METHODICAL BACKGROUND OF COMPETENCE-BASED MATHEMATICS EDUCATION FOR STUDENTS OF INFORMATION TECHNOLOGIES SPECIALTIES

Anna Vintere, Baiba Briede
Latvia University of Life Sciences and Technologies, Latvia
anna.vintere@llu.lv, baiba.briede@llu.lv

Abstract. Currently, the competence-based approach is the main task of higher education to prepare young professionals for a successful career and to ensure the country's socio-economic growth. In order to implement the competence-based approach in practice, it is necessary to develop a methodical framework that includes mathematical competence and skills necessary for professional activities to be developed within a mathematical subject, including also personal qualities that are formed in mathematics studies. In the context of competence-based learning, mathematics studies at the university must be more focused on acquiring sustainable development competences in real life context taking into account the characteristic aspects of an engineer's professional activities. To realise the competence-based approach in mathematics studies in practice, it is necessary to develop a methodological framework from a perspective of the constructivist approach: contextual, interdisciplinary and discipline-based and information technology methods. Therefore, the aim of the article is to establish the methodological background to assess information technologies professionals and stakeholders' math education needs, to create a methodology for the application of mathematical competences worked out by the European Society for Engineering Education Maths Working Group to the students of information technologies specialties, as well as work out an integrative professional and mathematical competence structure with the following components: cognitive, contextual, motivational and value-based components. Based on the interviews with professionals and other stakeholders, in the article the model is described with specified didactical requirements for the mathematics teaching principles appropriate to sustainable development and contributing to mathematics competence building.

Keywords: competency-based education, mathematics, constructivist approach, competences.

Introduction

Mathematics role in sustainable development (SD) is characterised by numerous aspects. Looking at the development of human resources, it should be noted that more than half a century ago mathematician Willy Serve emphasized the role of mathematics in the development of the intelligence and the formation of character, with particular focus on logical thinking and its impact on establishment of good working skills [1]. Throughout the history of mankind mathematics has been a vital part of human culture, a means to understanding the world, a foundation of the development of science and technology. Learning of mathematics has a system-forming function in education, developing an individual's cognitive abilities and logical thinking, and affecting the progression of teaching other disciplines. Mathematics is considered also to be an exclusive construction of human thinking. Disregarding its high level of abstraction and generalization, the subject has fundamental and vital links to our daily world, in both simple daily events and sophisticated scientific matters [2]. Developments over the past decades have led to a remarkable increase in the importance of mathematics and need for the mathematics knowledge and skills in a growing number of occupations. Mathematics develops such skills as complex problem solving, critical thinking, creativity, decision making, cognitive flexibility, which have been identified as some of 10 top skills necessary for the future jobs by the World Economic Forum in 2016 [3].

In spite of the above, several studies have shown that the quality of the mathematics studies is decreasing and the level of students' preparation and knowledge is getting worse. One of the factors that influence the development of mathematics education is that teaching of mathematics consists mainly of transmitting of main concepts to students focusing on tasks-solving techniques. It means, teaching involves passive transmission of abstract, symbolic and existing mathematical structures to students, thus forcing them to adopt thinking structures developed by others, which does not motivate students to get better results. In turn, students are interested in explaining in detail how the particular mathematical concepts and calculation techniques are applied in real life context.

The European Society for Engineering Education Maths Working Group (SEFI) has developed eight levels of mathematical competences and their assessment levels and criteria in the paper entitled "The Framework for Mathematics Study Programs in Engineering" [4]. The problem is that at the moment at the Latvia University of Life Sciences and Technologies the mathematics studies aim is

mainly focused only on the assistance for acquisition of other subjects. However, in the context of SD, SEFI, and knowledge-based learning, university studies in mathematics should focus more on acquiring SD competence in real life, taking into account the skills required for an engineer's professional activity. Therefore, it is necessary to integrate SD competencies into the mathematics study programs according to professional/individual needs and employers' demands.

Therefore, to achieve the target 4.7 of the SD Goal 4 [5], which envisages that by 2030 all learners acquire the knowledge and skills needed to promote SD, mathematics education has to be transformed in order to build the information and communication technologies (ICT) industry specialists' competences necessary for SD, by assessing the potential contributions of mathematics to SD and taking into account that all study programs preparing specialists for the ICT industry are mathematics-intensive.

Materials and methods

In order to improve the education of ICT engineers, the focus should be on mathematics, as the mathematical knowledge of students deteriorates over the last decade, but the technologies are developing very rapidly, which is a key feature of the ICT industry.

Currently, the competence-based approach is the main task of higher education to prepare young professionals for a successful career and to ensure the country's socio-economic growth. In order to implement the competence-based approach in practice, it is necessary to develop a methodical framework that includes mathematical competence and skills necessary for professional activities to be developed within a mathematical subject, including also personal qualities that are formed in mathematics studies.

In this article the methodical background of the competence-based mathematical education is based on the pedagogical findings from different theoretical approaches, disciplines and traditions, and on policy documents concerning mathematical education and professional competence. In the development of the methodology such pedagogical findings have been taken into account: competence-based learnining, constructivist approach, integrative professional and mathematical competence structure appropriate to SD, as well as the European Union and Latvian national documents.

Results and discussion

Several pedagogical studies show that the development of competence-based mathematics education is based on a constructivist approach: contextual, interdisciplinary, disciplinary and information technology approaches that can be considered as a didactic basis for competence development.

Mathematical education for engineers as well as competencies to be acquired in the learning process are determined by "A Framework for Mathematics Curricula in Engineering" worked out by the SEFI Mathematics Working Group [4]. The methodology of this study is worked out based on the recommendations for engineering mathematics curriculum. The competence-based learning of mathematics as a result of the study process involves eight mathematical competences, which are devided into two groups:

1. ask and answer questions using mathematics: mathematical thinking, reasoning, problem solving, modelling;
2. cope with the mathematical language and its tools: presentment, symbols and formalism, communication, assistive aids and tools.

Based on the SEFI methodologies on degree of coverage, mathematics competencies acquired in the mathematics study course consist of four levels – ability can be applied in different life situations and in a new context, can be used in a certain situation that is just a little different from previously known, developed only at reproductive level, such competence is not required for students of this specialty.

In order to develop a professional and mathematical competence structure for ICT specialists that is appropriate for the SD, it should be taken into account that the development of professional mathematical competence can be developed through solving professionally oriented problems.

Research has shown that by addressing a variety of professionally oriented problems, students acquire the ability to analyze the situation that is inherent in the future professional activity [6]. According to Svetlova N.I., students need to learn the different mathematical models of processes and phenomena used in professional activity [7].

Several studies show that the link between mathematics and ICT is based on the content of subject data. "In the process of learning mathematics a logical and algorithmic training of students is forming, skills of building mathematical models of phenomena and processes and for fulfilling numeric evaluation are developing, etc. ICT training provides the basis for understanding the information nature of the studied phenomena, allows the formulation and solution of problems in an effective visual form" [8].

The development of integrative professional and mathematical competence suggested by different authors [9] is based on the following components: cognitive and contextual approach, motivational and value-based as well as eflexive and assessment-based. First two components relate to the use of mathematics in ICT engineering and include practical skills to be used in their professional activities. According to the authors' research, motivational and value-based components are a key that influences mathematics learning at the university [10]. In turn, the reflective and evaluation components of mathematical competence are attributable to the methods and approaches used in mathematics teaching.

In accordance with the "Learning for the Future: Competences in Education for Sustainable Development" [11], SD should be seen as a continuous process of learning and change, involving a variety of actors and focusing on professional development in education, curriculum development and monitoring, and assessment. According to Pidlisnyuk (2010), effective education for sustainable development depends upon a combination of the following factors: legitimacy through the curriculum, new ways of learning, competence of staff, institutional development, partnership and finances [12].

The methodical background of the competence-based mathematics education has to include all themes of the UNESCO programme "Teaching and Learning for a Sustainable Future" [13]: curriculum rationale, sustainable development across the curriculum, contemporary issues and also teaching and learning strategies, which focus on developing teaching/learning skills with interactive, reflection and outdoor methods, and have to be worked out in cooperation with all stakeholders.

According to the World Economic Forum (WEF) 2018, a competent specialist of the 21st century will meet a challenge to "create a shared future in a fractured world" by mending it and leading systems in relation to "preparing workers for future, safeguarding our oceans, making meat sustainable, tackling waste and pollution, unlocking nature's value and secure air travel" [14]. The WEF predicts that the importance of mathematics education and IT skills, and demands for specialists with developed logical and analytical thinking will increase. The role of mathematics will increase crucially to keep a way to real sustainability of societies. In 2018, the WEF also focused on trends that will have a positive impact on business development by 2022. Clearly, these trends are mainly related to the field of ICT, which once again confirms the importance of ICT specialists' education. On the basis of the "Future of Job Survey", the WEF made an analysis of increase in skills until 2022 and further. Skills like analytical thinking, critical thinking and analysis, complex problem solving, reasoning, problem solving and ideation, systems analysis and evaluation are still in the top 10 of the most demanded top skills, and as mentioned above, these are the professional skills that can be developed through mathematics [15]. It is also planned that one of the professionals' skills will be active learning in 2022, as well as being familiar with various learning strategies, the development of which can be contributed by the teaching strategies used by the teacher during the studies at the university.

In the "National Development Plan (NDP) of Latvia for 2014-2020" one of the priority directions of action defines the development of the competences of the inhabitants of Latvia [16]. In order to develop the knowledge, skills and attitudes important for the life in the 21st century, a gradual transition to a competence-based model of education is being introduced in Latvian schools and preschools. In the "Education Development Guidelines 2014-2020" [17] the need is foreseen for researchers to support regular monitoring of the quality of education as well as the development of scientifically based instruments and indicators for the assessment of the quality of the learning

environment is indicated. In the "Science, Technology Development and Innovation Guidelines 2014-2020" [18] as one of the priorities of Latvia's growth the education system has been defined in line with modern and future labour market, which contributes to the implementation of the priorities of the national economy transformation and smart specialization strategy. As ICT has a special role in the field of smart specialization in Latvia, and the special advantages of competitiveness are seen in subsequent research and innovation in this field, building of the ICT industry specialists' competence from the perspective of sustainable development takes place.

By contributing to the building of mathematical competence and promoting the qualification of highly qualified ICT specialists necessary for SD as well as for the development of the state, Latvia is brought closer to the level of European countries and contributes to the increase of competitiveness in Latvia and its regions to the level of the rest of the European Union countries and to increase the relevance of the supply of secondary and higher education to the development trends of society. Moreover, complex problem solving, critical thinking, creativity, decision making, competences of cognitive activity and flexibility, etc., as well as effective use of ICT opportunities contribute to higher education quality and skills, which in turn contributes to SD of society by means of building a knowledge-based economy and improving the quality of life through access to knowledge and cultural resources.

Based on the UNESCO documents, the principles of Education for Sustainable Development (ESD) include: inter-disciplinarity; value-driven; critical thinking and problem solving; participatory decision-making; and applied learning, which is relevant and culturally appropriate to local and other contexts. The researches regarding ESD prove that students need to develop sustainable skills using holistic and systemic approaches, making critical judgements on real life issues, applying theory to practice and vice versa [19, 20]. Different pedagogical approaches have been identified as part of the methodical background of the competence-based mathematics education: interdisciplinary/transdisiplinary, inquiry learning, problem-based approach, self-directed/self-regulated and transformative learning, etc.

Based on the above considerations, the authors distinguish four main components as basis for the methodical background of the competence-based mathematics education:

1. mathematics curriculum rationale: what kind of mathematics is needed for ICT specialists, what, how and why to teach mathemtics;
2. mathematical competence building: eight mathematical competences worked out by SEFI;
3. integrative professional and mathematical competence building: analytical skills – critical thinking, problem solving; systems thinking, creativity, decision-making;
4. ESD appropriate pedagogical methods to ensure competencies building: task solving using IT, games, team work, work in pairs, discussion, brain storming, case stadies, project work, etc.

The framework for transformation of the mathematics education in order to build the ICT industry specialists' competences necessary for SD has been developed (Fig. 1), taking into consideration the above as well as the authors' knowledge and experience in the development and implementation of the curriculum in mathematics and competence-based education:

1. establish a methodology to assess ICT specialists and stakeholders (program heads, employers, decision makers, society, ICT professional organization etc.) mathematical education needs, based on SEFI, for different ICT professional fields – software engineers/ systems engineers/ database engineers/ database administrators/ computer programmers and others;
2. create criteria and indicators to apply SEFI mathematical competences for ICT industry specialists;
3. develop an integrative professional and mathematical competence structure, appropriate to SD, based on the following components described below;
4. develop criteria for selecting a new content and create a model with specified didactical requirements for the content and identify the math teaching methods and principles appropriate to SD contributing to mathematics competence building;
5. develop and implement a strategy for academic staff capacity building and empowerment for transformations in mathematics education from the prospective of sustainable development;

6. create a framework to provide customized non-formal educational support for IT industry professionals to promote getting competences for living and working in the changing world with the main focus on analytical ones;
7. promote cooperation with the ICT industry for application and transfer of mathematical knowledge.

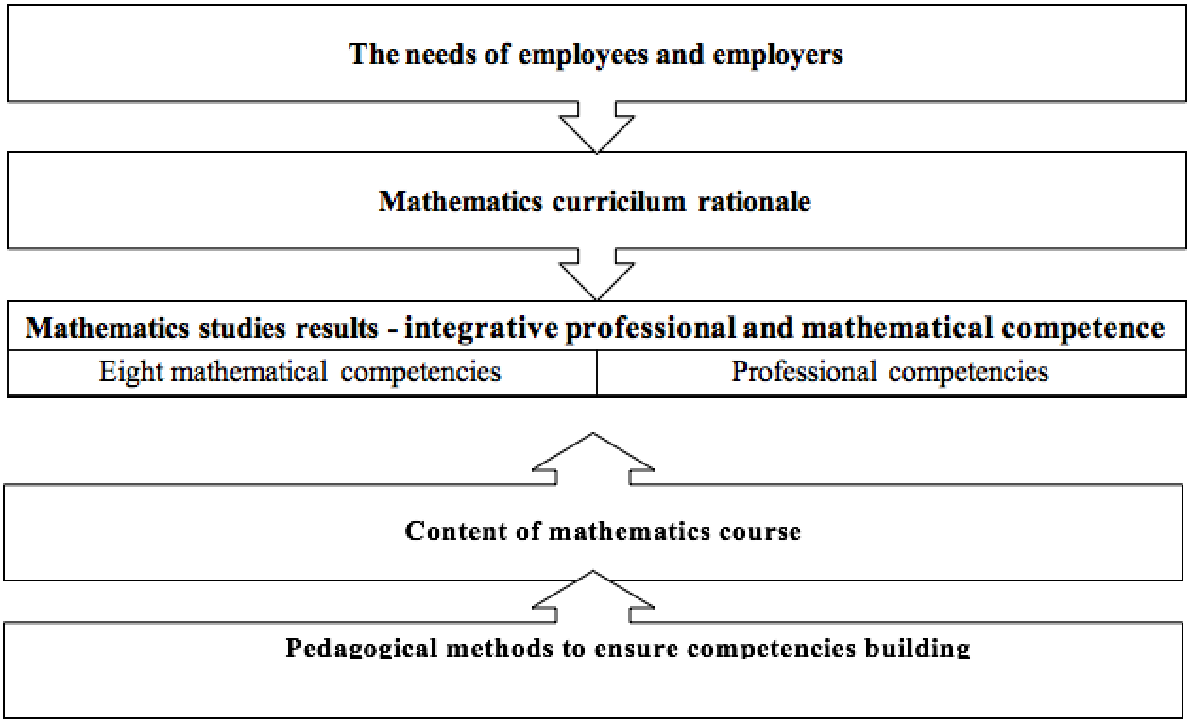

Fig. 1. **Framework for transformation of mathematics education in order to build ICT industry specialists' competences**

In order to determine the requirements of the employers/labor market regarding the knowledge and skills of mathematics specialists in ICT and how the mathematical skills and knowledge acquired at the higher education institution are used in the professional activity, a survey of ICT industry specialists and graduates shall be carried out with focus on how ICT specialists with higher engineering education assess their mathematical competences; how they assess teaching/learning of mathematics at university; how mathematics is applied in the professional activities and which mathematical knowledge and competencies are necessary to perform their profesional activities as well as questions on mathematics as a real instrument of practical activities.

In order to find out the mathematics curriculum rationale, the discussion with the directors of the study programs, the deans and the teachers of professional subjects should be used as a research method. The aim of the discussions is to show the existing mathematics courses contribution for development of competences for future specialists, to show the wide range of mathematics usage in they profession in comparison with the going program as well as ask to remark what fields of mathematics are oriented to the needs and specifics of particular specialty for the purpose of practical knowledge application. The questions for discussion: what is the general educational value of mathematics; what kind of matemtics is needed for ICT specialists; what mathematical competence may be required from ICT specialist to perform the tasks of his profession; which topics of mathematics are most important in teaching mathematics to a student; what should attention be drawn to, what should be emphasized, what teaching methods should be used; the role of mathematical software in teaching mathematics has been discussed as well.

The opinion of the programme managers, the deans and the professors of professional courses is also important in determining the teaching philosophy of mathematics: emphasis on the structure, strictness of mathematics, proofs, tasks of applied nature, solution of practical problem, etc.

Based on the opinion of the ICT specialists and the survey of the graduates, and according to the results of the discussions, the results of mathematics studies, namely, the integrative mathematical and professional competence to be achieved during the study course can be revealed.

Mathematics competence is determined according to the eight mathematical competencies defined by SEFI at three levels of development, from the ability to apply the competence in different life situations and in a new context to only reproductive level.

In view of the above theoretical considerations, it is expected that the professional skills to be developed in the course of mathematics could be analytical skills: critical thinking, problem-solving, systemic thinking, creativity and decision-making skills. There are also three levels of assessment of these competencies, similar to the assessment of mathematical competence.

The next step in the transformation of mathematics education into competence-based education to promote the competence of ICT specialists is to determine the content of a mathematics course, summarising the findings from the ICT industry specialists and graduates survey and taking into account the needs of mathematical knowledge and skills for studying other professional subjects. The content of the course should be determined by evaluating also the mathematics programs and content of other higher education institutions' ICT specialties.

Information about the pedagogical methods that contribute most to the development of mathematics and professional competences can be found in the survey of the ICT specialists and graduates. Mathematics teachers can assist the students who are currently studying mathematics in defining the SD methods with the greatest impact on mathematical and professional competence.

Conclusions

1. As ICT has a special role in the field of smart specialization in Latvia, the building of the IT industry specialists' competence from the perspective of sustainable development takes place. And as the ICT industry is mathematics-intensive, mathematics education at university has to be transformed in order to build the ICT industry specialists' competences necessary for SD.
2. According to constructivism, mathematics studies have to be based on contextual, interdisciplinary and discipline-based, and information technology approaches.
3. Contextual approach usually is associated by the content of studies with the real-world situations of students. The contextual approach to teaching mathematics means that ICT professions require mathematical knowledge for performance of the basic tasks of professional activity.
4. An interdisciplinary approach to teaching blurs the lines between the subject boundaries. Interdisciplinarity usually is understood as usage of knowledge and methods of different disciplines and an ability to work on complex problems in interdisciplinary context.
5. There are four main components as a basis for the methodical background of the competence-based mathematics education: mathematics curriculum rationale, mathematical and integrative professional and mathematical competence development and pedagogical methods to ensure competences development.
6. Based on the analysis of the scientific literature, the methodical background of the competence-based mathematics education has to include the findings of research from different theoretical approaches, policy documents concerning mathematical education and professional competence as well as the views of stakeholders (program heads, graduates, employers, decision makers, society, ICT professional organization etc.) on the educational process.

Acknowledgements

The paper was supported by the grant from the LLU program "Strengthening the Scientific Capacity in the LLU" No. Z32 entitled "Development of the didactical model for transforming mathematics studies into education for sustainable development".

References

[1] Serve V. Teaching mathematics in secondary schools. Mathematical Education, Vol.1, 1957, pp. 22-32. (in Russian)

[2] Gustafsson L., Mouwitz L. Adults and mathematics – A vital subject. Gothenburg, Sweden: National Center for Mathematics Education, 2004. [online] [6.03.2019] Available at: http://ncm.gu.se/media/ncm/rapporter/adult-en.pdf
[3] World Economic Forum. The Future of Jobs Employment, Skills and Workforce Strategy for the Fourth Industrial Revolutio. Global Challenge Insight Report, 2016. [online] [20.02.2019] Available at: http://www3.weforum.org/docs/WEF_Future_of_Jobs.pdf
[4] Alpers B. (Eds.) A Framework for Mathematics Curricula in Engineering. Brussels: European Society for Engineering Education, 2013.
[5] Sustainable development goals, 2015. [online] [20.02.2019] Available at: https://www.un.org/sustainabledevelopment/
[6] Dalinger V.A. Computer technology in teaching geometry: method. recommendations. Omsk: OmGPU, 2011.
[7] Svetlova, N.I. Information technology in the implementation of mathematical methods in economics. Yaroslavl Pedagogical Gazette T.3, 1, 17, 2011.
[8] Vasileva L.N., Kartuzova T.V., Merlin A.V., Merlina N.I. Formation of Professional-Mathematical Competence of Students in the Field of Technical Training Based on Interdisciplinary Integration of Mathematics and Computer Science. Mediterranean Journal of Social Sciences, Vol 6 No 2 S3, MCSER Publishing, Rome-Italy April 2015, pp. 90-97.
[9] Kytmanov A.A., Noskov M.V., Safonov K.V., Savelyeva M.V., Shershneva V.A. Competency-based Learning in Higher Mathematics Education as a Cluster of Efficient Approaches. Bolema, vol.30 no.56 Rio Claro Sept./Dec, 2016. [online] [12.03.2019] Available at:
[10] http://www.scielo.br/scielo.php?script = sci_arttext&pid = S0103-636X2016000301113
[11] Vintere A. Study on the factors contributing
[12] to the motivation of mathematical studies at the university. 15th International conference on Cognition and Exploratory learning in digital age (CELDA 2018): Proceedings, Budapest, Hungary, Oct. 21-23, 2018, International Association for Developemnt of the Information Society. Budapest, 2018, pp. 241-247.
[13] UN Economic Commission for Europe: Learning for the Future: Competences in Education for Sustainable Development, ECE/CEP/AC.13/2011/6. [online] [09.02.2019]. Available at: http://www.unece.org/fileadmin/DAM/env/esd/6thMeetSC/Learning%20for%20the%20Future_%20Competences%20for%20Educators%20in%20ESD/ece.cep.ac.13.2011.6%20ADVANCED%20COPY.pdf
[14] Pidlisnyuk V. Education in Sustainable Development: the role of universities. Economic and Environmental Studies, Vol. 10, No. 1 (13/2010), March 2010, 59-70.
[15] Teaching and Learning for a Sustainable Future. UNESCO programme, 2010. [online] [14.03.2019] Available at: http://www.unesco.org/education/tlsf/
[16] World Economic Forum Creating a Shared Future in a Fractured World. World Economic Forum Report, 2018. Retrieved: http://www3.weforum.org/docs/WEF_AM18_Report.pdf
[17] World Economic Forum. TheFuture of Jobs Report 2018. Insight Report. [online] [14.03.2019] Available at: http://www.unesco.org/education/tlsf/
[18] National Development Plan of Latvia for 2014-2020. Riga: Saeima, 2012. [online] [20.03.2019] Available at: http://www.pkc.gov.lv/sites/default/files/images-legacy/NAP2020 %20dokumenti/NDP2020_English_Final.pdf
[19] Izglītības attīstības pamatnostādnes 2014.-2020.gadam (Guidelines for Education Development 2014-2020) IZM, Rīga, 2013. (in Latvian) [online] [18.02.2019] Available at:
[20] http://www.lsa.lv/wp-content/uploads/2013/03/Izglitibasattistibaspamatnostadnes.pdf
[21] Zinātnes, tehnoloģijas attīstības un inovācijas pamatnostādnes 2014. – 2020.gadam (Guidelines for Science, Technology Development and Innovation 2014-2020). Ministru kabineta 2013.gada 28.decembra rīkojums Nr. 685. (in Latvian) [online] [18.02.2019] Available at: https://www.izm.gov.lv/images/zinatne/ZTAIP_2014-2020.pdf
[22] Dawe G., Jucker, R., and Martin, S. Sustainable development in higher education: Current practice and future developments. A report for the Higher Education Academy: York, 2015.
[23] Parkin S., Johnson, A., Buckland, H. and White, E. Learning and Skills for Sustainable Development: Developing a Sustainability Literate Society, HEPS, London, 2004.