer Interaction
- IAS Information Assurance and Security
- IM Information Management
- IS Intelligent Systems
- NC Networking and Communications

- OC Operating Systems
- PBD Platform-based Development
- PD Parallel and Distributed Computing)
- PL Programming Languages
- SDF Software Development Fundamentals
- SE Software Engineering
- SF Systems Fundamentals
- SP Social Issues and Professional Practice

CS2013 captures important IT development trends. In particular, this is the increased importance of system solutions, parallel and distributed computing, information security services, and platform-oriented software developments. The attention is again focused on network technologies, in which revolutionary changes are taking place in connection with the advent of the Internet of Things era and the introduction of new network technologies.

Characteristics of the CS2013 Curriculum Standard

1. The basis of this curriculum is the definition of a body of knowledge CS BoK and Learning Outcomes associated with its didactic units. The CS BoK architecture is a four-level hierarchical structure:
   - at the top level of the hierarchy are subject areas (area - disciplinary subfields) - 18 areas;
   - subject areas are divided into thematic modules (units) - 163 modules;
   - modules are divided into topics, revealing the contents of the modules, and they, in turn, can be divided into subtopics.
2. When describing the modules, a list of mandatory topics is highlighted, that is, those topics which make up the core. A two-level core design is proposed, which, for technological reasons, is divided into two parts - two layers (tiers). The core volume, measured in lecture hours, is approximately 300 lecture hours (300 * 4 = 1200 - total hours, taking into account the independent work of students). The first layer of the core includes a list of unconditionally binding topics; for topics in the second layer, some variation is allowed, when it is difficult for universities to implement a complete list of core topics. Module topics can be marked as belonging to the core or be topics of choice (Electives).
3. Learning outcomes are defined at the level of knowledge modules. Thus, a set of topics and sets of learning outcomes are associated with each knowledge module. Result sets can relate to the first layer of the core (Core-Tier1), to the second layer (Core-Tier1), or be unrelated to core themes. In total, 1111 learning outcomes were determined, 562 of which relate to core modules.
4. Each record of the learning outcome is clearly associated with a level of cognition or mastery (level of mastery). Classification of cognitive levels is a simplified Bloom classification/taxonomy model [21]. CS2013 uses a three-level skill assessment scale: Familiarity, Usage, Assessment. From examples of the use of other didactic parameters, the hourly volume (in lecture hours) of the core material (used at the level of knowledge modules), as well as a sign of the presence of optional topics in the module, should be noted.

2.2 Profile Computer Engineering (CE)

For the CE profile, the latest revision of the curriculum is CE2016: Computer Engineering Curricula 2016, a revised version of the previous standard - CE2004, in which the developers tried to reflect the achievements of the last decade in the Computer Technology. CE2016 is designed to develop undergraduate programs.

The introductory part of CE2016 defines the basic principles of its development. The very first is the principle of the continuity of the curriculum updating process, that is, providing the continuous updating of its individual components, taking into account the dynamics of the development of computer technology. The student learning strategy for lifelong learning (LLL) is declared to be an important principle.

CE2016 focuses on building a body of knowledge (CEBoK) in a three-tier architecture. The upper level of the CEBoK hierarchy consists of subject areas (areas), which are divided into basic (core) or additional (supplementary) knowledge modules (units). The lower level of the CEBoK hierarchy (at the topic level) contains learning outcomes associated with the modules and revealing their contents.

The total material of the fields of knowledge is approximately 50% of the total study load in a typical four-year CE bachelor's degree program.

One of the main tasks of CE2016 is the selection and specification of the basic component – the professional knowledge core, which contains the most important concepts and methods of the CE area, which should be included in any CE bachelor's program, which, as has already been pointed out, supports student mobility, guaranteed curriculum compilation, guaranteed level of training quality, flexibility in the development of individualized curricula.

An undoubtedly important part of CE2016 should include a description of the set of laboratory works, both mandatory and optional (about 20 in total), without which it is impossible to train qualified engineers, as well as a description of the requirements for practice and design activities.

The main chapters of CE2016 include the second and third chapters. Chapter 2 defines the characteristics of the graduate, and Chapter 3 describes the architecture of the body of knowledge and its core.

- CE2016 contains 12 subject areas, including:
- CE-CAE Circuits and Electronics
- CE-CAL Computing Algorithms
- CE-CAO Computer Architecture and Organization
- CE-DIG Digital Design
- CE-ESY Embedded Systems
- CE-NWK Computer Networks
- CE-PPP Preparation for Professional Practice
- CE-SEC Information Security
- CE-SGP Signal Processing
- CE-SPE Systems and Project Engineering
- CE-SRM Systems Resource Management
- CE-SWD Software Design

The core of CE2016 also includes four mathematical disciplines, namely:

- CE-ACF Analysis of Continuous Functions
- CE-DSC Discrete Structures
- CE-LAL Linear Algebra
- CE-PRS Probability and Statistics.

Additionally, the minimum set of mathematical areas and modules is determined; they are presented in Table 1 with the minimum required amount of lecture hours [14, p. 27].

Table 1. The minimum set of mathematical fields and modules including the minimum number of lecture hours, required for the study.

Mathematics knowledge areas and units	
CE-ACF analysis of continuous functions [30 core hours]	CE-DSC discrete structures [30 core hours]
CE-ACF-1 History and overview [1] CE-ACF-2 Relevant tools and engineering applications [1] CE-ACF-3 Differentiation methods [4] CE-ACF-4 Integration methods [6] CE-ACF-5 Linear differential equations [8] CE-ACF-6 Non-linear differential equations [3] CE-ACF-7 Partial differential equations [5] CE-ACF-8 Functional series [2]	CE-DSC-1 History and overview [1] CE-DSC-2 Relevant tools and engineering applications [1] CE-DSC-3 Functions, relations, and sets [6] CE-DSC-4 Boolean algebra principles [4] CE-DSC-5 First-order logic [6] CE-DSC-6 Proof techniques [6] CE-DSC-7 Basics of counting [2] CE-DSC-8 Graph and tree representations and properties [2] CE-DSC-9 Iteration and recursion [2]
CE-LAL linear algebra [30 core hours]	CE-PRS probability and statistics [30 core hours]
CE-LAL-1 History and overview [1] CE-LAL-2 Relevant tools and engineering applications [2] CE-LAL-3 Bases, vector spaces, and orthogonality [4] CE-LAL-4 Matrix representations of linear systems [4] CE-LAL-5 Matrix inversion [2] CE-LAL-6 Linear transformations [3] CE-LAL-7 Solution of linear systems [3] CE-LAL-8 Numerical solution of non-linear systems [4] CE-LAL-9 System transformations [3] CE-LAL-10 Eigensystems [4]	CE-PRS-1 History and overview [1] CE-PRS-2 Relevant tools and engineering applications [2] CE-PRS-3 Discrete probability [5] CE-PRS-4 Continuous probability [4] CE-PRS-5 Expectation and deviation [2] CE-PRS-6 Stochastic processes [4] CE-PRS-7 Sampling distributions [4] CE-PRS-8 Estimation [4] CE-PRS-9 Hypothesis tests [2] CE-PRS-10 Correlation and regression [2]

The bulk of the material in CE2016 is presented in two appendices. Appendix A provides a detailed description of the fields and modules of knowledge, together with the associated learning outcome requirements.

Characteristic features of CE2016 structure

1. The main part of CE2016 is the description of the body of knowledge (CEBoK) in the form of a three-level hierarchical structure. The upper level of decomposition of this hierarchy is made up of subject areas (arrears); a purpose (thematic scope) and a set of knowledge modules (units) - obligatory (core), i.e. constituting the core, and additional (supplementary) are defined. At the lowest level in the CEBoK architecture, a set of learning outcomes is defined for each module. The entire volume of professional knowledge is divided into 12 areas plus 4 mathematical areas, 135 modules plus 37 mathematical modules. For the modules of professional fields of knowledge, 923 learning outcomes were identified, 754 of which belong to the core.
2. The core volume is determined by the set of mandatory CEBoK modules. The total academic workload for the professional part of the core is 420 lecture hours, which is significantly higher than the core volume for CS direction (about 300 h), in addition, the CE2016 core also includes modules of mathematical disciplines in the amount of (minimum) 120 lecture hours. (Compared to the previous edition of CE2004, the volume of the mathematical part of the kernel is almost doubled, while the authors of CE2016 admit that 120 h is clearly not enough for training CE-professionals, noting that, as a rule, CE programs give significantly more hours for the mathematical education of engineers).
3. Each level of learning is associated with a learning outcome, which varies from basic abilities, such as understanding and defining concepts, to advanced abilities, such as participating in synthesis and evaluation. Learning outcomes are divided into Core Learning Outcomes and Elective Learning Outcomes.
4. The level of training is determined implicitly using the semantics of the verbs used to describe the learning outcomes and generally corresponding to Bloom's taxonomy, while the learning outcomes provide a mechanism for describing not only knowledge and relevant practical skills, but also personal and transferable skills.

2.3 Profile Software Engineering (SE)

Among the SE documents, two documents are currently relevant:

- SE2014: Curriculum Guidelines for Undergraduate Degree Programs in Software Engineering 2014 – it is a revised version of the previous curriculum SE2004 and is focused on undergraduate studies;
- GswE2009: Curriculum Guidelines for Graduate Degree Programs in Software Engineering 2009 – It is intended to train masters in software engineering.

Let's take a closer look at them.

Curriculum SE2014

This document is a revision of the curriculum SE2004. The new edition largely repeats the structure of the previous version, however, the contents of the original document underwent a thorough revision, starting from the first chapters. In particular, a detailed understanding of the discipline of software engineering is given, taking into account its development over the past decade (Chapter 2), the results of student training on SE programs and the principles on which the SE2014 itself (Chapter 3) is based are rewritten in a more consolidated form. The main contents of the document are:

- The specification of the SEEK knowledge set (The Software Engineering Education Knowledge), which SE graduates should own, with the allocation of a core (Chapter 4), i.e. minimum required amount of knowledge for all bachelor programs in SE profile.
- The core is defined by a set of essential topics (essentials), which are marked with a sign (E - Essential). Topics not marked as E are considered desirable (D - Desirable).
- Methodological aspects determining:
  - methods of studying the body of knowledge and the acquisition of practical skills, guidelines for the development of curricula and plans, possible pedagogical strategies (Chapter 5);
  - ways of organizing curricula and the procedure for learning material from the body of knowledge, requirements for a graduation project (Capstone Project) (Chapter 6);
  - issues of adaptation to various institutional environments (Chapter 7);
  - issues of the implementation and evaluation of training programs (Chapter 8).
- Description of examples of curricula (Appendix A).
- Description of an extensive collection of sample courses (Appendix A).

As already noted, the overall structure of SEEK in Chapter 4 has remained virtually the same as in SE2004, but the contents of the body of knowledge have undergone a full revision and adjustment.

The following 10 subject areas comprise the upper level of the hierarchy of knowledge volume SE2004:

1. Computing essentials – CMP.
2. Mathematical and engineering fundamentals – FND.
3. Professional practice – PRF.
4. Software modeling and analysis – MAA.
5. Requirements analysis and specification – REQ.
6. Software design – DES.
7. Software verification & validation – VAV.
8. Software process – PRO.
9. Software quality – QUA.
10. Security – SEC.

It is important to note that SE2014 in terms of structure and content is harmonized with document SWEBOK v3 [22] - a kind of gospel for software developers and practitioners, which makes it easier for curriculum developers to detail the content of topics for individual courses.

SE2014 presents the logical and semantic relationship of the above subject areas, illustrated in Fig. 3.

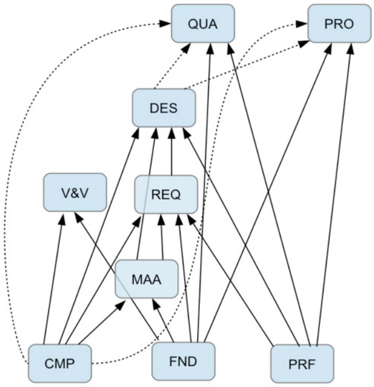

Fig. 3. Relationship between subject areas [15, p. 53].

The main features of SE2014 are:

1. The basis of this curriculum is the definition of the body of knowledge - Software Engineering Education Knowledge - SEEK. SEEK architecture is a three-level hierarchical structure: the top level is subject areas (areas – disciplinary subfields), subject areas are divided into thematic modules (units), modules are divided into topics (topics). In total - 10 areas, 37 modules, 213 topics.
2. The structuring of subject areas into modules is described with the use of tables containing, for each module, the minimum number of contact hours required for study. The structuring of modules on topics is also presented in tabular form, indicating for each topic whether it is mandatory (Essential ©) or desired (Desirable (D)), as well as indicating the minimum level of cognitive development of this topic.
3. The training results give the names of topics with the minimum level of cognitive skill (skill) corresponding to the topic indicated for each topic. The scale of cognitive levels is a simplified model of Bloom's taxonomy and includes three values: k (Knowledge) - Knowledge, c (Comprehension) - Understanding, a (Application) - Application.
4. The total hourly load for studying SEEK core material is 467 h.

Curriculum GswE2009 (*Graduate Software Engineering 2009: Curriculum Guidelines for Graduate Degree Programs in Software Engineering).*

In 2009, a curriculum for the preparation of masters in software engineering - Graduate Software Engineering 2009 (GswE2009) appeared. It represented an example of the transfer to the magistracy of curriculum development technology based on curriculums with their characteristic features - a clear description of the goals and learning outcomes, a detailed specification the volume of knowledge of vocational training, the allocation of a mandatory set of knowledge (core) for all curricula, the definition of an approximate list of relevant areas of specialization.

GswE2009 was created as part of the iSSEc project (Integrated Software & Systems Engineering Curriculum (iSSEc) Project - for integrated software and systems engineering). Its main sponsor is the United States Department of Defense. An active role in the project was played by professional organizations - the International Council for Systems Engineering (INCOSE), the US National Defense Industry Association (NDIA), IEEE-CS, ACM, etc.

GswE2009 includes a description:

- a set of expected learning outcomes (Expected Outcomes When a Student Graduates);
- a set of input requirements for the preparation of students wishing to study under the GswE2009 programs;
- architectural model of curriculum;
- Core Body of Knowledge - CboK, which defines the required body of knowledge for GswE2009 programs;
- a modified Bloom method used to specify educational goals when studying the volume of knowledge;
- training courses containing CboK material, supplementing the SWEBOK knowledge base, taken as the basis for the content of CboK, etc.

The scope of knowledge of GswE2009 (and CboK) is built in the form of a three-level hierarchical system of structural elements (didactic units), including:

- subject areas at the highest level of the hierarchy,
- knowledge modules (second level),
- topics (third and fourth levels, respectively).

Each didactic unit is associated with a certain index that determines the necessary level of mastering of this unit by students and is scaled using the modified Bloom method.

Let's look at the architectural model of the curriculum, shown in Fig. 4.

The curriculum architecture presented includes:

- preparatory material, the possession of which is necessary upon admission to the GswE2009 programs;
- core materials, i.e. CboK;
- university-specific materials;
- elective materials;
- mandatory capstone experience, the figure shows that below it extends the space of professional activity of the master.

In the list of outgoing requirements for graduates under the GswE2009 programs, the first is the requirement for mastery level knowledge in CboK, formed on the basis of the SWEBOK knowledge body, supplemented by a number of topics in systems engineering, information security, training, a human-machine interface, and engineering economics risk management, software quality.

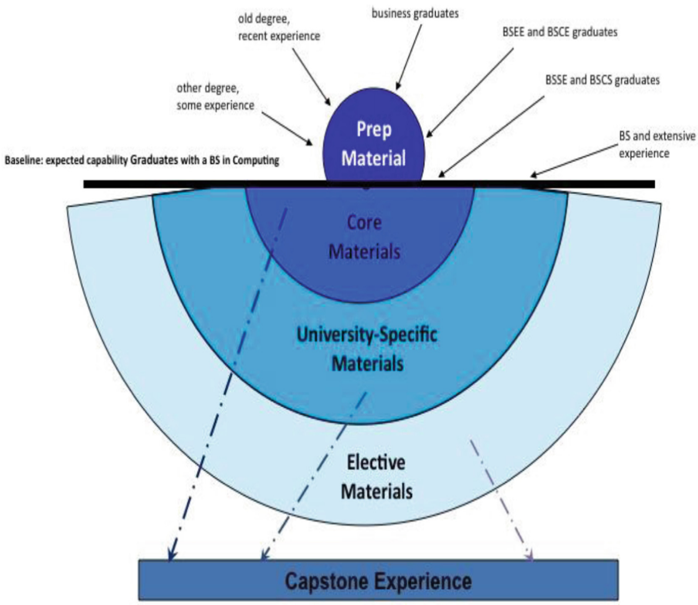

Fig. 4. Architectural model of the curriculum of master's programs in SE profile [16, p. 27]

The core volume is estimated at 200 classroom hours or contact hours needed to study it (i.e., the total hours are four times as much as 800), which is equivalent to 5 semester study courses of 40 classroom hours per semester (160 general hours for each course).

The core structure is shown in Fig. 5 as a right semicircle consisting of sectors corresponding to the nuclear part of a certain subject area of knowledge, while the size of the sector corresponds to the percentage of this part in percent relative to the entire curriculum.

In total, the kernel includes modules from 11 subject areas, taken mainly from SWEBOK:

1. Ethics and Professional Conduct,
2. System Engineering,
3. Requirements Engineering,
4. Software Design,
5. Software Construction,
6. Testing,
7. Software Maintenance,
8. Configuration Management (CM),
9. Software Engineering Management,
10. Software Engineering Process,
11. Software Quality.

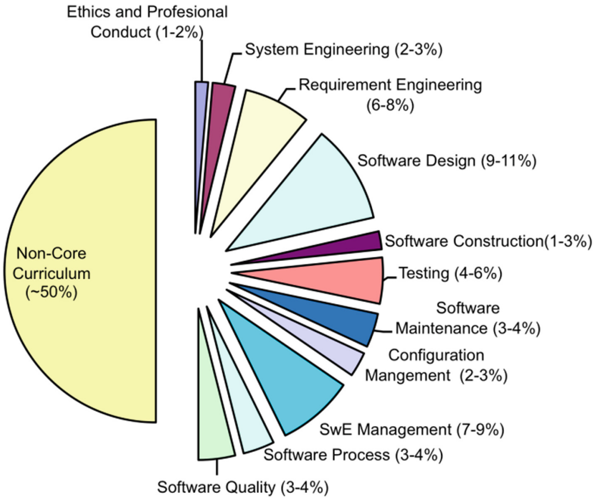

Fig. 5. The core of the curriculum GswE2009 structure [16, p. 46].

Characteristic features of SE2014 are:

1. The body of knowledge GswE2009 (and therefore CboK) is built in the form of a three-level hierarchical system of structural elements (didactic units), including:

   – subject areas at the highest level of the hierarchy (11 areas),
   – knowledge modules - second level, 53 modules,
   – topics/subtopics of knowledge modules - third level, more than 200 topics.

2. The affiliation of the didactic unit (region/module) to the core is indicated both for the regions (in this case, all the modules of the region are considered to be part of the core) and for the modules. SWEEBOK is used to form the content of topics in the body of knowledge
3. A certain didactic parameter is associated with each module. The parameter determines the necessary level of mastering of this unit by the student and is scaled using the modified Bloom method. In particular, the following scale is used to determine the cognitive level of the knowledge module:

   • Knowledge (K)
   • Understanding ©
   • Application (AP)
   • Analysis (AN).

4. The amount of mandatory material in CboK at 200 class hours seems to be very significant. This is essentially about 50% of the entire curriculum.

5. The CboK analysis shows the extremely important importance that GswE2009 devotes to the study of modern international standards, especially in the field of system and software engineering, including: SWEBOK, CMMI, ISO/IEC 12207, ISO/IEC 15288, IEEE software engineering standards package (about 40)
6. Knowledge and systems of educational standards of computing is required of masters.
7. 10 Outcomes of a high level are identified. They are related to the educational program as a whole. The level of development of educational material (didactic parameter) is determined for the modules. The final results of the mastery of the module material are more than 200 topics.

2.4 Information Systems

For the IS profile, the following documents are relevant:

– IS2010 Curriculum Update: The Curriculum Guidelines for Undergraduate Degree Programs in Information Systems – It focuses on the training of IS bachelors, it is developed in the form of two technically equivalent manuals - in the form of a traditional document, as well as in the form of a Wiki resource - IS Curriculum Wiki.
– MSIS2016: Global Competency Model for Graduate Degree Programs in Information Systems – Global competency model for master's programs in information systems.

IS2010

The development of IS2010 aims at displaying significant changes in this area, including: standardization of IS design processes, the widespread adoption of web technologies, the creation of new architectural paradigms, the extensive use of large-scale ERP systems, the extensive use of mobile computers and gadgets, and the extensive use of infrastructure frameworks (such as ITIL, COBIT, ISO 17799), etc.

IS2010 defines the highest level outcome expectations, and the graduate must be able to do the following:

- Improving organizational processes
- Harnessing the power of technological innovations
- Understanding and resolving information requirements
- Design and management of enterprise architecture
- Identification and evaluation of solutions and sources of alternatives
- Securing data and infrastructure and
- Understanding, managing and controlling IT risks.

The body of knowledge IS BoK, described in Appendix 4 of IS2010, is traditionally built in the form of a three-four-level hierarchy - at the top level there are areas divided into units of knowledge (units), which, in turn, are represented as sets of topics/subtopics (topics). IS BoK contains 20 subject areas, divided into four categories, as shown in Table 2 [17, p. 82].

Table 2. The structure of subject areas (areas) of the IS BoK knowledge base.

Areas of the IS BoK knowledge base	
General computing knowledge areas (details from CS 2008)	Programming Fundamentals Algorithms and Complexity Architecture and Organization Operating Systems Net Centric Computing Programming Languages Graphics and Visual Computing Intelligent Systems
Information Systems Specific Knowledge Areas	IS Management and Leadership Data and Information Management Systems Analysis & Design IS Project Management Enterprise Architecture User Experience
Professional Issues in Information Systems	Foundational Knowledge Areas Leadership and Communication Individual and Organizational Knowledge Work Capabilities
Domain-related Knowledge Areas	General models of the domain Key specializations within the domain Evaluation of performance within the domain

The category of general subject areas of computing uses the corresponding amount of knowledge from CS2008 (now from CS2013).

The category of areas specific to this profile is structured into knowledge modules as shown in Table 3 [17, pp. 83–84].

For IS2010, the following features of its construction are characteristic:

1. A structural model of the curriculum is introduced. It consists of core courses and elective courses, which include descriptions of the body of knowledge and learning outcomes. The latter are associated with courses (core courses or additional courses), and not with BoK didactic units.
2. Two categories of courses are used here: - core courses and optional courses or electives. The core courses contain the topics necessary for all tracks of vocational training, and the electives contain the topics from which the profiling of training or tracks of vocational training are built.

Table 3. IS BoK-specific areas for this profile.

Information Systems Specific Knowledge Areas	
IS Management and Leadership	Information Systems Strategy Information Systems Management Information Systems Sourcing and Acquisition Strategic Alignment Impact of Information Systems on Organizational Structure and Processes Information Systems Planning Role of IT in Defining and Shaping Competition Managing the Information Systems Function Financing and Evaluating the Performance of Information Technology Investments and Operations Acquiring Information Technology Resources and Capabilities Using IT Governance Frameworks IT Risk Management Information Systems Economics
Data and Information Management	Basic File Processing Concepts Data Structures Data Management Approaches Database Management Systems Data and Information Modeling at Conceptual and Logical Levels Physical Database Implementation Data Retrieval and Manipulation with Database Languages Data Management and Transaction Processing Distributed Databases Business Intelligence and Decision Support Security and Privacy Policies and Compliance Data Integrity and Quality Data and Database Administration
Systems Analysis & Design	Systems Analysis & Design Philosophies and Approaches Business Process Design and Management Analysis of Business Requirements Analysis and Specification of System Requirements Configuration and Change Management Different Approaches to Implementing Information Systems High level System Design Issues Identification of Opportunities for IT-enabled Organizational Change Realization of IT-based Opportunities with Systems Development Projects System Deployment and Implementation System Verification and Validation
IS Project Management	Project Management Fundamentals Managing Project Teams Managing Project Communication Project Initiation and Planning Project Execution & Control Project Closure Project Quality Project Risk Project Management Standards
Enterprise Architecture Enterprise	Architecture Frameworks Component Architectures Enterprise Application Service Delivery Systems Integration Content Management Interorganizational Architectures Processes for Developing Enterprise Architecture Architecture Change Management Implementing Enterprise Architecture Enterprise Architecture and Management Controls

(*continued*)

Table 3. (*continued*)

Information Systems Specific Knowledge Areas	
User Experience	Usability Goals and Assessment Design Processes Design Theories and Tradeoffs Interaction Styles Interaction Devices Information Search Information Visualization User Documentation and Online Help Error Reporting and Recovery Professional Issues in Information Systems Societal Context of Computing Legal Issues Ethical Issues Intellectual Property Privacy IS as a Profession

Such an approach for the architectural construction of IS2010 is illustrated in Fig. 6.

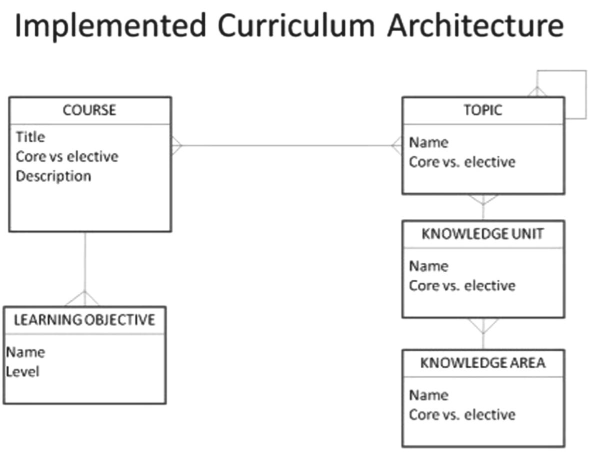

Fig. 6. The implemented structure of the curriculum IS2010 [17, p. 24].

Curriculum includes 7 core courses:

– Information Systems,
– Data and Information Management,
– Enterprise Architecture,
– Project Management,
– IT Infrastructure,
– System Analysis and Design,
– Strategy, Management and Acquisition of Information Systems.

Figure 7 shows the composition of core courses and their relationship to each other.

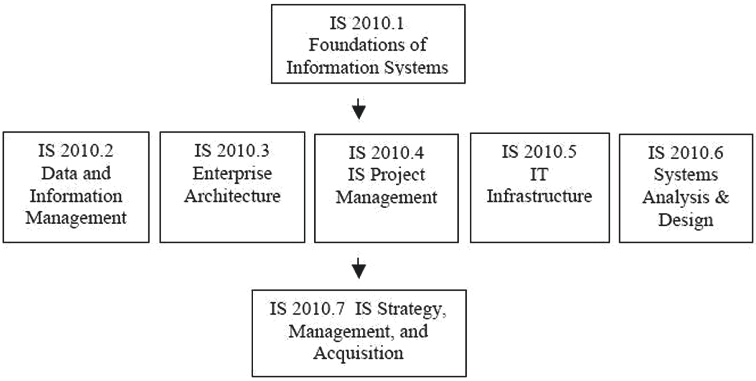

Fig. 7. IS 2010 Core Courses [17, p. 27].

An illustrative list of elective courses includes the following courses:

– Application Development,
– Business Process Management,
– Corporate Systems,
– Introduction to Human-Machine Interaction,
– Audit and Management in It,
– IP Innovations and New Technologies,
– IT Security and Risk Management.

3. There is a novel tool for diversifying programs by presenting educational content in the form of a set of courses in a tabular form, shown in Fig. 8. In these tables the rows correspond to basic or optional courses, and the columns are specialization tracks. A black or white circle is placed at the intersection of the rows and columns of the table. If the circle is black then it is believed that the course should be delivered in full scale, if the circles is white then it may not fully cover the course topics.
In total, 17 specialization tracks were developed:

– Application Developer
– Business Analyst
– Business Process Analyst
– Information Technology Management Analyst
– Database Administrator
– Database Analyst
– E-Business Manager
– ERP Specialist
– Information Audit and Data Compatibility Specialist
– Information Technology Developer

Structure of the IS Model Curriculum:Information Systems specific courses

Career Track:	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Core IS Courses:																	
Foundations of IS	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Enterprise Architecture	○	●	○	○	○	●	○	○	○	○	●	○	○	○	●	○	○
IS Strategy, Management and Acquisition	○	●	○	○	○	●	○	○	●	○	●	○	○	○	●	○	○
Data and Information Management	●	○	○	●	●	○	○	●	●	○	●	○	●	○	○	○	○
Systems Analysis & Design	●	●	●	○	○	○	●	○	○	○	○	○	○	○	●	●	●
IT Infrastructure	○	○	○	●	○	○	○	●	●	●	○	○	●	●	○	○	○
IT Project Management	●	○	○	○	○	●	○	○	○	○	●	○	○	○	●	●	●
Elective IS Courses:																	
Application Development	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●	●
Business Process Management		●	●			○	○	○		○	●				○		
Collaborative Computing						○								○			○
Data Mining / Business Intelligence		●		●	●	○	○	○	●		○	○	○	○	○		○
Enterprise Systems		●	●	○	○	○	●	●	○		●	●	○	○			
Human-Computer Interaction	●					○	○				○					●	
Information Search and Retrieval		○		○	●								○				●
IT Audit and Controls	○		●	○	○	○	○	●		●	○		○	○	○		○
IT Security and Risk Management	○			○	○	○	○	●	●	○	○		●	●	○		○
Knowledge Management		●		○		○	○			○							
Social Informatics													○		○		

A = Application Developer
B = Business Analyst
C = Business Process Analyst
D = Database Administrator
E = Database Analyst
F = e-Business Manager
G = ERP Specialist
H = Information Auditing and Compliance Specialist
I = IT Architect
J = IT Asset Manager
K = IT Consultant
L = IT Operations Manager
M = IT Security and Risk Manager
N = Network Administrator
O = Project Manager
P = User Interface Designer
Q = Web Content Manager

Key:

● = Significant Coverage

○ = Some Coverage

Blank Cell = Not Required

Fig. 8. Tracks for the training of bachelors IS [17, p. 26].

– Information Resources Processing Manager
– IT Consultant
– Information Technology Operations Manager
– Information Technology Risk and Security Manager
– Network Administrator
– Project Manager
– Web Content Manager

4. Courses are described as follows:

   – Catalog description
   – Learning objectives
   – Topics
   – Discussion.
   In this way, learning outcomes are described in terms of learning objectives and are associated with courses. There are 161 results in total, 95 of them belong to the IS BoK core.

5. A parameter of a depth metric is associated with each learning objective. This level is implicitly set using the verbs used to describe the learning objectives. The document provides a table of correspondence of such verbs and values of depth of knowledge. As a scale for knowledge levels, a simplified Bloom taxonomy is used (1 - Awareness, 2 - Literacy, 3-Concept/Use, 4 Detailed, 5 Advanced).

MSIS2016

MSIS2016 provides a competency model and curriculum development guide for an IS degree. This joint effort of AIS and ACM is based on previous curriculum standards for IS profile.

The main feature of MSIS2016 is that in it the content of training is not set using the specification of the body of knowledge, it is set indirectly through a structured competency system for graduates of master's programs in the direction of IS.

The overall structure of the MSIS2016 competency framework is shown in Fig. 9.

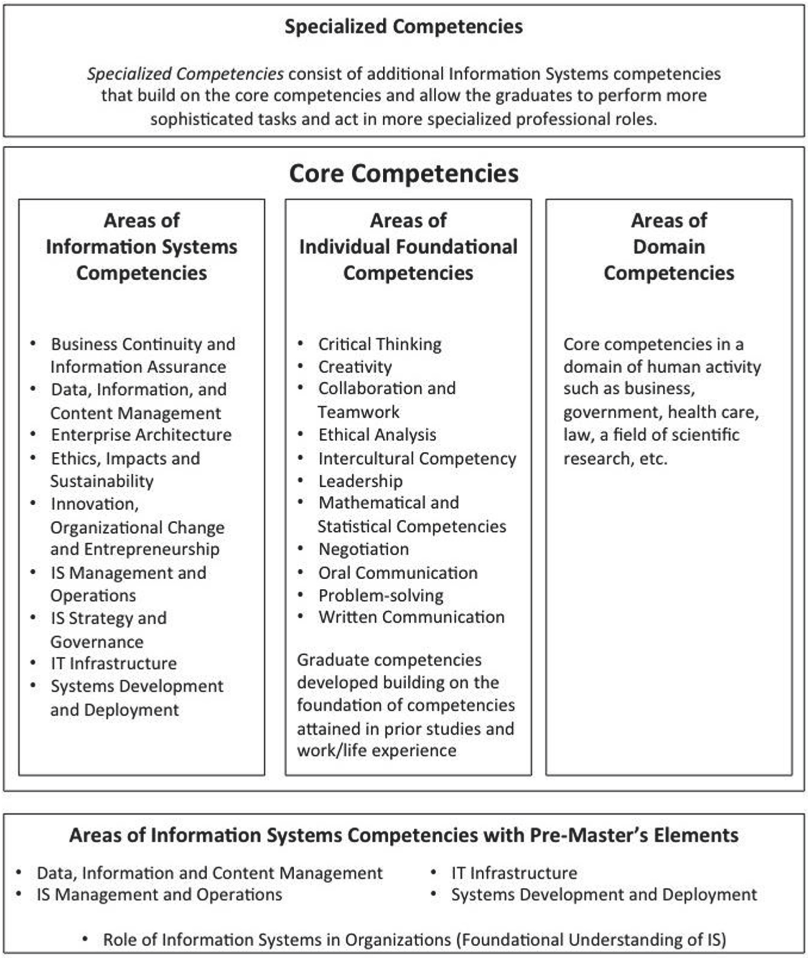

Fig. 9. The competency structure of MSIS 2016 [18, p. MSIS-v].

The figure shows that MSIS 2016 includes nine areas of competence in the field of information systems:

1. Business Continuity and Information
2. Data, Information and Content Management
3. Enterprise Architecture
4. Ethics, Consequences and Sustainability
5. Innovation, Organizational Change and Entrepreneurship
6. IP Management and Operations
7. IP Strategy and Management
8. IT Infrastructure
9. Development and Deployment of Systems.

The composition of the areas of competence for the field of professional training on the course of Information Systems and Management is illustrated in Fig. 10.

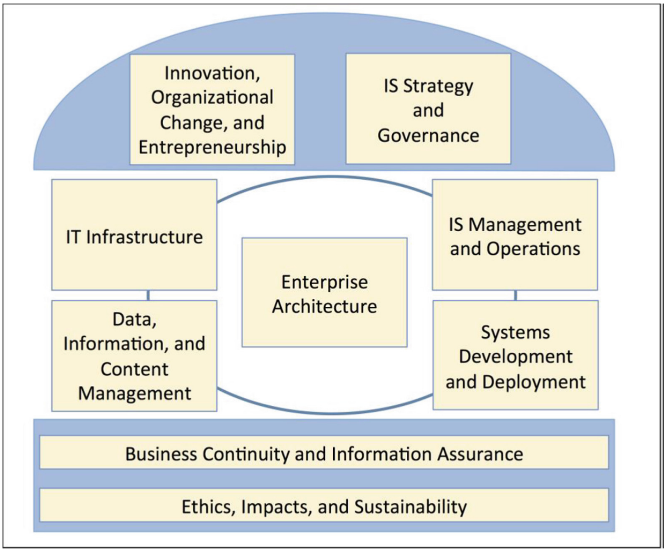

Fig. 10. The composition of the fields of competence for the field of professional training on Information Systems [18, p. MSIS-15].

Each competency area is structured into categories of competencies that could potentially be specified to actual competencies, but this level of consideration is considered overly detailed for MSIS 2016.

MSIS2016 also includes the following areas of individual core competencies: critical thinking, creativity, cooperation and collaboration, ethical analysis, intercultural competence, leadership, mathematical and statistical competencies, negotiations, oral communication, problem solving and written communication.

Another area of competence is competencies in the application area in which IS masters have to work. They identify key areas of competence related to the field of real practice that a particular master's program focuses on. This may be business, healthcare, law, government, education, etc.

Thus, the competency model defined in MSIS2016 is considered as initial data for the design of specific master's programs in the direction of IS, while at the methodological level, an instrument for the transition from competencies to the implemented master's IS-program is considered.

This approach is illustrated in Fig. 11.

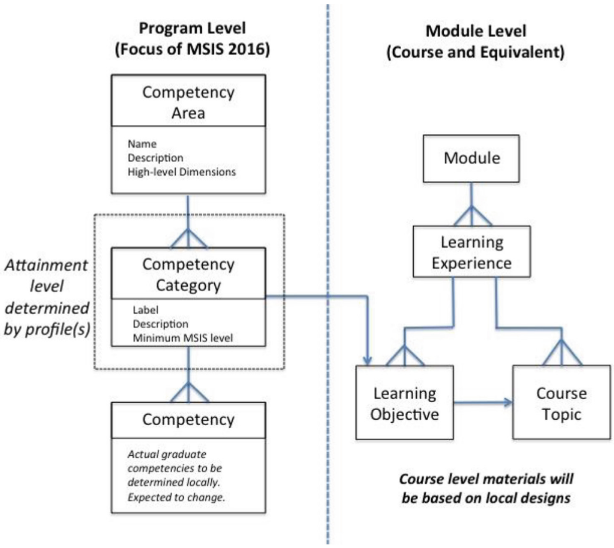

Fig. 11. The MSIS2016 approach involving the design of master's programs based on the competency model of curricula defined in this document for the direction of IS [18, p. MSIS-8].

The main features of building MSIS 2016 are:

1. The integrative nature of the direction of MSIS master's training, aimed at integrating competencies in the field of information systems, a specific applied field of activity and individual basic competencies.
2. The central component of this recommendation contains specifications for the hierarchy of areas of competence and categories of competencies related to technological aspects and management in the field of information systems. The specification of the competency model is two-level.
3. First, a description of the areas of competence at the upper level of abstraction (the level of areas) is given, and then for each area of competence, the competencies of the categories are determined in tabular form with an indication of the minimum acceptable level of their mastery. At this level, there are 88 competencies for technologies and management in the field of information systems, which are considered mandatory, i.e. related to the core BoK.
4. Moreover, category competencies are detailed to 314 competencies. There is also a description of the required areas of individual fundamental competencies

(11 competencies) and examples of areas of competence in the applied sphere (at least 4).

5. Four levels of mastering by each graduate of each competency category are determined: Awareness level, Novice level, Supporting (role) level and Independent (contributor level). For each competency of the category, the minimum acceptable level of its development is set explicitly. The competencies of the category class and the levels of their achievement form the basis for determining the modules (courses and their equivalents).
6. A technique is proposed in the form of a guide to the transition process from the MSIS2016 competency model to the curriculum being implemented.
7. Models of targeted professional profiles of MSIS programs for the preparation of IS masters of the following specializations are proposed:

   – IT Consultant/Systems Analyst
   – Project Manager Profile
   – Analytics Specialist
   – Start-up Entrepreneur.

2.5 Profile Information Technology (IT)

For the IT profile, the current curriculum is IT2017: Information Technology Curricula 2017.

IT2017 is a revised version of IT2008 and is designed to develop IT bachelor's programs (IT programs) for a professional career in IT or for further academic studies.

IT2017 begins by the definition of the IT discipline as a discipline aimed at studying systemic approaches to the selection, development, application, integration and administration of secure computing technologies that allow users to fulfill their personal, organizational and social goals.

Unlike most of the curricula of ACM and IEEE organizations, this document is developed using a competency-based approach in which the content and principles of training are implicitly determined using a structured competency system rather than explicitly defined by a set of professional knowledge. Competencies also determine the results of training the necessary skills that allow graduates of IT programs to successfully perform integrative tasks, apply systemic approaches to the development and administration of safe technological solutions and support users to achieve their ultimate goals.

IT2017 also reflects the need to develop students' personal qualities corresponding to three dimensions: knowledge, skills and dispositions/relationships. In particular, IT2017 proposes a working definition of the concept of competence as an entity linking knowledge, skills and dispositions into a single category. These three related dimensions have the following meanings.

- Knowledge requires knowledge of the basic concepts and content of IT, as well as the ability to learn in new situations.
- Skills relate to opportunities and strategies that develop in practice when interacting with other people and the world around us.

- Dispositions cover socio-emotional skills, behavior and relationships, including responsibility, adaptability, flexibility, self-direction and self-motivation, as well as self-confidence, integrity and self-control, tolerance, perseverance in dealing with complex problems, enthusiasm, innovation, energy, self-generation, respectfulness or resilience.

The competency system structuring is carried out by breaking it into domains covering the main field of activity and knowledge of IT profile graduates. In this case, the domains are divided into essential (essential), which are mandatory, and additional (supplemental).

Essential domains include:

1. Information Management
2. Integrated Systems Technology
3. Platform Technologies
4. System Paradigms
5. User Experience Design
6. Cybersecurity Principles
7. Global Professional Practice
8. Networking
9. Software Fundamentals
10. Web and Mobile Systems.

Essential domains cover those competencies that all students in all IT programs must master. Essential domains represent the minimum amount of competency that should be part of a complete educational IT program.

Additional domains cover competencies, where students perform more specialized work in accordance with the objectives of the program. Additional domains give IT programs more choice and flexibility. They include:

1. Cybersecurity Emerging Challenges
2. Social Responsibility
3. Applied Networks
4. Software Development and Management
5. Mobile Applications
6. Cloud Computing
7. Data Scalability and Analytics
8. Internet of Things
9. Virtual Systems and Services

IT2017 suggests that in the implemented IT programs, approximately 40% of their volume will be significant domains, 20% - additional, and the remainder - specialization domains.

The domain-specific part of the curriculum is determined as a percentage for each domain. The program model with domain weights, expressed as a percentage, is shown in Fig. 12.

IT Domains	Essential Percent	Supplemental Percent
Essential Only (5)		
Information Management	6%	0
Integrated Systems Technology	3%	0
Platform Technologies	1%	0
System Paradigms	6%	0
User Experience Design	3%	0
Subtotal:	**19%**	**0**
Essential + Supplemental (5+5)		
Cybersecurity Principles / Cybersecurity Emerging Challenges	6%	4%
Global Professional Practice / Social Responsibility	3%	2%
Networking / Applied Networks	5%	4%
Software Fundamentals / Software Development and Management	4%	2%
Web and Mobile Systems / Mobile Applications	3%	3%
Subtotal:	**21%**	
Supplemental Only (4)		
Cloud Computing	0	4%
Data Scalability and Analytics	0	4%
Internet of Things	0	4%
Virtual Systems and Services	0	4%
Subtotal:	**0**	
IT2017 TOTAL:	**40.0%**	

Fig. 12. Model IT program with domain weights, expressed as a percentage [19, p. 48].

Essential and additional domains are structured into subdomains, and a didactic parameter is associated with each subdomain - the level of learning engagement.

Three levels are introduced - L1, L2 and L3, determining the nature of training for domain material. L2 level includes L1 level, and L3 level - L2 level, where L1 level corresponds to the first function of the spiral curriculum model, and L2 and L3 levels correspond to the second level [23]. The L1 level used in the subdomain indicates the minimum degree of development related to skills training, the L2 and L3 levels indicate an average and high degree of participation in training.

Another significant domain is mathematical. It includes the following subdomains:

ITM-DSC Discrete Structures:

- ITM-DSC-01 Perspectives and impact [L1]
- ITM-DSC-02 Sets [L1]
- ITM-DSC-03 Functions and relations [L1]
- ITM-DSC-04 Proof techniques [L1]
- ITM-DSC-05 Logic [L1]
- ITM-DSC-06 Boolean algebra principles [L1]
- ITM-DSC-07 Minimization [L1]
- ITM-DSC-08 Graphs and trees [L2]
- ITM-DSC-09 Combinatorics [L1]
- ITM-DSC-10 Iteration and recursion [L1]
- ITM-DSC-11 Complexity Analysis [L1]
- ITM-DSC-12 Discrete information technology applications [L1].

A typical design is used to describe each domain. It includes the following components:

1. Title, for example: ITE-CSP Domain: Cybersecurity Principles
   General description (purpose) of a domain or Scope, for example, **Scope**

   – A computing-based discipline involving technology, people, information, and processes to enable assured operations.
   – A focus on implementation, operation, analysis, and testing of the security of computing technologies.
   – Recognition of the interdisciplinary nature of the application of cybersecurity including aspects of law, policy, human factors, ethics, and risk management in the context of adversaries.
   – The practice of assuring information and managing risks related to the use, processing, storage, and transmission of information or data and the systems and processes used for those purposes.
   – Measures that protect and defend information and information systems by ensuring their availability, integrity, authentication, confidentiality, and non-repudiation

2. Domain level competencies, for example, **Competencies**:

   – Evaluate the purpose and function of cybersecurity technology identifying the tools and systems that reduce the risk of data breaches while enabling vital organization practices. (*Cybersecurity functions*)
   – Implement systems, apply tools, and use concepts to minimize the risk to an organization's cyberspace to address cybersecurity threats. (*Tools and threats*)
   – Use a risk management approach for responding to and recovering from a cyber-attack on system that contains high value information and assets such as an email system. (*Response and risks*)
   – Develop policies and procedures needed to respond and remediate a cyber-attack on a credit card system and describe plan to restore functionality to the infrastructure. (*Policies and procedures*).

3. A list of subdomains indicating the level of training, for example, **Subdomains**:

   – ITE-CSP-01 Perspectives and impact [L1]
   – ITE-CSP-02 Policy goals and mechanisms [L1]
   – ITE-CSP-03 Security services, mechanisms, and countermeasures [L2]
   – ITE-CSP-04 Cyber-attacks and detection [L2]
   – ITE-CSP-05 High assurance systems [L2]
   – ITE-CSP-06 Vulnerabilities, threats, and risk [L2]
   – ITE-CSP-07 Anonymity systems [L1]
   – ITE-CSP-08 Usable security [L1]
   – ITE-CSP-09 Cryptography overview [L1]
   – ITE-CSP-10 Malware fundamentals [L1]

– ITE-CSP-11 Mitigation and recovery [L1]
– ITE-CSP-12 Personal information [L1]
– ITE-CSP-13 Operational issues [L2]
– ITE-CSP-14 Reporting requirements [L1]

The document presents a model of the IT bachelor's curriculum, structured in the form of tapestry fabric, in which the processes of studying the material of significant domains, depicted by straight lines, going from left to right, are stitched with classes on additional domains, forming a structure resembling a tapestry structure. Such a model is illustrated in Fig. 13.

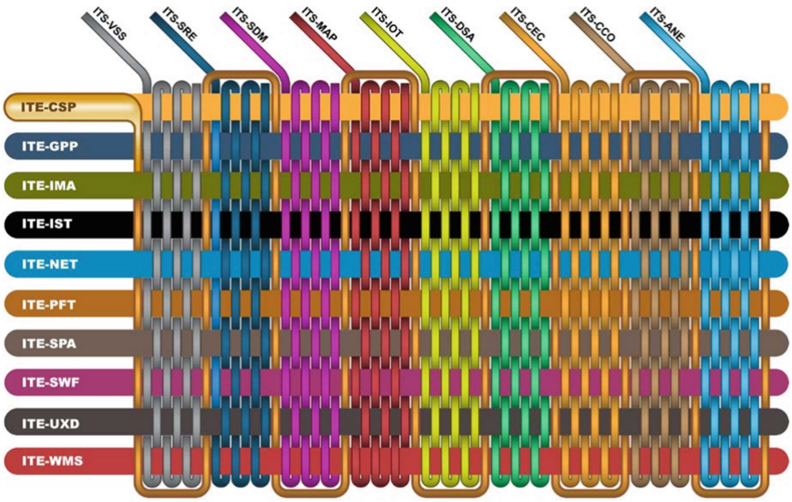

Fig. 13. Tapestry IT program paradigm [19, p. 65].

Appendix B provides a detailed description of the domains, in which for each subdomain a list of competencies corresponding to it is determined. In particular, more than 460 competencies are defined for material domains.

The use of competency of both the domain level and the subdomain implies the association with it of a cognitive parameter called "the learning transfer".

The learning transfer level scale includes the following values:

– **Explain -** students explain the essence of the issue in their own words (with support), use appropriate analogies; they are able to teach others.
– **Interpret -** students understand the meaning, provide a disclosure of the historical or personal dimension of ideas, data and events; they provide a convincing and consistent theory.
– **Apply -** students use what they learn in diverse and unique situations; they go beyond the context in which they learned new topics, courses, and situations.

– **Demonstrate Perspective -** students see the big picture, know and consider different points of view; they take a critical and selfless attitude; they avoid bias in how positions are formulated.
– **Show Empathy -** students are sensitive; they can "walk in someone else's shoes", find potential value in what others may find strange, alien, or implausible.
– **Have Self-Knowledge -** students demonstrate metacognitive awareness of motivation, confidence, responsibility, and honesty; the importance of new learning and experience; they can recognize prejudices and habits that both form and impede their own understanding.

However, when describing competencies in explicit form, this scale is not used. Its implementation is carried out implicitly using a fixed list of Performance Verbs, corresponding in meaning to the considered values of the scale of learning transfer levels.

The main features of IT2017 are:

1. The basis of the document is the definition of the content of educational programs for the preparation of IT bachelors by developing a hierarchical system of competencies. Therefore, this approach to building a curriculum is called competency-based. Competencies are defined at two levels of abstraction: at the domain level (10 substantive subject areas and 14 additional; a total of 80 competencies at this level, including 47 essential) and at the subdomain (module) level - a total of 164 modules, including 83 essential and 12 mathematical), for which defined competencies in the form of actions (Performances) - more than 460 essential (mandatory), and about the same number of additional competencies.
2. Two didactic parameters are defined:

   – the minimum allowable part of the general program volume required to study the material of each substantial and additional domain (determined as a percentage in relation to the volume of the curriculum);
   – for each subdomain, the level of learning engagement is determined - level L1 indicates the minimum degree of load in the development of the corresponding skill, levels L2 and L3 indicate the average and high degree of training load.

3. For each competency, one of six character scenarios of its development, called the level of learning transfer with a scale: Explain, Interpret, Apply, Demonstrate Perspective, Show Empathy, Have Self-Knowledge, is implied.
4. In the competencies wording (both for domains and for subdomains), activity verbs are used, which allows not to explicitly use the parameter level of learning transfer.
5. A tapestry paradigm for organizing IT training programs is proposed to provide a higher degree of integration and interconnectivity of domain material. Also, the authors of the document return to the concept of spiral curriculum [23].

2.6 Cybersecurity. CSEC

For CSEC discipline, Cybersecurity Curricula 2017 has been developed. Curriculum Guidelines for Post-Secondary Degree Programs in Cybersecurity. (CSEC2017).

The construction of cybersecurity as an independent educational discipline is due to the growing dependence of society on the global cyber infrastructure and the digital socio-economic ecosystem, as well as the increasing demand for training highly qualified specialists in a number of work roles related to ensuring the security of system operations, including the creation, operation, protection, analysis and testing of secure computer systems.

Cybersecurity as an educational discipline has extensive and deep educational content that covers many areas of knowledge, including mathematics, cryptography, software development, computer networking, database management, web technologies, automated manufacturing, smart cities, as well as aspects of law, politics, human factors, ethics, risk management, etc.

All this has led to the emergence of internationally standardized recommendations for the development of training programs for specialists in the field of cybersecurity, namely, Cybersecurity Curricula 2017. Curriculum Guidelines for Post-Secondary Degree Programs in Cybersecurity. (CSEC2017).

The development of this document was aimed at the following:

- to develop a comprehensive and flexible curriculum for university education in cybersecurity
- to create educational content, structuring the content of the cybersecurity discipline to develop training programs for training of human resources.

The development of CSEC2017 JTF leads to the expansion of the architecture of computing curricula, introduced in CC2005, the introduction of cybersecurity as another discipline/profile of computing.

Since cybersecurity is an interdisciplinary discipline based on computer and information technologies, the implementation of the academic programs of cybersecurity specialists can develop on the basis of any bachelor's degrees in computer science, but this requires the inclusion of the necessary aspects of law, politics, human factors, ethics and management risks. The cybersecurity architecture presented in Fig. 14 shows these features.

The criteria for the development of CSEC2017 were the following objectives and provisions:

- The foundation for cybersecurity is one of the areas of computing (for example, computer science or information systems),
- The use of cross-category concepts that permeate all areas of cybersecurity knowledge (for example, hostility of the environment in the field of activity)
- Creating a body of knowledge containing the most essential knowledge and skills in the field of cybersecurity,
- Direct connection with a range of specializations that meet the requirements of the relevant sector of the labor market.

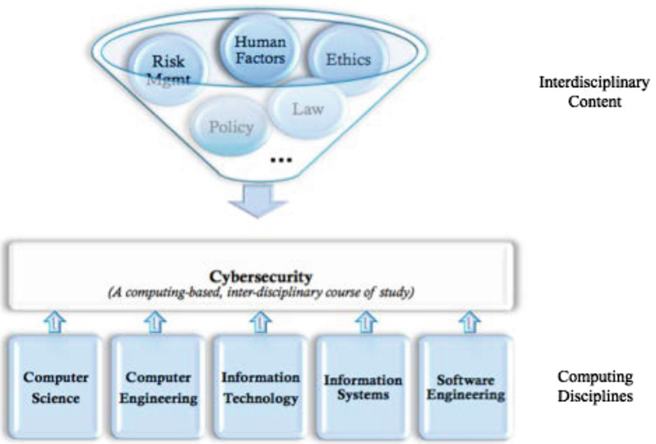

Fig. 14. The structure of cybersecurity as an academic discipline [20, p. 18].

- Focus on ethical behavior and professional responsibility.

When developing this document, we used some abstract cybersecurity model (CSEC thought model), then just a CSEC model, shown in Fig. 15.

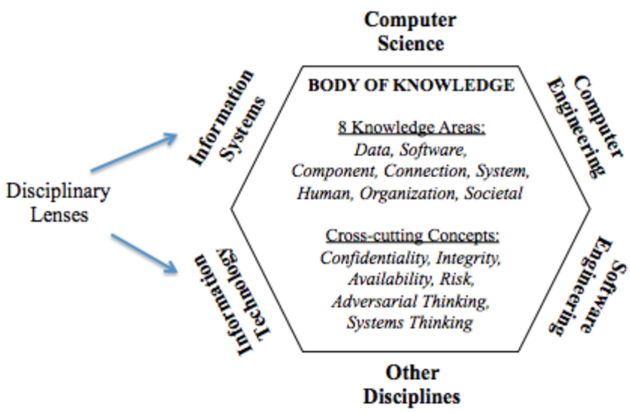

Fig. 15. CSEC- model [20, p. 20].

As you can see from the figure, the main component of the CSEC model is the amount of knowledge covering the security of such entities as data, software, components, systems, organizations, society, and is built on the basis of the concepts of confidentiality, integrity, accessibility, risk, a hostile environment, systematic thinking.

The body of knowledge CSEC is designed in a traditional way. It represents a three-level hierarchical structure. At the top level, its organizational basis is knowledge areas (KAs). Collectively, the fields of knowledge represent the full body of knowledge of the cyber security discipline. Areas of knowledge are divided into knowledge units (KUs) - thematic groups covering many related topics that describe the necessary content for each KU.

Each area of expertise includes a number of critical concepts that are critical to all cybersecurity content. Such concepts are called the fundamentals or the main themes/concepts (essentials)/It is assumed that each student should master them regardless of the direction of the CSEC program. A total of 44 such basic concepts have been identified. In a real program, they can be implemented in the form of modules or topics of educational content.

Learning outcomes (outcomes) are the descriptions of what students should know or be able to do after studying topics in their area of expertise. Learning outcomes are associated with basic concepts (!).

In total, 8 areas of knowledge fundamental for cybersecurity are identified:

– *Data Security*
– *Software Security*
– *Component Security*
– *Connection Security*
– *System Security*
– *Human Security*
– *Organizational Security*
– *Societal Security*

The description of all cybersecurity content is divided into a description of the content for each area of expertise. The description of each field of knowledge is given in two tables. The first table defines a list of basic concepts, then a list of knowledge modules for which the topics included in their composition are indicated, and a description of its content is given for each topic. An example of such a table (its fragment) for the "Data Security" area is illustrated with the Table 4 [20, pp. 24–30].

The second table links the basic concepts of the field of knowledge with learning outcomes. An example of such a table is shown with the Table 5 [20, pp. 30–31].

CSEC2017 also demonstrates an approach to linking learning outcomes from a CSEC program with competencies (Competence = Knowledge, Skills, and Abilities (KSA)) of the workplace. This approach is illustrated in Fig. 16.

The main features of CSEC2017 are:

1. The basis of the document is the definition of the content of educational programs for the training of cybersecurity specialists, as well as the definition of learning outcomes. The amount of knowledge is traditionally determined in the form of a three-layer architecture: knowledge areas (KAs), knowledge units (KUs), topics (topics).
2. For each field of knowledge, a set of critical concepts that are of fundamental importance for the formation of cybersecurity specialists is determined. Such concepts are called fundamentals or basic concepts (essentials), and they serve as the core of the volume of knowledge - the minimum required amount of knowledge. In CSEC programs, the basics can be implemented using stand-alone modules or themes. A

Table 4. Knowledge area "Data Security".

Units	Topics	Topic description
Cryptography	Basic concepts	• Encryption/decryption, sender authentication, data integrity, non-repudiation, • Attack classification (ciphertext-only, known plaintext, chosen plaintext, chosen ciphertext), • Secret key (symmetric), cryptography and public key (asymmetric) cryptography, • Information-theoretic security (one-time pad, Shannon Theorem), and • Computational security
	Advanced concepts Mathematical background	• Advanced protocols: - Zero-knowledge proofs, and protocols, - Secret sharing, - Commitment, - Oblivious transfer, - Secure multiparty computation, • Advanced recent developments: fully homomorphic encryption, obfuscation, quantum cryptography, and KLJN scheme. • Modular arithmetic, • Fermat, Euler theorems, • Primitive roots, discrete log problem, • Primality testing, factoring large integers, • Elliptic curves, lattices and hard lattice problems, • Abstract algebra, finite fields, and • Information theory
Digital Forensics	…	…
Data Integrity and Authentication	…	…
Access Control		
Secure Communication Protocols		
Cryptanalysis		
Data Privacy		
Information Storage Security		
Digital Forensics		

total of 44 concepts and about 140 compulsory learning outcomes associated with them are identified.

3. Learning outcomes in the form of outcomes are associated with essentials.
4. Didactic parameters are not used explicitly.
5. The general approach to linking curricula with the skills required for a particular workplace for roles that are directly related to cybersecurity is discussed.

3 Curriculum Analysis

Let us briefly analyze the material discussed above.

1. The most important component of curricula is the description of educational content. The following solutions are possible:

   – direct construction in the form of a Body of Knowledge or BoK, as a rule, in the form of a hierarchical structure - areas, modules, themes/subtopics.

Table 5. Learning outcomes.

Essentials	Learning outcomes
Basic cryptography concepts	Describe the purpose of cryptography and list ways it is used in data communications Describe the following terms: cipher, cryptanalysis, cryptographic algorithm, and cryptology, and describe the two basic methods (ciphers) for transforming plaintext in ciphertext Explain how public key infrastructure supports digital signing and encryption and discuss the limitations/vulnerabilities Discuss the dangers of inventing one's own cryptographic methods Describe which cryptographic protocols, tools and techniques are appropriate for a given situation
Digital forensics	Describe what a digital investigation is, the sources of digital evidence, and the limitations of forensics Compare and contrast variety of forensics tools
End-to-end secure communications	[*See also Connection Security KA for related content, p. 32*.]
Data integrity and authentication	Explain the concepts of authentication, authorization, access control, and data integrity Explain the various authentication techniques and their strengths and weaknesses Explain the various possible attacks on passwords
Information storage security	Explain the concepts of authentication, authorization, access control, and data integrity Explain the various authentication techniques and their strengths and weaknesses Explain the various possible attacks on passwords
Data erasure	Describe the various techniques for data erasure

CS2013, CE2016, IS2010, MSIS2006, GSwE2009, SE2014, CSEC2017.
– Implicit definition of BoK through the description of competencies (competency-based approach): MSIS2016, IT2017.

2. Another important task is to determine the BoK core (CoreBoK - CBoK):

– direct build BoK:
– at the area level - CSEC2017 (main topics, critical oblast topics)
– at the course level - IS2010, course topics
– at the module level - GSwE2009
– at the topic level - CS2013, CE2016,

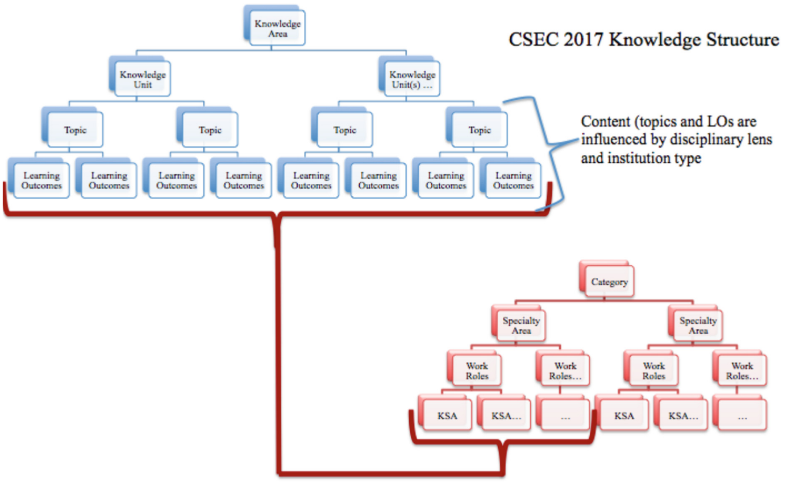

Fig. 16. Establishing the relationship between the learning outcomes of a certain CSEC program with the competencies of the workplace, while competency is understood as a set of knowledge, skills, abilities (Competence = Knowledge, Skills, and Abilities (KSA)) [20, p. 83].

- implicit through the description of competencies (competency-based approach): MSIS2016 (competencies of the categories of areas included in the core - 88, detailed to 314 competencies), IT2017 (significant domains of competencies - more than 460),

3. Definition of learning objectives:

- in the form of learning outcomes - SE2014 (at the topic level), CE2016 (for each topic), GSwE2009 (program level)
- in the form of learning objectives - IS2010 (at the level of courses), MSIS2006 (at the level of courses), CS2013 (at the level of modules),
- in the form of competencies - MSIS2016 (at the level of categories of regions), IT2017 (at the level of domains and subdomains).

4. Didactic parameters:

- the minimum amount of training load necessary to study the material of the didactic unit of educational content (area/domain, module/subdomain, topic) - hours, credits, percent of the total curriculum volume. We will denote it by DEV (Didactic Element Volume);
- level of learning engagement or LLE - the intensity of teaching a didactic unit;
- the level of training, the level of cognition or the level of learning transfer - the minimum allowable part of the total program volume necessary to study the material of each significant and additional domain (in percentage terms), the corresponding part of the curriculum;
- for each subdomain, the level of learning engagement.

Table 6 summarizes the listed above properties of the above curriculum standards in the IT field.

Table 6. The curriculum standards in the IT field.

Curriculum	Body of Knowledge (BoK)	Core BoK	Outcomes	Didactic parameters
CS2013	CSBoK hierarchical structure: - areas - units, - topics, (subtopics) Total 18 areas, 163 modules	Core BoK - approximately 300 (280--308) contact hours, they are defined at the module level A two-level core formation mechanism is used	Learning outcomes are defined explicitly, they are tied to knowledge modules, a total of 1111 learning outcomes, of which 562 relate to core modules. Modules and themes are marked as belonging to the core or as optional (Electives)	• The minimum number of hours to study the part of the core related to the core. Module parameter • Each record of the learning outcome is clearly associated with a level of mastery (a simplified Bloom model): Familiarity, Usage, Assessment • An indication of the presence of optional topics in the module
CE2016	BoK - hierarchical structure: - areas, - units, - learning outcomes. In total there are 12 areas plus 4 math, 135 modules plus 37 math modules	Core BoK 420 plus 120 - mathematics	Learning outcomes are defined when describing modules as mandatory (core related) or optional (elective). There are about 1000 (923) total learning outcomes related only to professional areas, of which 754 are CEBoK core	Levels of learning for learning outcomes are determined implicitly by the semantics of the verbs used. Bloom's taxonomy is the source
SE2014	Body of Knowledge - Software Engineering Education Knowledge (SEEK). The SEEK architecture is a three-level hierarchical structure: areas (area - disciplinary subfields), modules (units), topics (topics). In total - 10 areas, 37 modules, 213 topics	The core is defined by a set of essential topics (essentials), which are marked with a sign (E - Essential). Topics not marked as E are considered desirable (D - Desirable). The total hourly load for studying SEEK core material is 467 h	Expected Student Outcomes - Learning outcomes are measured using the topics themselves by indicating for each topic the minimum level of cognitive skill corresponding to the topic. 213 topics are identified	The scale of cognitive levels is a simplified model of Bloom's taxonomy and includes three values: k (Knowledge), c (Comprehension), a (Application). For each topic, it is indicated whether it is mandatory (Essential - E) or desired (Desirable - D), as well as indicating the minimum level of cognition. Lecture hours are indicated for modules
GSwE2009	The scope of knowledge of GSwE2009 (and, accordingly, CBoK) is built in the form of a three-level hierarchical system of structural elements including: - subject areas (11 areas), - knowledge modules (53 modules), - topics (over 200)	The affiliation of a didactic unit (region/module) to the core is indicated both for the regions (in this case, all the modules of the region are considered to be part of the kernel) and for the modules The core volume is estimated at 200 lecture hours, which corresponds to 5 semester courses The core includes a significant portion of the SWEBOK material	10 high level outcomes are defined. The educational material level of learning is determined for each module. The final results are topics with a didactic parameter - (more than 200 topics)	Each module is associated with a parameter that determines the level of development of the material of the module. Bloom's simplified taxonomy is used: • Knowledge (K) • Understanding (C) • Application (AP) • Analysis (AN) For modules, the SYS attribute is used, indicating that the module topics belong to the core

(*continued*)

Table 6. (*continued*)

Curriculum	Body of Knowledge (BoK)	Core BoK	Outcomes	Didactic parameters
IS2010	The Body of Knowledge IS BoK described in Appendix 4 is traditionally built in the form of a three-level hierarchy: - areas, - knowledge modules (units), - topics/subtopics. IS BoK contains 20 areas divided into 4 categories A curriculum structural model is introduced, it consists of 7 core courses (core courses) and 7 elective courses, which include topics/subtopics of the body of knowledge and learning outcomes	The core consists of core courses. Volume - 280 h	Learning outcomes are described in terms of Learning objectives and are associated with courses In total of 161 results were determined, 95 of which belong to the IS BoK core	Each learning outcome is associated with a depth of knowledge metric parameter. This level is implicitly set with the verbs used to describe the learning outcome. The document provides a table of correspondence of such verbs and values of depth of knowledge. A slightly simplified Bloom taxonomy is used as a scale for levels (1 - Awareness, 2 - Literacy, 3-Concept/Use, 4 Detailed, 5 Advanced - 6)
MSIS2016	The content of training is set indirectly through a structured system of competencies for graduates of master's programs in the direction of IS: - competence areas, - competency categories	All 88 competencies of the category level belong to the core of MSIS, therefore all MSIS programs should provide the opportunity for graduates to master them, at least at the level of awareness	The competency specification is two-level: - at the level of areas of competence - at the level of categories of areas of competencies, a total of 88 competencies of this level for the IS are defined. Competencies of categories are detailed to 314 competencies	Four levels of mastering by each graduate of each competency category are defined: Awareness level, Novice level, Supporting (role) level and Independent (contributor level). For each category competency, the minimum acceptable level of its development is explicitly set
IT2017	The definition of BoK is implicit; it is made through a hierarchical system of competencies. 10 essentials, i.e. Mandatory, domains and 14 additional (Supplemental) domains of competencies spitting mathematical domain	The core is determined by the content of the essential domains of competencies, which determine the competencies that the graduate should receive. Is defined 10 essential domains. The total amount of core material is estimated at 15% of the entire bachelor's program (18 US credits)	Learning outcomes are defined as competencies at two levels: at the level of domains (subject areas) and at the level of subdomains (subdomains or modules). In total, there are 80 domain level competencies, including 47 essential ones), and at the subdomain level, which is only 164, including 83 essential and 12 mathematical ones), more than 460 competences in the form of actions (Performances), and about the same number of additional competencies	Two didactic parameters are defined: 1) DEV - as a percentage of the entire BoK, for substantial and additional domains. 2) LLE: levels L1, L2 and L3. They are used for subdomains. 3) Each competency corresponds to one of six levels of learning transfer: Explain, Interpret, Apply, Demonstrate Perspective, Show Empathy, Have Self-Knowledge. 4) Learning transfer levels are implicitly determined through Performance verbs
CSEC2017	CSEC BoK has a three-level hierarchical structure: Knowledge areas (KAs) - knowledge units (KUs) - topics (topics); thematic groups, which cover many related topics that describe the necessary content for each KU. A total of 8 subject areas are identified	Each area includes a number of critical topics, called essentials, which form the core of the content of a CSEC program. A total of 44 such frameworks are identified.	Learning outcomes in the form of outcomes relate to the basics of areas. A total of about 140 compulsory learning outcomes are defined for 44 foundations	Didactic parameters not used

4 Conclusion

The article attempts to provide an analytical review of the current state (at the beginning of 2018) of the curriculum system for undergraduate and graduate programs in the field of computing, with an emphasis on the study of the principles of building curricula, studying their content, methods for specifying educational content and the minimum required amount of knowledge (core) in training programs, methods for determining learning outcomes, as well as methods for applying didactic parameters to describe the pedagogical emphasis of training programs and learning outcomes. The work examined the entire set of relevant curricula of the last decade, including the following documents: CC2005, CS2013, CE2016, SE2014, GSwE2009, IS2010, MSIS2016, IT2017, CSEC2017.

The article will be useful to methodologists-developers of curricula and educational standards, in particular for comparing the domestic educational regulatory and methodological base with international experience in standardizing curricula in the field of training IT personnel. The material presented in the article can also be useful to students and graduate students to represent the international structure of the methodological bases of the modern system of IT education.

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