PROBLEMS
OF EDUCATION
IN THE 21st CENTURY
Vol. 81, No. 4, 2023

ENGINEERING PEDAGOGY AND ENGINEERING EDUCATORS' COMPETENCY MODEL FOR EFFECTIVE TEACHING AND LEARNING STEAM

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Abstract

The aim of this research is to give an overview of the psycho-didactical model of Engineering Pedagogy, as the basis of effective STEAM (Science, Technology, Engineering, Arts (Design), Mathematics) teaching and instructional design. Attributes of engineering graduates and basic skills of 21st century graduates are presented. The competency model of Engineering Educators by the International Society for Engineering Pedagogy (IGIP) is introduced. Micro-credentials pedagogical continuing education programme for STEAM teachers and engineering educators is presented, ensuring the acquisition of competencies for effective STEAM teaching. Learning activity as a system with a large number of elements is introduced, which under certain conditions can also become subsystems, being interconnected, with integrative properties and with the function of achieving certain specific goals. A Psycho-Didactical Model of Engineering Pedagogy is introduced as the basis for a toolbox of effective teaching STEAM.
Keywords: *engineering pedagogy, STEAM didactics, competency model, micro-credentials programme, pedagogical training*

Introduction

Engineering and STEAM have never mattered more. The explosion of new information technologies, robotics, biotechnology, increased blending of the invention with scientific discovery are affecting every field of STEAM. Today's engineers, situated in distributed, global chains of supply and distribution formulate and solve complex problems. What engineers know and can do are critical resources for the society and the whole world. Engineering practice has become exponentially more complicated, and conditions of engineering work have rapidly changed due to the new communication technologies (Wankat & Oreovicz 2015).

The problems that engineers respond to are typically ill-defined and underdefined, that is:

1. There are usually many acceptable solutions to design problems.
2. Solutions for design problems cannot normally be found by routinely applying mathematical formulas in a structured way and focusing on activities for integrating knowledge and technology.

The intensified global chase after greater economic value has in turn supported technological innovation, and developed rearrangements in design and production. Engineering practice is always problem-solving, it is an iterative process in which the basic science and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective (ABET 2022).

1. To analyse the IEA competency model for engineering graduates and its relevance to the IGIP prototype curriculum for engineering educators.

PROBLEMS
OF EDUCATION
IN THE 21st CENTURY
Vol. 81, No. 4, 2023

2. To analyse the micro-credential program for engineering educators' pedagogical training designed at TalTech and its relevance to the IGIP prototype curriculum and Psycho-Didactical Model of Engineering Pedagogy (IGIP).
3. To peer-observation teaching of STEAM subjects at the Estonian Centre for Engineering Pedagogy at TalTech and identify the most used methodology.

Based on the results, a toolbox for effective teaching and learning STEAM was developed at the Estonian Centre for Engineering Pedagogy at TalTech for faculty members and doctoral students.

Methodology

In the present research qualitative thematic analysis was used for analysing data that entails searching across a data set to identify, analyse, and report repeated patterns (Nowell et al., 2017). Different competency models were analysed along with the newly designed TalTech micro-credentials program. Their relevance was analysed according to the Psycho-Didactical Model of Engineering Pedagogy by IGIP.

48 faculty members, including 16 doctoral students participated in the peer-observation process. Didactical experts visited 48 STEAM lessons and protocolled a peer-observation analysis sheet designed for the research to define the used teaching methods, strategies, and models.

The IGIP Psycho-Didactical Model of Engineering Pedagogy was used for the instructional design as the basis of the toolbox for effective teaching and learning STEAM.

STEAM Competency Models

STEAM education provides interdisciplinary competencies to solve real-life problems facing the modern world. During STEAM studies, in addition to professional terminology and knowledge, STEAM literacy and mindset, professional skills, methods, values, judgmental skills and the ability to solve engineering problems must be acquired. The expectations of the 21st century engineer provide a framework for success in the fourth industrial revolution. The modernized cognitive/cognitive, interpersonal, digital, and self-management basic skills of the future professions presented at the 2021 World Economic Forum (WEF) (McKinsey 2021) are also of high importance. The International Engineering Alliance (IEA 2021) has prepared, based on the Washington, Sydney and Dublin accords, the model of international quality indicators for engineering education - the competence model for engineering graduates, supported by the World Federation of Engineering Organizations (WFEO) and United Nations Educational, Scientific and Cultural Organization (UNESCO), see Figure 1.

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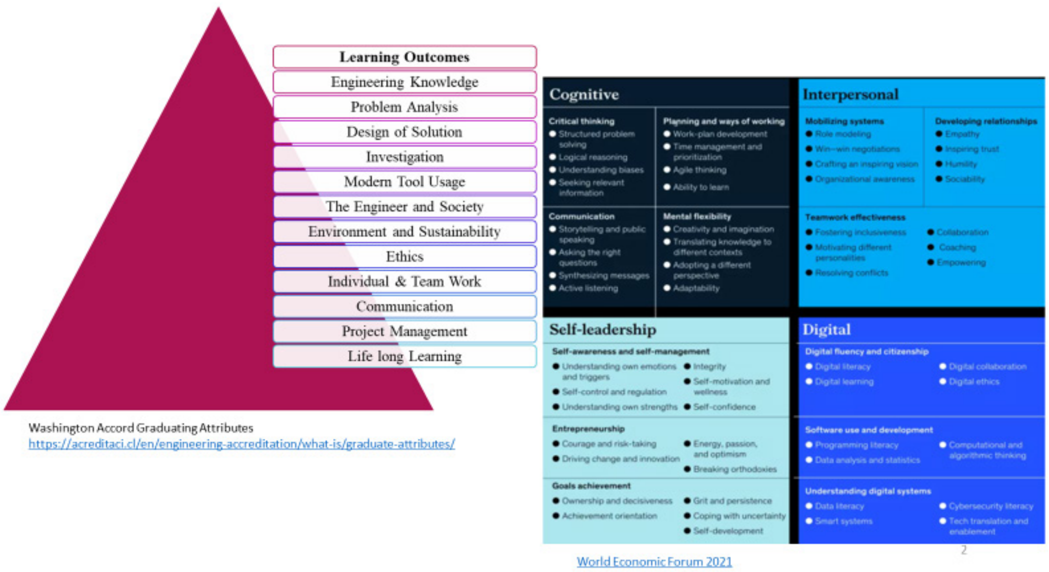
PROBLEMS
OF EDUCATION
IN THE 21st CENTURY
Vol. 81, No. 4, 2023

Figure 1

Attributes of Engineering Graduates (IEA) and Basic Skills of the Future Professions (WEF)



There are 12 engineering graduates' quality attributes in the IEA competency model, the most important of which are STEAM/engineering knowledge, followed by problem analysis/critical thinking skills, design of problem solutions, engineering design/projecting skills, etc (Figure 1).

To ensure the mentioned quality indicators, STEAM didactics and engineering pedagogy must be relied upon when teaching the field. In order to effectively implement the IEA competency model, the International Society for Engineering Pedagogy (IGIP 2023) has designed a STEAM teacher/lecturer competency model, which has been recognized by international engineering education organizations around the world. However, in addition to training engineers, engineering teachers who can teach STEAM subjects in general education schools, especially gymnasiums, must also be trained accordingly.

Competency Models and Relevant Micro-Credential Degree Program at TalTech

Engineering educators and STEAM teachers should acquire the necessary professional competencies of an international engineering educator. The general, professional competencies consist of two main groups: technical expertise and typical engineering pedagogical competencies in the narrower sense of the term.

It is assumed that engineering educators have acquired a high level of technical knowledge while studying engineering and have met the requirements as defined by the Federation of Professional Engineers "Engineers Europe" (Previously FEANI - *Fédération Européenne d'Associations Nationales d'Ingénieurs*) for registration as European Engineer – EUR ING. An engineering diploma from a nationally recognised and/or accredited program in engineering with a degree on the level of Second Cycle Degree (Master of Engineering, Master of Science in any discipline of engineering science) etc, and professional experience in engineering education for at least 1 year is required. It is assumed that engineering educators have acquired knowledge in engineering speciality at a high level during the 5-year academic study course and professional experience.

PROBLEMS
OF EDUCATION
IN THE 21st CENTURY
Vol. 81, No. 4, 2023

Engineering Educators should acquire the following necessary engineering pedagogical competencies stated by IGIP (IGIP 2023):

1. STEAM Professional Competencies.
2. Pedagogical, Social, Psychological and Ethical Competencies.
3. STEAM Didactical Skills and Subject Expertise.
4. Evaluative Competencies.
5. Organisational / Management Competencies.
6. Communicative and Teamwork Competencies.
7. Reflective and Developmental Competencies.

The IGIP competency model assumes that a STEAM teacher/lecturer has completed a master's degree in the taught STEAM subject/major and teacher training. A STEAM teacher/lecturer must be primarily a professional in the STEAM field, who is competent in the subject content and STEAM didactics. The IGIP engineering pedagogy micro-credential degree program has been prepared at TalTech that ensures the acquirement of all competencies of the IGIP STEAM teacher/lecturer competency model (see Table 1), (Rüütmann et al, 2021).

After passing the redesigned curriculum engineering educators will be able to (Rüütmann 2021):

1. Design their course syllabus based on selected didactical models.
2. Manage and analyse the process of teaching and learning based on the integrated principles of relevant learning theories.
3. Select appropriate teaching models, strategies and methods for effective teaching and learning.
4. Select appropriate methods for evaluation and feedback.
5. Use new technologies, modern learning environments and ICT tools for effective teaching.
6. Create supportive learning environments and involve learners, considering their individual differences.
7. Compile an academic portfolio and a teaching philosophy statement.
8. Participate in mentoring and in the processes of peer evaluation.

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PROBLEMS
OF EDUCATION
IN THE 21st CENTURY
Vol. 81, No. 4, 2023

Table 1
TalTech Micro-Credential Programme for Engineering Educators and STEAM Teachers

Module	Name of the Module	ECTS credits	Content of the Module	Relevance to IEA and IGIP Competency Models
Module 1 **"Course Design"** Compulsory 6 ECTS	STEAM Didactics and Engineering Pedagogy Science	2	Engineering pedagogy and STEAM didactics. Goals and learning outcomes. Didactic taxonomies. Students' individual differences. Learning theories. Methodology. Active learning. Assessment and feedback. A supportive learning environment.	IGIP – 1, 2, 3 IEA – 1, 2,
	Laboratory Didactics	2	Laboratory Didactics. Laboratory manuals. Structure and methodology of laboratory work. Supervising laboratories and supporting critical thinking. Problem-based learning in laboratory.	IGIP – 1, 2, 3 IEA – 1, 2, 3, 4, 7, 9, 10, 11
	Curriculum Theory and Practice	2	Legislation regulating higher education. Curriculum theory and practice. Compilation and analysis of the syllabus. Design and analysis of curriculum/study program.	IGIP – 1, 2, 3 IEA – 6, 7
Module 2 **"Design of Learning Process"** Compulsory 6 ECTS	ICT tools supporting interactive e-learning	2	Educational technology. Media in teaching. E-learning. Hybrid learning. Distance learning. Modern ICT tools. Interactive learning. Remote and virtual laboratories. Flipped learning.	IGIP – 1, 2, 3 IEA – 3, 4, 5, 6, 8, 12
	Rhetoric and Effective	2	Self-expression skills. Rhetoric and communication. Academic writing. Presentation skills.	IGIP – 5, 6 IEA – 6, 8, 9, 10
	Educational Psychology and sociology	2	Psychological characteristics and teaching problems. Developmental stages of thinking. Engineering thinking. Motivation in learning and teaching. Group processes.	IGIP – 1, 5 IEA – 2, 3, 4, 6, 7, 9
Module 3 **"Analysis of Learning Process"** Compulsory 6 ECTS	Problem-based and meaningful learning	2	Problem-based, project-based learning, challenge-based learning, CDIO principles. Supporting technical, creative, and critical thinking. Meaningful learning.	IGIP – 1, 2, 4, 6 IEA – 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
	Analysis of the study process. Ethical problems in education	2	Analysis of teaching (self-analysis, video analysis), analysis of student learning. Peer-observation. Reflection and feedback. Ethical problems in education, science, and society.	IGIP – 1, 2, 3, 6 IEA – 1, 3, 4, 8
	Final project. Portfolio design	2	Analysis of pedagogical situations. Analysis of student feedback. Reflection. Self-analysis. Creating an academic portfolio and teaching philosophy. Planning for self-development.	IGIP – 1, 2, 3, 4, 5, 6 IEA – 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12

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	Internship in a company. Cooperation projects with partners	2	Collaborative projects with partners. Creating problem-based learning tasks. Case studies. Internship.	IGIP – 1, 2, 3, 6 IEA – 5, 6, 7, 9
	Standards and quality	1	Standards and quality in engineering and education. Quality management in industry and education	IGIP – 3, 4, 6 IEA – 1, 2, 3, 4
	Product development and innovation	2	Effectively solving problems by a systematic approach, finding as many solutions as possible. Project team building and project management.	IGIP – 2, 3, 4, 6 IEA – 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
	New Technologies	1	Application of new technologies in education. Robots, virtual and augmented reality, drones, autonomous vehicles, AI, ChatGPT, etc.	IGIP – 2, 3, 6 IEA – 1, 3, 5, 6
	Coaching and mentoring	1	Principles and methods of coaching and mentoring in education. Covision and supervision.	IGIP – 1, 2, 5, 6 IEA – 2, 3, 6, 8, 9, 10, 11
	Multicultural learning environment	1	Culture and identities. Differences between cultures. Intercultural communication.	IGIP – 1, 2, 3, 5 IEA – 6, 8, 9, 10
	Sustainable development	1	Green turn. Climate neutrality. Circular economy. Environmental safety. Sustainability.	IGIP – 5, 6 IEA – 2, 3, 4, 5, 6, 7, 8, 1
Module 4 **“Electives”** Minimum 6 ECTS to be selected	Teaching Practice	2	Teaching analysis with a mentor/didactic expert. Video analysis of the teaching process.	IGIP – 1, 2, 3, 4, 5, 6 IEA – 2, 5, 6, 8, 10
	Learning Lab	1	Supporting student learning. Learning to learn. Learning skills (techniques and strategies). Self-management. Time management.	IGIP – 1, 2, 3, 5, 6 IEA – 2, 3, 5, 10
	Tradition, inspiration, and innovation in pedagogy	3	Design and analysis of integrated tasks for problem-based learning and project-based learning. Development of studio learning (in cooperation with bachelor's, master’s, and doctoral students) to solve real-life complex tasks with the involvement of industrial engineers. Supporting a learning community. Implementing new pedagogical ideas in teaching. Etc	IGIP – 1, 2, 5, 6 IEA – 2, 3, 4, 5, 6, 10
	Management	1	Involvement of teaching staff in the planning and execution of university activities. Mobility. Organization of conferences.	IGIP – 4 IEA – 11
	Excursions to companies	1	Contacts and communication with companies. Finding opportunities for cooperation. Preparation of cooperation projects. Getting to know the technological base of companies.	IGIP – 4, 5, 6 IEA – 1, 2, 3, 4, 5, 6, 8, 11
	Academic counselling	3	Academic counselling of engineering educators and STEAM teachers, group mentoring, analysis of everyday pedagogical problems to improve teaching. Sharing best practices	IGIP – 1, 6 IEA – 10, 12
In Total Minimum		24	ECTS credits	

PROBLEMS
OF EDUCATION
IN THE 21st CENTURY
Vol. 81, No. 4, 2023

The final project allows educators to conclude, share and present their teaching credentials and experiences acquired during their engineering pedagogical training, thus proving their compliance to the qualification of an engineering educator.

As seen in Table 1, TalTech micro-credential program covers all criteria of IEA and IGIP competency models. TalTech micro-credential program for engineering educators' pedagogical training has been accredited by IGIP in 2022.

Engineering Pedagogy Science Toolbox for Effective Instructional Design

The basic psycho-didactical model of engineering pedagogy of the Klagenfurt school for planning an effective learning process. This psycho-didactical model was designed by the founder of Engineering Pedagogy Science, Prof. Dr. Adolf Melezinek (Melezinek, 1999) and updated by Tiia Rüütmann (Rüütmann, 2019), see Figure 2. The model was used as the basis for designing a toolbox for effective teaching and learning STEAM.

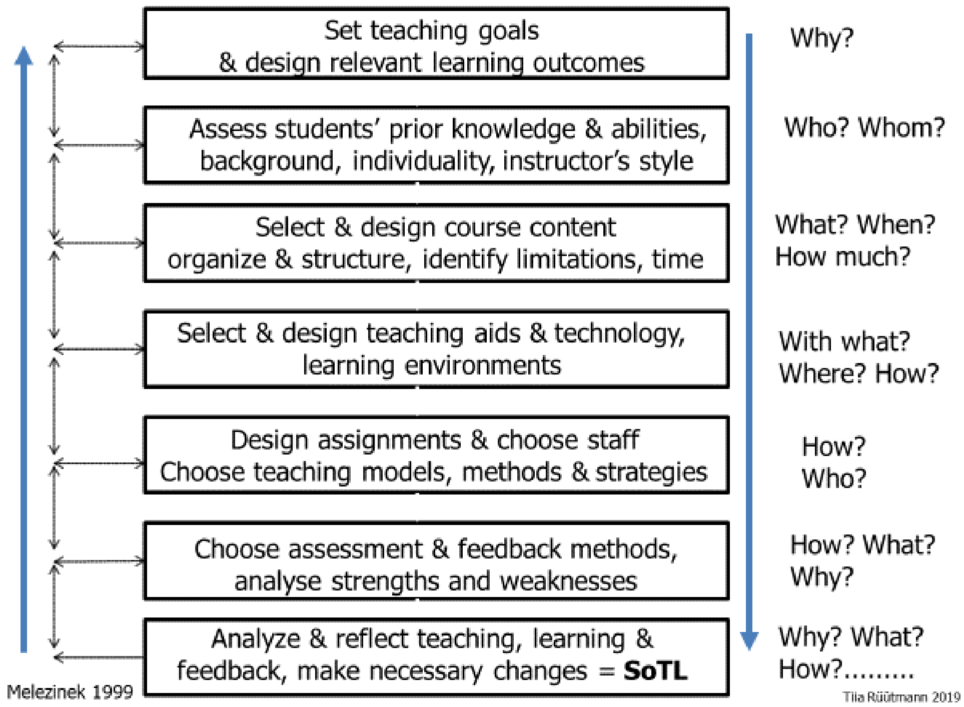
A scientifically proven didactical model used in engineering pedagogy for instructional design, including designing an effective lecture, practical lesson, presentation, or task, presented in Figure 2, is based on the iterative psycho-didactical model of engineering pedagogy and consists of the following basic strategies following each other (Melezinek 1999, Rüütmann 2019):

1. Set goals - why do we teach? You need to set yourself clear and precise goals. Determine in advance the expected knowledge and skills that the students should have after your course, following your lesson, and reading your research article or technical text. By reaching learning goals, we create conditions and opportunities for our students to achieve learning outcomes. When creating and formulating goals and planning learning activities, use didactical models suitable for the content of the STEAM subject (Rüütmann 2019), the characteristics of the students, and the learning environment as a basis, which can also be integrated with each other (Rüütmann 2019).

2. Assess the audience - whom do we teach? For effective teaching, you need to consider the background of your audience and students' individual differences. As a teacher, you must take account of the prior knowledge, learning skills, attitudes, interests, expectations, and motives of your students. The psychological, social, and other individual characteristics of students also play an important role. If necessary, you can use an ungraded prior knowledge test at the beginning of the course to determine the basic knowledge level of your students to adapt the material taught to them. Analyse how students learn and teach accordingly. Check whether the goals are suitable for the students' preliminary knowledge. It is also important to consider the personality and competence of the teacher. Focus on the development of students as engineers. What knowledge do students need when they come to university, and what should be taught to them first? What could be changed so that students come to university with better knowledge? How to support university studies?

3. Select learning material (learning content) - what to teach? Every day brings us new information, and when teaching technical subjects, we must deal with an ever-increasing flood of new information. Choose from the available information, according to the goals and the prior knowledge of the students. Don't overload your students with too much information. Concentration on the most important phenomena and concepts is particularly valuable pedagogically - in this case, the most important and precise nature of the topic is understood. Create didactically effective learning materials. Learning time should be taken into account as a resource, to achieve a balance between the time allotted for learning and the volume and complexity of the learning content selected. The logical sequence, structure and interdisciplinary approach of learning activities should be determined, and the rational integration of learning content and learning experience should be analysed. Match the presented material to the goals and the level of prior knowledge of the listeners, so that they can better understand the material and more easily learn with deep understanding.

Figure 2
The Psycho-Didactical Model of Engineering Pedagogy



4. Select technical tools and create a learning environment that supports learning - what and where to teach? Human personality cannot be exchanged for anything in teaching. A human example is irreplaceable, and its importance will remain in future communication processes and teaching. The teacher was, is, and will remain an irreplaceable support of educational activities. With today's flood of information, new technical tools, offer irreplaceable help to the teacher: classic technical tools (text materials, blackboard, laboratory equipment, apparatus, models, etc.) and new technical tools (video systems, computers, internet, software, smartboard, smart devices, etc.) and modern learning environments (including e-learning, e-laboratories, remote laboratories, virtual laboratories, simulations, digital platforms, etc.) we can teach our subject more effectively. Technical tools and learning environment should be chosen according to the goals, the students' preliminary knowledge and skills, and the selected learning content.

5. Select teaching models, methods, and strategies - how to teach? The most important topic we will focus on in the toolbox are teaching and learning methods, strategies and models, communication tools and forms to be used for effective teaching. Teaching models, methods and strategies should be chosen in accordance with the goals, student characteristics and technical tools, and the learning environment to support effective learning with deep understanding.

6. Select assessment and feedback methods - how to evaluate? Choose assessment and feedback methods suitable for your subject content, technical tools, learning environment and applied methodology. Check that the designed learning outcomes are accessible and choose assessment methods accordingly. Analyse what students should do to demonstrate the

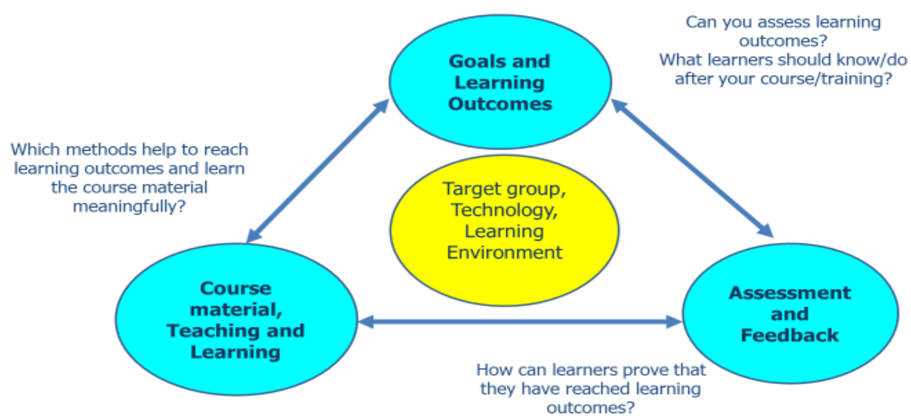
PROBLEMS
OF EDUCATION
IN THE 21st CENTURY
Vol. 81, No. 4, 2023

achievement of the learning outcomes - how to check whether and to what level students have achieved the learning outcomes. Constantly ask and give feedback to your students and evaluate their performance. Explain your requirements, assessment methods and criteria already in the first lesson. The chosen assessment and feedback methods should assess the achievement of learning outcomes. The assessment methods must be suitable for different students, subject content, limitations of teaching methods, learning environment and technical tools.

7. Analyse teaching and learning, make changes if necessary - how to improve? Analyse your teaching while planning, before teaching, during teaching and after teaching. Have the chosen learning and assessment methods been effective and efficient in accordance with the goals and learning outcomes, students' individual differences, selected subject content, technical tools, and learning environment? Ask for feedback from students and colleagues and analyse it. Make changes if needed to improve the quality of teaching and learning. Improve your teaching skills and teach your students how to learn STEAM. Reflect on your teaching.

There are several axes in the presented didactical model. The main axis of didactics combines learning objectives and learning outcomes, which must be relevant and based on which the foundations of learning activities are planned. The personality axis connects the teacher and the study group and takes account of the individual characteristics/differences of both the teacher and the students. The information axis combines learning content and methodology, which determines one of the fundamentals of didactics - methodology is selected according to the course content with the aim of supporting students learning with deep understanding. The organizational axis combines learning tools and teaching forms, including the creation of a supportive learning environment. The axes of influence of didactics are the basis for the psycho-didactic model of engineering pedagogy that support the constructive alignment of a course (see Figure 3) (Biggs & Tang 2011; Felder & Brent 2016).

Figure 3
Constructive Alignment



In engineering pedagogy, learning is a systemic process, like any other process related to human activity (Melezinek, 1999; Nainiš, 2015; Zhukov 2014). Systematicity appears especially in pedagogical processes where the STEAM teacher plays an important role.

Nowadays, the use of a systematic approach in teaching the STEAM field is one of the most effective strategies. The elements of the learning activity system are as follows (Nainiš, 2015; Zhukov, 2014):

1. Concepts (the system and structure of concepts - the so-called instrument of consciousness).
2. Objects, devices, and installations (facilities, buildings, technical installations, technology, equipment, computers, etc.).
3. Persons (students, teachers, assistants, service personnel, etc.).
4. Processes (production, quality control, feedback, research and teaching, goal setting of educational activities, etc.).

Learning activity as a system has many elements, which under certain conditions can also become subsystems, being interconnected, with integrative properties and with the function of achieving certain specific goals. The systemic process of learning is relative because each system can be an element of another higher-level system and contain other lower-level systems.

Important regularities of STEAM educational activity as a system are the following (Nainiš, 2015; Zhukov, 2014):

1. *Connection with goals, tasks, and functions* - purposefulness, emergence, synergy. The educational activity combines system elements such as the teacher, students, curriculum, subject courses, learning objectives, technical learning tools, study time, material-technical base, etc. All the named elements are interconnected and interdependent. Thus, for example, a teacher, without knowing all the other elements, cannot teach anyone anything - so teaching professional knowledge in the STEAM field is emergent. Synergy allows a teacher, who is aware of all the important elements of the learning activity system, to set goals, choose learning material and methodology corresponding to the subject content, manage learning activities, participate in administrative work, use time effectively, etc. At the same time, if the only goal of the administration is, for example, the saving of resources, and not the quality of educational activities, then a contradiction with the goals of the educational process arises here - as a result, new computers, software, laboratory equipment, materials, etc. are not purchased, the absence of which in turn reduces the effectiveness and quality of the educational process, the workload of teaching staff increases, which reduces their motivation - in this way, the disorganizing activity of the administration can, in turn, have a negative impact on the learning process and its quality.
2. *Connection with structure* – hierarchy, completeness, additivity – structure of the system and connection of elements. This includes the pedagogical competencies (professional and pedagogical preparation, technical teaching tools, learning content, learning time, etc.), learning content (modules, learning time, curriculum, syllabus, methodology, etc.), material and technical equipment of learning activities (workplaces, ICT, modern laboratory equipment, furniture, safety equipment, teaching materials, methodology, teaching time, sports equipment, household items, etc.), teaching time (teachers, material and technical equipment, finances, etc.), finances (material equipment, equipment, teaching time, teachers, subject content, methodology, etc.), technical teaching tools and equipment. The important elements of the learning activity are closely related, changes in one element cause changes in the entire system.
3. *Connection with the environment* - communicativeness. Learning activity has its own internal system but is also closely connected with external systems – social relations, norms, standards, legislation, communication with employers, alumni, media, and the public, etc.

If it is possible to point out the above-mentioned regularities of the learning activity, it becomes possible to determine the mechanism and make them more effective in teaching.

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The general algorithm of the learning activity system (Nainiš, 2015; Zhukov, 2014):

1. *Stage 1* - knowledge acquisition - students get new knowledge either from the teacher (taking account of the specifics of the subject and learning content - in a lecture, seminar, practice class, etc.), from educational literature or from active learning (including problem-based learning and laboratory work, etc.). The teacher's task at this stage is to enable the students to acquire the necessary knowledge according to the learning outcomes, the subject content, and the individual differences of the students.
2. *Stage 2* – application of knowledge and acquisition of skills – consolidation of what has been learned, practice, solving tasks, etc. – acquisition of knowledge, skills, and experience individually or in teamwork, if necessary, under the guidance of a teacher in accordance with the principles of didactics.
3. *Stage 3* - knowledge-skills check - quality control of acquired knowledge and skills, students demonstrate acquired knowledge and skills, teacher and/or students check the quality according to the learning goals and learning outcomes, provide feedback and feed forward.
4. *Stage 4* – assessment – classification of the level of acquisition of learning outcomes, according to the assessment criteria and assessment principles (continuous assessment, formative assessment, summative assessment, test, exam, etc.).
5. *Stage 5* - improvement - the significance of this stage arises when there is a difference between the learning outcomes and the knowledge skills acquired by the student. Reflection and informed judgements/decisions to improve the quality of educational activities going forward.

The system of educational activities is constantly changing - both qualitatively and quantitatively - every year new students enter the educational institution, every year the academic success, and quality of education change, the qualifications of teaching staff change, new various technologies are developed, including modernized educational technology, IT solutions develop and learning opportunities improve, curricula are developed, employers' requirements for graduates change, funding changes, etc.

Results and Discussion

Pedagogy is not a universal science and does not provide the same recipes for teaching all different fields. If, according to Pascal's law, known in technical and engineering sciences, the pressure in a liquid or gas is transmitted equally in all directions, the given analogy does not apply in pedagogy. Therefore, a STEAM teacher/lecturer must have knowledge of general pedagogy and general didactics but must also be competent in STEAM didactics and engineering pedagogy.

The tools of a history professor are not suitable for a mechanics teacher, and the tools of a music teacher are not suitable for a chemistry teacher. A false image of the modern methodology cult has been created as if the same methodology could be used universally in all subjects and fields. Different learning environments and different goals require different learning content, and the methodology is always selected according to the course content to support student learning. There are inevitably different methods in different fields, e.g., in the organization of active learning. Active learning in the STEAM field makes learners think critically, evaluate, analyse, synthesize, find optimal solutions, and learn with deep understanding.

Understandably, different fields of study require different specific starting points for goal setting, different choice of course content, different learning environments for organizing studies and different methodologies with appropriate learning activities. For supporting deep

PROBLEMS
OF EDUCATION
IN THE 21st CENTURY
Vol. 81, No. 4, 2023

learning, it is important to pay attention to the choice of learning content, its organization, and the creation of learning-supportive environments, which allow the design of different learning systems and better consideration of learners' individual di and individual differences. The selection of teaching methodology without knowing the learning content is neither intelligent nor scientifically justified - the methodology must help students to learn with understanding. Based on the study content, it is also possible to integrate STEAM subjects at the level of theory, concept, and fact.

There is considerably less subjectivity and much more objectivity in the teaching and learning of STEAM subjects than in other fields. Subjectivity appears in creativity, in finding different solutions and in communication. Objectivity comes from the laws of nature - neither democracy, plurality of opinions, nor consensus have any meaning in them. Gravity as any other laws of Physics applies regardless of democracy, regardless of our assumptions, opinions, agreements, and consensus. In the STEAM field, you simply must take account of the laws of nature, the relevant norms, ISO standards and proven facts. The engineer must know for sure and prove with calculations that this bridge will last - for safe use by all bridge-crossers. Knowledge, facts, and responsibility are closely related (trial and error and guesswork cost too much for the society).

It is crucial to be responsible for one's decisions and actions, including making very quick, well-considered decisions (even if Google doesn't help) and knowing what possible consequences of this decision to society, nature, and the world's ecosystem may be. In many countries, chess is a compulsory subject to teach independent decision-making, analysing possible consequences and constantly thinking: "What if..."

Today's STEAM education has the following 4 dimensions:

1. Don't do the wrong thing - for example, the MIT Trash Track Study (MIT 2022) showed that trash marked by students was initially transported to the East Coast of the USA and from there back to the West Coast.
2. Do less, but do it smartly - reducing emissions, energy efficiency, reducing climate warming, etc. - use all new technological solutions for this, starting with digital twins.
3. Do better - why is the weight of cars increasing? Why is there an average of 1.6 passengers in a five-seater car in Europe?
4. Fix the things you did wrong - use engineering design, AI, digital twins, autonomous vehicles, drones, new technology for that. The 3D experience harmonizes nature, the product and modern life.

Learning STEAM must be interesting, motivating, and demanding, but not always fun. The syndrome of effortless learning (also effortless work) is a contagious disease that emerged in the welfare state about 25 years ago. There is nothing more beautiful than confirming that school should be a relaxed and interesting environment for free communication, where there is no discriminatory assessment and hard work to be done. It is easy to create such an ideal school, and in the last few decades, the world has seen schools with various new orientations - an interesting school, a school without grades, happy school, a school without efforts, a university without teachers, etc. However, learning takes place only through efforts, overcoming difficulties and contradictions. A student's development takes place through the processes he/she experiences through negative and positive emotions, efforts and activities, success and failure, reflection and learning from mistakes and experiences.

Empirical educational research has proved that active engagement in learning is superior to passive reception of information for promoting students' motivation to learn, academic achievement, and persistence in academic programs (Ambrose et al., 2010; Cabo & Klaassen, 2018; Freeman et al., 2014; Pritchard, 2010; Hernandez-de-Menéndez et al., 2019; Wankat &

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PROBLEMS
OF EDUCATION
IN THE 21st CENTURY
Vol. 81, No. 4, 2023

Oreovicz, 2015). A meta-analysis of 225 studies in STEM courses by Freeman et al. (2014) proved that the failure rate in lecture-based courses was 1.5 times that in courses where students were actively engaged. According to Abramovich et al. (2019), action learning and challenge-based learning spark interest and increase motivation of students.

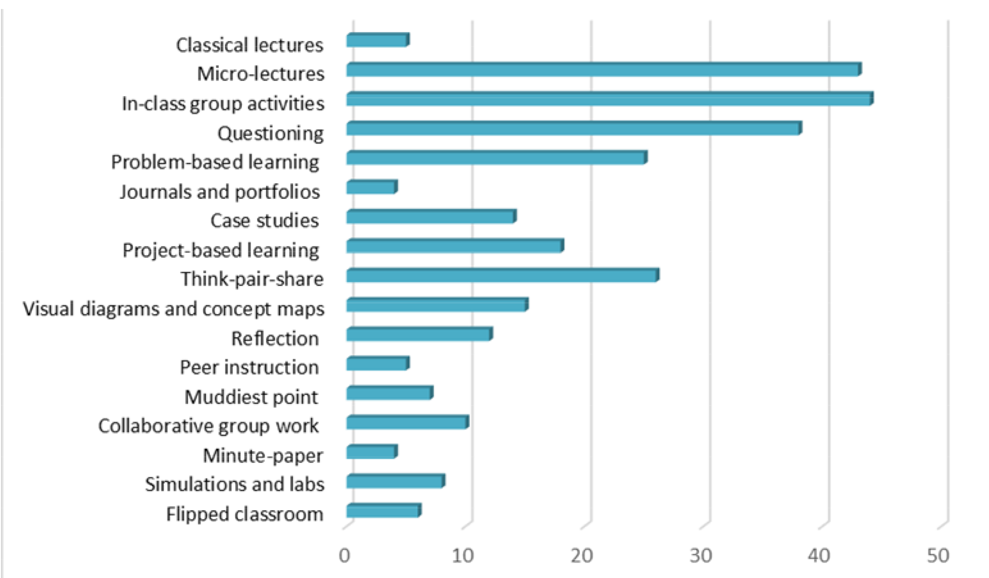
Techniques for teaching professional skills to STEM students and assessing the students' mastery of them have been developed and validated (Felder, 2021). For example, creative thinking can be taught by assigning exercises of brainstorming, problem-formulation exercises, troubleshooting and explanation of unexpected results (Felder, 2021).

Extensive research has shown that active student engagement in face-to-face instruction promotes the attainment of almost every conceivable learning outcome (Freeman et al., 2014; Prince et al., 2020). Active learning engages students in the process of learning through activities and/or discussion in class, as opposed to passively listening to an expert (Freeman et al., 2014).

Peer-observation process carried out during the present research has proved that teaching STEAM courses at TalTech at a relevantly high level – active learning methods, strategies and models have been implemented in all 48 peer-observed lessons. Mostly interactive learning has been used in teaching STEAM courses. 54% of peer-observed lessons were inductive and 46% were deductive lessons. Micro-lectures (for 10-15 minutes) were used in turn with active learning strategies in 78% of observed lessons, 22% of observed lessons were labs and practical lessons.

An overview of the different used teaching methods and strategies recorded during the observation process (284 teaching methods and strategies in 48 observed lessons) is presented in Figure 4.

Figure 4
Recorded Teaching Methods and Strategies



Different active learning methods were implemented in observed lessons:

1. Flipped classroom.
2. Simulations and labs.
3. Minute-paper – students write reflections in controlled time after a topic or lesson.
4. Collaborative group work.
5. Muddiest point - students point out what they are most confused about, what is muddy.

6. Peer instruction.
7. Reflection.
8. Visual diagrams and concept mapping.
9. Think-pair-share.
10. Project-based learning.
11. Case studies.
12. Journals and portfolios.
13. Problem-based learning.
14. Questioning.
15. In-class group activities - groups complete any activity that requires them to reflect on course content (brainstorm, answer a question, start a problem solution, etc.).
16. Micro-lectures (10-15 min).
17. Classical lecture (45 min).

As can be seen in Figure 4, the more often used methods and strategies were in-class group activities (44) and micro-lectures (43). Questioning (38), problem-based learning (25) and think-pare-share strategy (26) were also frequently used. Projects (18), case studies (14), visual diagrams and concept maps (15), reflections (12) and collaborative group work (10) were also popular. Less used were flipped classrooms (6), simulations (8), minute-paper (4), muddiest point (7), peer instruction (5), journals and portfolios (4) and classical lectures (5 min).

The IGIP Psycho-Didactical Model of Engineering Pedagogy (Figure 2) was used for the instructional design and as the basis of the toolbox for effective teaching and learning STEAM. All the steps of the Psycho-Didactical Model of Engineering Pedagogy were analysed, and the most important recommendations were provided for effective teaching and learning STEAM.

In addition to the teaching methodology and strategies presented in Figure 4, the most popular teaching methodology will be added and introduced in the designed toolbox. The toolbox will provide the basic knowledge for effective teaching STEAM, taking account of the most important principles of STEAM didactics and introduced above research results.

Conclusions and Implications

It is often believed that engineering graduates must be so-called ready-made, experienced engineers. Engineering education is based on professional experience that should be acquired after graduation. Therefore, the responsibility for the training of contemporary engineers also rests with companies, which should further train university graduates with the necessary basic knowledge and skills in everyday working conditions, in cooperation with universities. Every 3 years engineers need modernized continuing education to keep up with the new trends and technologies. The designed toolbox for effective teaching STEAM introduced in the present article is suitable for new faculty pedagogical training and for workplace-based continuing education. The toolbox is planned to be supplemented in the near future and develop a handbook for effective teaching and learning STEAM.

We certainly don't know what our students should be taught to cope as citizens of the 21st century in the future, but they probably need a broad view, which is offered by classical subjects at school - both in the STEAM field and in the humanities. Therefore, today we should focus on teaching critical thinking, creating a supportive learning environment, using context-based teaching, real-life learning situations, problem-based, project-based, and challenge-based learning along with active learning. We should also support our students in the process of learning to learn. It is necessary to acquire basic knowledge of the STEAM field and develop

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PROBLEMS
OF EDUCATION
IN THE 21st CENTURY
Vol. 81, No. 4, 2023

analytical skills with the support of professional STEAM teachers who are competent in STEAM didactics.

Conflict of Interest

The author has no conflict of interest to disclose.

Note

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