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MANUFACTURING ENGINEERING

Innovative methods of engineering education popularization at schools

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Abstract. In recent years, there is constant deficit of students in technical specialities in higher educational institutions, especially in industrial engineering area. To solve this issue, three universities of the Baltic region initiated the joint project "Innovative methods for implementing interdisciplinarity in career counselling (IMATEII)". The aim of the project is to develop a new approach to prepare schoolchildren choosing appropriate profession through collective efforts of the university, schools and enterprises. Authors introduce the new approach based on the metal and machinery industry. Readers can apply the results of the current analysis in other geographical regions and different industrial sectors.

Key words: IMATEII, career education, design, technologies and economics competencies, machinery industry.

1. INTRODUCTION

After joining EU, students of the Baltic states can improve their professional level in other European countries. Often people leave their own country because they do not have complete information about the opportunities to obtain the appropriate speciality in their own country. Therefore, students usually break studies and leave their country seeking for suitable position abroad, if they do not have enough information related to all aspects of the selected profession. Schoolchildren have difficulties in orienting themselves in the professional area and in finding the way how they can realize themselves in interests of their own country. It is necessary to help them to solve one of the most difficult and important questions – "What do you want to become?" Appropriate choice of high school, regarding the future profession makes the education process complete and efficient. A significant role in professional orientation belongs to the higher education institutions.

Another major challenge is the need for further integration of cross-sectoral skills into the teaching and learning process [1]. An important task is to encourage young people to choose a profession in the fields of mathematics, science or technology because high demand for graduates in those fields is extremely important for further innovation and growth of the industries.

In the context of Latvia, Lithuania and Estonia, the fields of Wood-Forestry, Metal-Machinery, and Agriculture-Food are considered to be fast-growing industries. Number of trained specialists is insufficient, and the motivation and interest of potential employees should be increased by school career counsellors.

Adequate training of qualified specialists is possible only in close cooperation between schools, universities and enterprises. Educational programs of the universities

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should correspond to the needs of the industrial companies developed in a particular region. Therefore, there is a need for constant monitoring of the competencies of the participants in education and production systems.

2. THE PROJECT "IMPLEMENTING INTERDISCIPLINARITY IN CAREER COUNSELLING"

The target of the project is to develop new (interdisciplinary) approach in career consulting, using the results of the project materials.

Audience would be teachers who are working with career issues, such as career consultants, class teachers, youth workers. Goal of the project is developing teachers' professional competence and popularization of engineering education in schools.

2.1. Career education

Career education is the planned provision of events, courses and programs at educational institutions that are helping learners to develop the skills that correspond to their interests, abilities and opportunities, to set their career goals and to manage their achievements. It provides knowledge and understanding of the world of work, its link with education, career planning and further education opportunities, and ensures active participation in one's working life [2].

A modern, competitive economy requires employees who have the skills, knowledge and attitudes that can be used in any work situation and who have the ability and desire to adapt and succeed in a changing world continuously. Therefore, the skills suitable for employment are an essential part of career management skills. Employment skills are defined as "the set of qualities, skills and knowledge that is needed by every participant in the labour market to ensure their effectiveness in the workplace – for their growth, for their employer and the economy of the country as a whole" [3].

When it comes to the professions of technical disciplines, it is essential to recognize the set of skills needed – the specific, technical and general work skills that are partly made certain and learned in general education, such as subjects of Design, Technology and Economics.

2.2. Project implementation

Researchers of three Baltic countries have divided several industrial domains like forestry and wood, metal and machinery, agriculture and food, between Latvian Rezekne Akademy of Technologies (RTA), Lithuanian Vytautas Magnus University, and Estonian Tallinn University of Technology (TalTech) for better project implementation.

The researchers set out the following objectives for the current project:

- to develop and implement innovative practices in career education at secondary schools;
- to provide secondary school teachers with career guidance competence based on interdisciplinarity among Design, Technology and Economics;
- to facilitate learners to make a motivated and targeted career choice in selected fields of industries.

2.2.1. Analysis of enterprises' needs

The first task of the project was to study the most demanded professional competencies in the Wood-Forestry, Metal-Machinery, and Agriculture-Food industries and elaborate recommendations for methodology of the professional development training for career counsellors on career guidance in secondary school. A questionnaire was used to collect information about employers' needs for their staff competencies in Design, Technology and Economics. The results of this work were introduced in previous research papers of the same authors [4–6].

Results show that competencies related to Design are more often repeated in all sectors of the industries. It leads to the conclusion that competencies related to the Design are more general. Competencies related to the Technology were also repeated in all fields of industries, but not as often as Design. Competencies related to the Economics repeated very rarely. That leads to the conclusion that competences related to the Economics are perceived to be more specific for every industrial sector. Probably the size of the companies in different industries varies, and that leads to the specific demands of competencies.

In their recommendations authors try to determine the general principles of how to connect guidance and secondary school students' competencies development related to specific industries. The results give opportunity to connect demand for competencies in Design, Technology and Economics with Teaching and Learning Strategies for the Critical Thinking three phases – Evocation/anticipation, Comprehension/the building knowledge, Reflection/consolidation [6].

2.2.2. Dissemination of engineering education in schools

The primary objective of this project is to attract and train students in schools to apply for technical vocations in higher educational institutions.

Figure 1 shows the primary collaboration between the project group members from the universities and schools.

Within the framework of this project, the primary emphasis is on familiarizing the students with the realities of the chosen profession through visits to the enterprises and master classes in school and university laboratories. It is essential to show the students how companies make the selected products in real production process. The specifics of technological and work processes of different industrial sectors that limit the observation of work processes should be taken into consideration, e.g., safety issues in heavy industries like metal and machinery, also noise, smell and heat, which are related to certain technological processes of production of different metal products. In some cases, it is hard to observe these production processes directly. In such case the observation of simulated or smaller scale technological processes can successfully replace the observation of real and big scale production. For example, students can visit the metal lab, which accepts the visitors and even offers possibility to have a “hands-on” practical experience in some production processes. It could improve understanding technological processes and manufacturing of metal products, compared to just visiting a large company and observing technological processes from a distance.

University lecturers and researchers prepare slides and training materials to give over to schoolteachers to improve their technological knowledge and skills. Schoolmasters, supported by the university lecturers, explain the schoolchildren how to design and manufacture the selected products, based on practical lessons. Also, project leaders must organize visits to the companies, which produce previously studied products, so that the schoolchildren have a complete overview of a real manufacturing process and production environment.

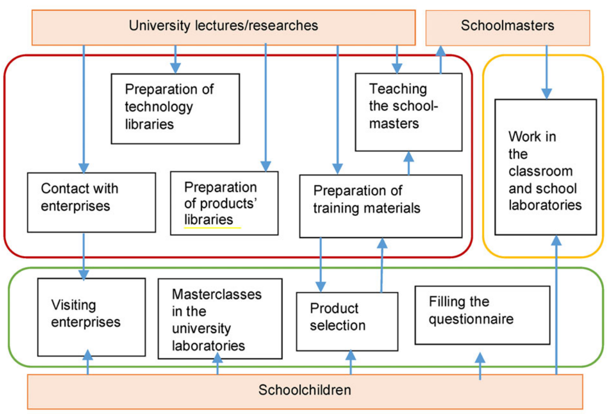

Fig. 1. The primary functions of the university and school in the frame of the current project.

It is essential because often working conditions and sensory experiences play a critical role in choosing a future profession.

Work in the classroom with schoolchildren must be based on teaching and learning strategies [7]. Authors give recommendations how to implement critical thinking, teaching and learning strategies in career guidance and how to introduce local industries to the pupils of secondary school through development of teachers competencies in Design, Technology and Economics.

The goal of the project is to implement the system of labour education and vocational guidance. The project develops the needs of young people in socially significant work activities, enables professional self-determination and social adaptation of schoolchildren adequate to their abilities.

2.2.3. The organizational activities of the project

This work results in elaborating teaching materials and preparation (training) of schoolmasters based on new methods and techniques developed during current project. Description on activities is introduced in Fig. 2.

The guidebook contains examples of how to implement the idea of the project, using critical thinking and learning strategies in career guidance, and how to allow secondary school students to get acquainted with local industries.

All materials were initially prepared in English, discussed in project team seminars and finally translated into Estonian, Latvian and Lithuanian. Schoolchildren do not easily understand new processes and new terminology. Therefore, teaching materials should be translated into all three languages of the Baltic states. Organizing the teachers' training of the three Baltic states, speaking different languages is not an easy task.

The next step was training the teachers to prepare them to carry out lessons in engineering classes in secondary schools. Slides and videos were prepared by the university lecturers to explain technological processes. Discussions how different products are produced were part of the practical work. Examples of slides made for the lessons are shown in Fig. 3.

2.3. The concept of the project

The concept of the project for each field of industry (Wood processing, Food, Mechanical engineering) is based on three phases of critical thinking: Design, Technology, and Economy (Fig. 4.).

The main idea in a constructivist approach is the student's thinking activity and the development of critical thinking. That requires a radical renewal of teaching

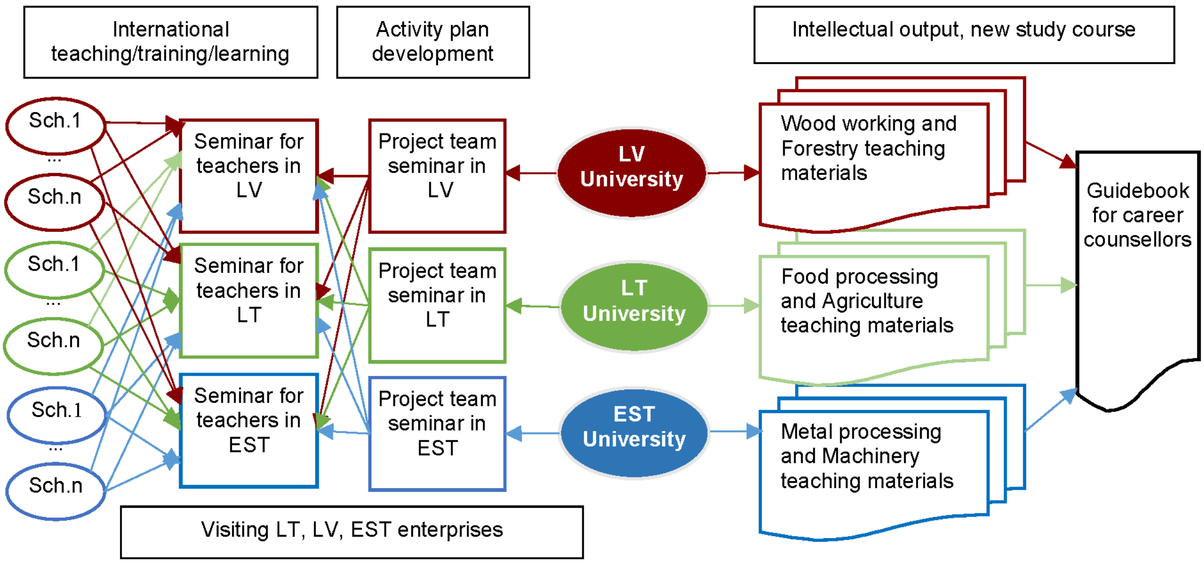

Fig. 2. Organizational activities for the project implementation.

Fig. 3. Example of teaching materials.

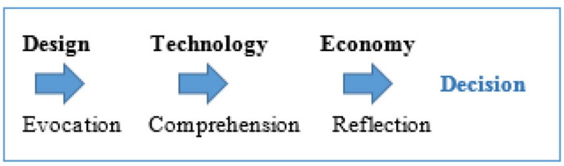

Fig. 4. The concept of the project.

methods and resources, and the teacher's ability to use diverse teaching techniques. It is essential for students to create an understanding of the succession and continuity of the learning process [8].

Learning process is structured in successive phases:

- evocation – the phase where educator uses structured pattern of questions to find out student's knowledge and skills and set learning goals;
- comprehension – the phase in which students are looking for a new knowledge and as a result of their actions, create their awareness and significance;
- reflection – the phase in which students look at the ideas they have learned and understand their meaning, ask questions, interpret, apply, discuss, test, and extend meaning by transferring it to other areas of activity.

For successful implementation of the system of principles, critical thinking offers innovative methodological solutions [9].

Critical thinking and problem solving skills include the ability of individuals to a) reason effectively, b) ask pointed questions and solve problems, c) analyse and evaluate alternative points of view, and d) reflect critically on decisions and processes [1].

Critical thinking is defined as the ability to analyse, interpret, evaluate, summarize, and synthesize information [10].

Each institution establishes a single module, which will be later integrated with other two parts of the curriculum.

The competencies of the Economy are: defining the most cost-effective solutions, analysing production processes, connections between different functions and departments, ability to see the whole picture of value chain from sales till support processes.

Based on this concept, Technological cards were developed for every considered type of industry [11–15]. Example of Technological card for metal cutting process is shown in Fig. 5.

2.4. Practical work for schoolchildren

Classes in schools are conducted by the schoolteachers with the support of university researchers and lecturers. Example of the practical work with schoolchildren is introduced in Fig. 6.

This example provides an opportunity to connect the competencies in Design, Technology and Economics with teaching and learning strategies using three phases of critical thinking – evocation/anticipation, comprehension/knowledge building, and reflection/consolidation [6].

2.4.1. Evocation/Anticipation phase – Design

At the beginning of the group counselling session the counsellor gathers the answers from schoolchildren to the following questions: What do you know about the machinery industry sectors? How much have you heard about it from the media (newspapers, magazines, TV, radio, the Internet (social networks, YouTube, company websites, etc)), family members, friends, neighbours? Have you done summer jobs in this field of industry? Have you volunteered in this industry? Have you visited a company in this industry? Do you have a plan after finishing school?

Presentations of the products designed by the companies, technological processes, working environment, materials and business give a real picture of companies' work and products. To validate whether the students have understood the topic, the following questions are asked: How is the product made? What kind of technologies are used? What equipment and tools are necessary? Where is this company located? How rich are the companies and their owners? Is it produced by talented hand or advanced technology?

There are several ways to present pictures for a group of students. The most popular way is to do PowerPoint presentation. The authors also recommend using social network Pinterest.com to discover hundreds of related pictures, styles, inspiration, and many other ideas. This method gives schoolchildren the possibility to navigate and search for the pictures of their preference, which is more effective for the evocation phase.

2.4.2. Comprehension/Building knowledge phase – Technology cards

The comprehension and building of knowledge phase can be tightly related to the introduction and analysis of the technological processes used for the production of a particular product from provided materials. Introduction of technological processes could be started at school by choosing particular products and analysing the technological processes used for their production. It is necessary to involve subject teachers for a better explanation. There is a wide range of different informative materials in the Technology cards that can be used for this purpose (such as pictures and videos, introduction and information on the production processes, materials and equipments used).

Visits to the companies could be organized as the next step where students can see the technological processes with their own eyes, they would have better understanding of the specificity of the technological and work processes in this sector, also aspects, which can limit the observation (e.g., safety concerns in the heavy industries like metal and machinery industry; also noise, smells and heat which play role in many metal production processes).

2.4.3. Reflection/Consolidation phase

After visiting a company, the consultant asks questions such as:

- Is it worthwhile to become an expert in this field?
- What would be the benefits for me entering this industry?

Based on the analysis of the results performed during the project, the most important competencies in the field of economics evaluated by Baltic companies are:

- handling problematic situations adequately and on time, making necessary decisions;
- setting objectives for achieving specific aims in order to produce value-added products;
- assessing service cost calculations, required investments and workforce;
- project design and management.

<table>
<tr><td></td><td>Metal processing</td><td>TECHNOLOGY GROUP</td><td>Metal cutting</td><td>SPECIFIC TECHNOLOGY</td><td colspan="2">Turning, milling, drilling, laser cutting</td></tr>
<tr><td>INTRODUCTION</td><td colspan="6">Metal cutting process is an industrial process in which metal parts are shaped by removal of unwanted material. In traditional chip-forming processes, such as turning, drilling, and milling metal is removed as a plastically deformed chip of required dimensions.
Metal cutting is one of the most widely used methods to produce metal parts allowing to get parts with defined dimensions and shapes and required surface roughness. Sheet metal cutting is mostly used with the help of lasers or water.</td></tr>
<tr><td>KEY WORDS, ABBREVIATIONS</td><td colspan="6">CNC – computer numerical control. Tool bit – a non-rotary cutting tool. Milling cutter – a rotary cutting tool.
Cutting fluid – fluid for cooling and lubrication during the metal cutting.
Lasers – a narrow single colour beam of light. Abrasive jet – jet of fine abrasive particles, usually about 0.025 mm in diameter.


Tool bit

Milling cutter

Drill

Cutting fluid</td></tr>
<tr><td>PROCESS DESCRIPTION</td><td colspan="6">Turning is a machining process in which a non-rotary tool bit describes a helix toolpath by moving more or less linearly while the workpiece rotates. Turning can be done manually, in a traditional form of lathe, which frequently requires continuous supervision by the operator, or by using an automatic lathe, which does not. Today the most common type of such automation is CNC.
https://www.youtube.com/watch?v=8EsAxOnzEms
Milling is a cutting process that uses a milling cutter to remove material from the surface of a workpiece. The milling cutter is a rotary cutting tool, often with multiple cutting points. As opposed to drilling, where the tool is advanced along its rotation axis, the cutter in milling is usually moved perpendicular to its axis.
https://www.youtube.com/watch?v=Ef59DogwLrI
Drilling is a cutting process that uses a drill bit to cut a hole of circular cross-section in solid materials. The drill bit is usually a rotary cutting tool. The bit is pressed against the workpiece and rotated at rates from hundreds to thousands of revolutions per minute. This forces the cutting edge against the workpiece, cutting off chips from the hole as it is drilled.
https://www.youtube.com/watch?v=KYfAjakKO5w
Laser cutting Laser cutting works by directing the output of a high-power laser most commonly through optics. The laser optics and CNC are used to direct the material or the laser beam generated. The focused laser beam is directed at the material, which then either melts, burns vaporizes away, or is blown away by a jet of gas, leaving an edge with a high-quality surface finish.
https://www.youtube.com/watch?v=PlF_oXvbu4s</td></tr>
<tr><td rowspan="3">ECONOMIC FACTS AND DATA</td><td colspan="2">Turning machine price</td><td colspan="2">Drilling/Milling machine price</td><td colspan="2">Laser metal cutting machine price</td></tr>
<tr><td colspan="2">1,000–40,000 EUR … > 100,000 EUR</td><td colspan="2">600–20,000 EUR … > 100,000 EUR</td><td colspan="2">> 8,000 EUR … > 100,000 EUR</td></tr>
<tr><td colspan="6">Price of the metal depends on the metal type, size and quality.
Low-carbon steel, sheet metal and standard profiles: 1.5–2.5 EUR/kg.
Stainless steel, sheet metal: 3.5–6.5 EUR/kg.
Aluminium alloys, sheet metal and standard profiles: > 3.5 EUR/kg.
Laser and water cutting: different sizes (e.g., sheets 4000×2000×20 mm).
Price of the instrument depends on the design and application.
Turning: tool holders 300–500 EUR/ps, inserts 10–20 EUR/ps.
Milling: tool holders 300–3000 EUR/ps, inserts 10–20 EUR/ps.
Drilling: solid carbide drills 40–300 EUR/ps.
Price of the metal cutting service depends on the technology and equipment.
Turning (CNC): 35–50 EUR/h.
Milling (hand/CNC): 25–35 EUR/h.
Drilling: 15–20 EUR/h.
Laser cutting: 25–35 EUR/h.</td></tr>
</table>

Fig. 5. Metal processing Technology card.

Design selection:

1.Product parts definition.

Size of product 200X200 mm

2.What pats may be produced/purchashed:

Art frame ❶ - produced,

Clock mechanism ❷ - purchashed

Technology selection based on material:

1.Metal	2.Wood	3.Plastick
3D printing *Casting* *Stamping* *CNC milling*	*Hand cutting* *CNC cutting*	*3D printing* *CNC machining* *Injection molding*

Production type (PT):
Unit production (U); Batch production (B); Mass production (M)

Cost definition:

Material	*Machining type*	*PT*	*Qnt*	*1 part material cost, 1pcs/€*	*Prepara-tion time, hours*	*Prepara-tion cost, h/€*	*Processing time, hours*	*Pro-cessing cost, h/€*	*Comments*	*1 pcs direct cost, €*
Metal										
Copper	3D	U	1	200	3	20	4	50	Programming cost 60 €	460
Copper	Casting	B	6	23	1	0.5	0.5	10	Mould cost 1000 €	190
Copper	CNC machining	B	5	40	3,25	20	1	40	Programming cost 60 € + machine setup 5 €	141
Titanium	3D	U	1	200	3	20	4	50	Programming cost 60 €	460
	Casting	B								200
Stainless steel	CNC machining	B	5	10	3,25	20	1	40	Programming cost 60 € + machine setup 5 €	111
Stainless steel	3D	U	1	10	3	20	4	50	Programming cost 60 €	270
...										
Wood										
Wood	Handmade	U	1				25	20		500
Wood	CNC machining	B			3				Programming cost 60 €	110
...										
Plastic										
Plastic	3D	U	1	5	3	20			Programming cost 60 €	42
Plastic	Stamping	M							Stamp cost 10000	5
...										

Fig. 6. Example of practical work.

Career counsellors organize practical work for schoolchildren using product cost calculations in Technology cards, information gathered during visits to the companies, and also other information available on the Internet. Independent tasks for students can be related to business sustainability in the selected industry.

3. CONCLUSIONS

As a result of this project there will be teachers and schoolmasters having competencies in career education and guidance, implementing new interdisciplinary methods at secondary schools. The possibility to communicate with enterprises will give schoolchildren realistic impression of a selected profession.

Authors have prepared teaching and training materials for the secondary school teachers in the format of service training course “Innovative methods for implementing interdisciplinarity in career counselling (IMATEII)”. The knowledge and supervision of the researches and lecturers of technical universities from three Baltic countries will help young people to find the right way in their selection of profession.

ACKNOWLEDGEMENTS

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Innovaatilised meetodid inseneriõppe populariseerimiseks koolides

Eduard Shevtshenko, Tatjana Karaulova, Maris Igavens, Gunars Strods, Ilona Tandzegolskiene, Vidmantas Tutlys ja Kashif Mahmood

Viimastel aastatel on kõrghariduse sektoris olnud tehnilistel erialadel tegemist pideva tudengite nappusega. Selle probleemi lahendamiseks otsustasid kolm Baltimaade ülikooli alustada koostööprojektiga “Innovaatilised meetodid ja õpetamise tehnoloogiad interdistsiplinaarsuse juurutamiseks karjääri nõustamises”. Projekti eesmärk on arendada uut lähenemist, mis toetab koolinoorte karjäärivalikut ülikoolide, üldhariduskoolide ja ettevõtete koostöö tulemusena. Autorid tutvustavad probleemi lahendamist metalli- ja masinatööstuse baasil, kuid antud projekti analüüsi tulemusi võib rakendada ka teistes tööstusvaldkondades.