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SELECTED ASPECTS OF IBL IN STEM-EDUCATION

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Abstract: *This article focuses on an important category of modern education in contemporary society based on innovation as well as SMART, and analyses Inquiry-Based Learning (IBL), inquiry-based science education (IBSE), problem-based learning and project-based learning in the context of STEM education. "At the third millennium in the midst of the digital age, it is expected that emerging technologies will be able to accelerate scientific literacy and enable the majority of citizens to enjoy the blessing of STEM." (Chen, 2017: XV) Additionally, the authors analyse advantages and some aspects STEM education, contemporary trends in modern professions and present several examples of good practice. The article also presents the results of research carried out among academic staff, teachers and students on educational trends and technologies. The survey showed a huge gap between the students' needs and the proposals for organizing the educational process put forward by teachers and academic staff. Interdisciplinarity - an important concept related to STEM-education is highlighted. The authors describe and compare educational technologies, IBL, PBL, PrBL. The stages of IBL provide an opportunity to analyse and implement educational technology in the educational process. In particular, the authors offer instruments for IBL. One of them is the creation of an inquiry learning space Go-Labs that allows for connecting different applications to organize activities at all stages of the research process.*

Keywords: Inquiry-Based Learning (IBL), STEM, innovation, inquiry-based science education (IBSE), problem-based learning, project-based learning, tools for IBL

INTRODUCTION

The world revolves around innovations: new ideas, new products, new solutions to the existing problems. Science, technology, engineering, and mathematics are the foundation for innovation. The development of STEM-directions in education is crucial for the development of society.

“Today, STEM education is at the centre of educational systems all over the world. However, two international comparative studies—TIMES and PIZA—demonstrate that only a small segment of the population reach acceptable mastery of the STEM knowledge core”. (Chen, 2017: XV)

At the World Economic Forum in Davos, it was noted that the fourth industrial revolution is accompanied by radical changes in the labour market. In particular, Klaus Schwab (2016), President of the Forum, in his speech “Future of Employment“, emphasized the fundamental transformation of the quality of life in the nearest future, the changes in communication, activities and cooperation of members of society. Thus, at the beginning of 2020, a fundamental change of more than 35% of the skills of modern workers will lead to the disappearance of even some professions, and those who do not yet exist will become commonplace. It was determined that talent (intellect) would be the more critical factor of innovation production, which would lead to an increase in demand for highly skilled specialists.

1. CONTEMPORARY TRENDS IN MODERN PROFESSIONS

The survey of leading employers from around the world helped to perform the ranking of 10 required competencies by 2020, including the ability and readiness to solve complex problems (tasks), critical thinking, creativity, management, coordination, cooperation, reflection, decision-making, service orientation, negotiation and cognitive flexibility (Hassan, 2000).

In 2013, there were projected to be 1.2 million vacancies in the STEM area, which seemed to be very large. With time, this number increased to the present figure of 2.4 million.

A successful economy is based on a way of thinking based on innovation and creativity, research and development. Many successful entrepreneurs around the world have experience working with STEM, which helps them establish innovative companies or develop existing ones.

"At the third millennium in the midst of the digital age, it is expected that emerging technologies will be able to accelerate scientific literacy and enable the majority of citizens to enjoy the blessing of STEM." (Chen, 2017: XV)

In 2020, demand is expected to increase at a faster rate: 80% of fast developing professions will need fundamental knowledge of STEM disciplines (Figure 1).

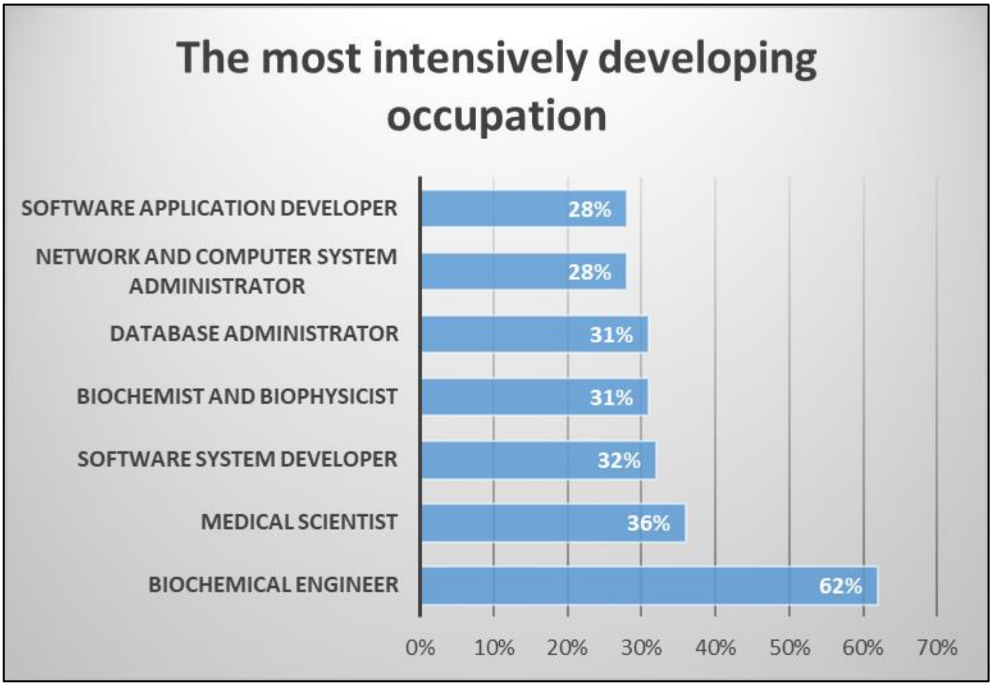

Figure 1. The most actively developing occupations

Source: Own work based on U.S. Bureau of Labour Statistics - https://www.bls.gov/

STEM education is becoming one of the most important educational trends among educators. This is evidenced in particular by the results of our survey carried out in September 2018 in Ukraine among academic staff, teachers and students. 562 academic staff, 239 teachers and 1602 students took part in the survey (Figure 2).

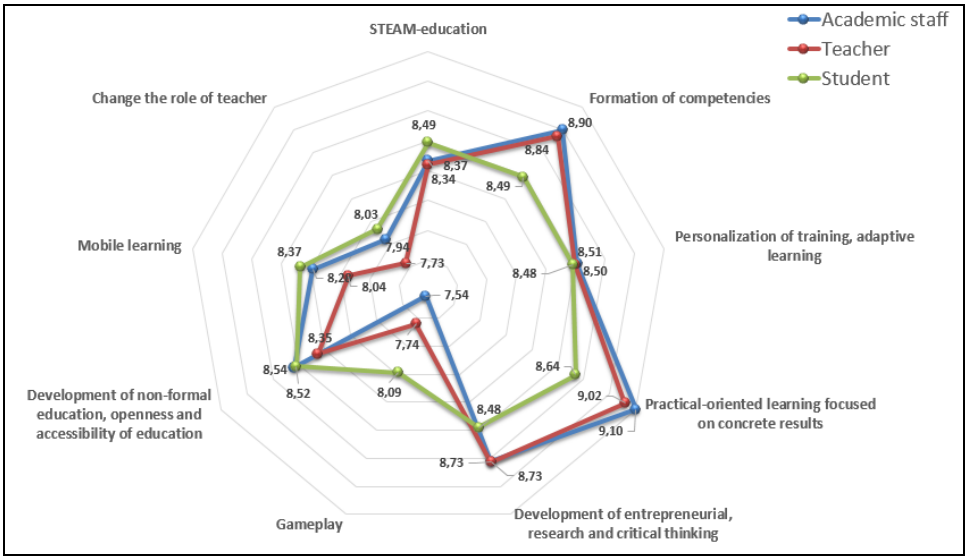

Figure 2. Determination of the priority of trends for groups of teachers, academic teachers, students

Source: Own research

2. STEM EDUCATION AND SOME OF ITS ASPECTS

An important concept related to STEM-education is interdisciplinarity.

Interdisciplinarity in education is regarded as a pedagogical innovation. A key pedagogical aspect in the development of STEM-oriented curriculum is the technology of integration of components which, on the one hand, are close disciplines, and on the other hand, are established independent ontologies: science as a way of knowledge which helps to understand the surrounding world; technology as a way of improving sensitivity to social change; engineering as a way to create and improve devices to solve real problems; mathematics as a way of describing the world i.e. "an analysis of the world and real problems with the help of numbers" (Meeth, 1978).

There are several types of interdisciplinary approach, depending on the nature of the relationship between disciplines, in particular:

- *interdisciplinary* (cross-disciplinary) approach - involves consideration of one discipline through the prism of another (for example, the history of mathematics);

- *multidisciplinary approach* - compares several disciplines that focus on one problem, but does not combine them;

- *pluridisciplinary approach* - combines related disciplines (for example, physics and mathematics, physics and engineering);

- *transdisciplinary approach* - goes beyond the boundaries of individual disciplines, focuses on a particular problem and obtains relevant knowledge (Meeth, 1978).

The advantages of STEM education are:

1. Integrated training in "topics", not subjects.

STEM-education combines an interdisciplinary and project-based approach, the foundation of which is the integration of science in technology, engineering creativity and maths. These disciplines should not be taught as separate, independent subjects. It is important to integrate science, technology, engineering art and mathematics, because these disciplines are closely interconnected in practice.

2. The usage of scientific and technical knowledge in real life.

STEM-education through practical lessons shows children the use of scientific and technical knowledge in real life. At each lesson, they create, build and develop products of the modern industry. Students carry out a specific project, and with their own hands create a prototype of the real product.

3. The development of critical thinking skills and problem solving.

The implementation of STEM education develops critical thinking skills and challenges that are needed to solve the difficulties children can face in life.

4. Increased self-confidence.

Children, when creating different products, building bridges and roads, launching airplanes and cars, testing their work and electronic games, developing their underwater and air designs, each time get closer and closer to the goal. They develop and test, develop again and once again test, and so improve their product.

In the end, solving all problems by themselves, they succeed. For children it is inspiration, victory, adrenaline and joy. After each victory, they become more confident in their abilities.

5. Active communication and team work.

STEM-learning also differs because of active communication and teamwork. During discussion a free atmosphere for discussions and dialogue is created. They are so free that they are not afraid to share their opinion; they learn to speak and present. For the most part, children do not sit at their desks, but test and develop their designs. They always interact with instructors and their teammates. When children take an active part in the process, they remember the lesson well.

6. Development of interest in technical disciplines.

The task of STEM-education at school is to create preconditions for developing students' interest in natural sciences and technical disciplines. Passion for work is the basis for the development of one's interest.

STEM classes are very entertaining and dynamic, which does not allow children to become bored. During the lessons, they do not notice how time is spent, and they are not tired at all. Building rockets, cars, bridges, skyscrapers, creating their electronic games, factories, logistics networks and submarines, they show increasing interest in science and technology.

7. Creative and innovative approaches to projects.

STEM training consists of six stages: questions (tasks), discussion, design, structure, testing and development. These steps are the basis of a systematic project approach. Coexistence or combined use of various opportunities is the foundation of creativity and innovation. Using study and science and technology implementation at the same time can create many new innovative projects.

8. The bridge between education and careers.

There are many publications that analyze the level of growth of the need for different specialties.

According to various estimates, 9 out of 10 specialties for which demand is growing at high rate will require exactly this STEM knowledge. In particular, by 2019, demand for the following specialties is expected to grow: chemical engineers, software developers, oil engineers, computer system analysts, mechanics engineers, construction engineers, robotics, nuclear engineers, architects of underwater structures and aerospace engineers.

9. Children's preparation for technological innovation in their lives.

STEM education also prepares children for a technologically advanced world.

Researchers *(Roslyn Prinsley & Krisztian Baranyai, 2015)* claim that STEAM education requires the following special skills: active learning, critical thinking, complex problem-solving, creative problem-solving, interpersonal skills, understanding how we do business, time management, occupation-specific STEM skills, lifelong learning, design thinking, knowledge of legislation, regulation and codes, system analysis and evaluation, programming.

To create such special skills, teachers should use innovative educational technologies.

The results of the survey of teachers, students and teachers indicate that the most significant for them are the following technologies: Integrated learning, IBL, PBL. Technologies for the formation of media literacy, problem-oriented learning, mixed learning. Technologies of formation of critical thinking, Technology of formative assessment, use of e-learning game environments (Figure 3).

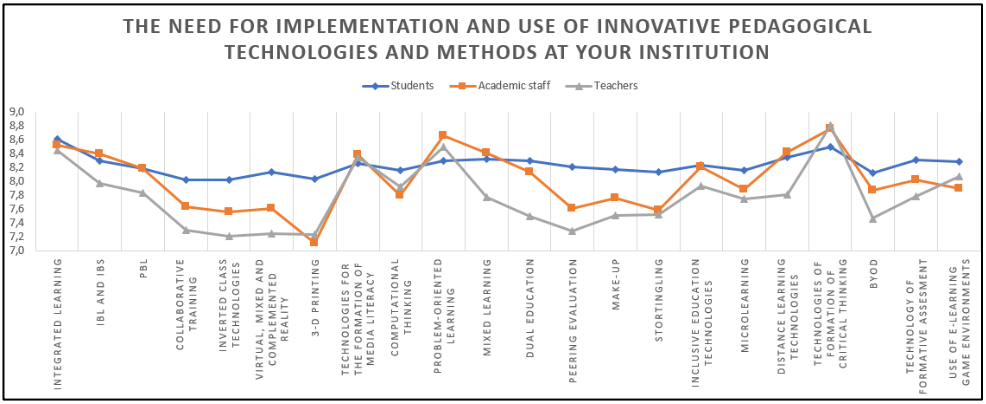

Figure 3. Determination of the need for implementation and use of pedagogical technologies and methods for lecturers, teachers and students groups

Source: Own research

To educate teachers, STEM-education should be introduced to educational technologies such as Integrated Learning, IBL, Project-based Learning (PBL), Problem-based learning (PrBL).

Let us describe and compare these technologies in order to better understand their purpose and usage.

Problem-Based Learning (PBL) is a teaching method in which complex real-world problems are used as a vehicle to promote student learning of concepts and principles as opposed to direct presentation of facts and concepts. In addition to course content, PBL can promote the development of critical thinking skills, problem-solving abilities, and communication skills. It can also provide opportunities for working in groups, finding and evaluating research materials, and life-long learning (Duch, Groh, Allen, 2001). In PBL, the teacher acts as a facilitator and mentor, rather than a source of "solutions."

Project-based learning is a dynamic classroom approach in which students actively explore real-world problems and challenges and acquire more in-depth knowledge.

Table 1 shows the common features of *Project based Learning and Problem based learning* and their differences.

Table 1.

Common features and different features of project based learning and problem based learning

Type of learning	Common features	Different features
Projects based learning	Often multi-disciplinary	Focus on an open-ended

	May be lengthy (weeks or months) Follows general, variously-named steps Includes the creation of a product or performance Often involves real-world, fully authentic tasks and setting	question or task Provides authentic applications of content and skills Build 21th century 4 C's competencies Emphasize student independence and inquiry Are longer and more multifaceted than traditional lessons or assignments
Problem based learning	More often single-subject Tend to be shorter Follow specific, traditionally prescribed steps The "product" may simply be a proposed solution, expressed in writing or in an oral presentation More often uses case studies or fictitious scenarios as " ill- structured problems"	

Source: Own work based on https://www.simplek12.com/learning-theories-strategies/project-vs-problem-based-learning/

3. INQUIRY-BASED LEARNING BACKGROUND IN CONTEXT. SOME ASPECTS

The term IBL is defined in several ways in the literature. First, it means the study of learning participants' interest in a topic in which they participated in social interaction for a common understanding (C. Pierce 1959, L.S. Vygotsky, 1978). De Jong and W. Van Joolingen (1998) defined it as an educational strategy based on the discovery of knowledge that promotes active participation and responsibility of the student. Pedaste and Sarapuu (2006) called IBL an approach by which students solve problems using their research skills.

Lately, survey education has increasingly been proposed as an effective approach to stimulating students' interest and motivation by linking academic teaching in non-formal and informal schools in everyday life (Specht, Bedek, Duval, Held, 2013). Such a strategy can help students develop their ability to work in unpredictable and complex environments, especially in a modern, ever-changing, technological society. In this context, reports based on UNESCO data (West &

Vosloo, 2013) have shown that ICTs enable students to engage in a wider range of non-formal learning activities, especially in order to teach students the responsibility for planning and implementation of educational activities. IC technologies provide opportunities for more personalized and autonomous unhindered learning in learning contexts (Thüs et al., 2012), in which students have the freedom and power to make active decisions. Sharples, Taylor, and Vavula (2005) argued that the strength of the students lies in the socio-cultural synergy between all those who want to advance knowledge, rather than relying on a certain student. Interdisciplinarity and the change in the trajectory of curricula (Chen et al., 2008, Sharples et al., 2005) can be facilitated by continuous learning projects that will make students more self-fulfilling (Suárez, et al., 2017).

IBL is an educational strategy in which students follow methods and practices, in the similar way as professional scientists do, to build knowledge (Keselman, 2003). During the inquiry process the student formulates hypotheses, tests them and carries out experiments and observations (Pedaste M., Mäeots M., Leijen Ä., SarapuuS Pedad, Meyots, Leyen and Sarapu, 2012). The proposed training emphasizes the student's active participation and responsibility for identifying new knowledge for the student (de Jong & van Joolingen, 1998) and this process is considered as an approach to developing students' ability to solve problems (Pedaste & Sarapuu, 2006). In this process, students often manage a self-regulated, partly inductive and partly deductive learning process, carrying out experiments on the study of relationships for at least one set of dependent and independent variables (Wilhelm & Beishuizen, 2003).

Other examples of the effective use of IBL method are described in their own research by F. Onder, C. Senyigit, I. Silay (2018), concerning the effect of an inquiry-based learning method on students' misconceptions about charging of conducting and insulating bodies.

Thuneberg, H.M., Salmi, H.S., Bogner, F.X. (2018) in their own study presented an informal mathematical module integrating Arts (modifying STEM to STEAM) and following an inquiry-based learning approach which was applied to a sample of more than 300 students (aged 12-13 years). Conclusions for appropriate educational settings to foster STEAM environments are discussed.

The authors presented and analysed in their own study “the EcoXPT research project, which has the goal of supporting authentic experiment-based inquiry within an immersive virtual world curriculum for middle school ecosystem science. It builds upon prior research with the EcoMUVE curriculum, which includes, as a culminating activity, student teams creating hand-drawn concept maps to represent their hypotheses about causal relationships in a virtual ecosystem.” (Metcalf et al., 2018).

IBL allows students to be involved in the learning process through real scientific discoveries. The complex scientific process is divided into smaller, logically related elements, which direct students and draw their attention to the important features of scientific thinking. These individual elements are defined as the stages of a query, and their set of links forms a cycle. The scientific literature describes different cycles and stages. For example, Model 5E of the educational cycle (Bybee et al., 2006) presents five steps of the queries (Figure 4):

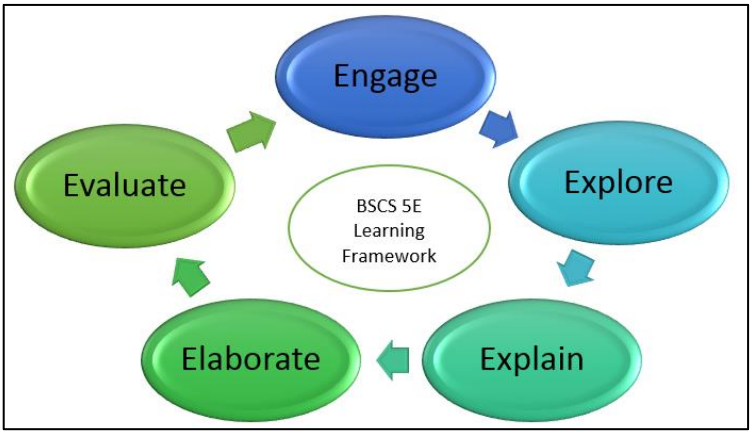

Figure 4. Five stages of queries. Conception 1

Source: Own work based on Bybee et al.,2006

According to (White & Frederiken, 1998), the Inquiry cycle has such elements: Question, Predict, Experiment, Model and Apply.

The difference between these cycles is that the primary stages of cycle 5E (Engagement and Research), start with the inductive approach, and the first two phases of the White & Frederiken 1998 (Question and Predict) cycle propose deductive approach. However, both induction and deduction may coexist in the request cycle. Scientists Klahr D., Dunbar K. describe the scientific process as a search in two environments, which they call the experiment‘s space and a simple hypothesis (Klahr, Dunbar 1988). These researchers suggest organizing the research process as the balance of inductive and deductive approaches in the request cycle.

The literature presents different terms for phases and links between phases, describes the cycles and their stages, the successful use of request cycles in different situations. These models can be used to organize classroom activity (Meyerson & Secules, 2001) for using computer environments (de Jong et al., 2010, Mäeots et al., 2011), but they all are the basis of study based on the survey.

The analysis of the descriptions and definitions of the stages of IBL presented in the articles under review led to the creation of the following structure of the IBL, which includes five general stages of the survey.

In general, this cycle is similar to the one above; but it uses the terms that were removed as the main terms from the articles in this review and covers the processes behind most of the description steps described in these articles. In addition, this cycle also covers many of the main stages of training that were not presented (Figure 5).

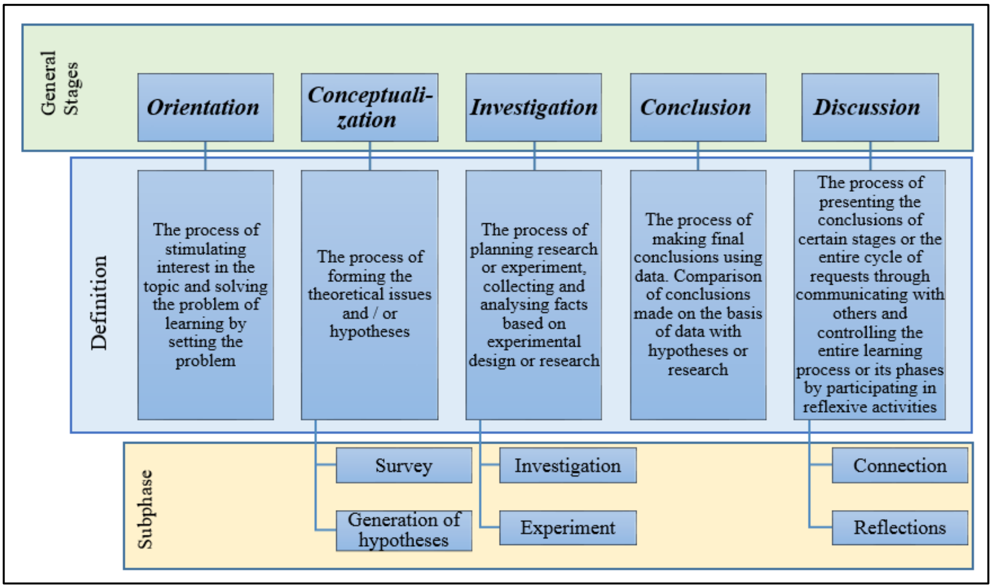

Figure 5. The main stages of learning-teaching, definition

Source: Own work based on Manoli, Pedaste, Mäeots, Siiman, De Jong, et al.2015

Inquiry-based learning for younger students should be implemented under the guidance of a teacher and with her/his participation and help. Progressive teachers, with development of technology, use opportunities of information and communication technologies (ICT) to improve the quality of didactic and methodological support of the educational process to identify the giftedness and personality of a student (Gladun, Buchynska, 2017). In most modern schools, learning activities, including research, require teachers' readiness to use ICT in their professional activities. In these circumstances, one of the priorities of modernization and promotion of research studies is the use of electronic educational resources both during lessons and outside class time. Research and use of instruments for organizing training, various virtual laboratories and integrated programs that help fully or partially to reproduce the progress of experiments, to see the results and changes in experimental conditions, to observe natural phenomena, to study the surrounding world and to be involved in a scientific experiment, will improve the quality of the didactic and methodological support of the educational process.

There are many benefits to implementing inquiry-based learning programs. These benefits include the following (Figure 6):

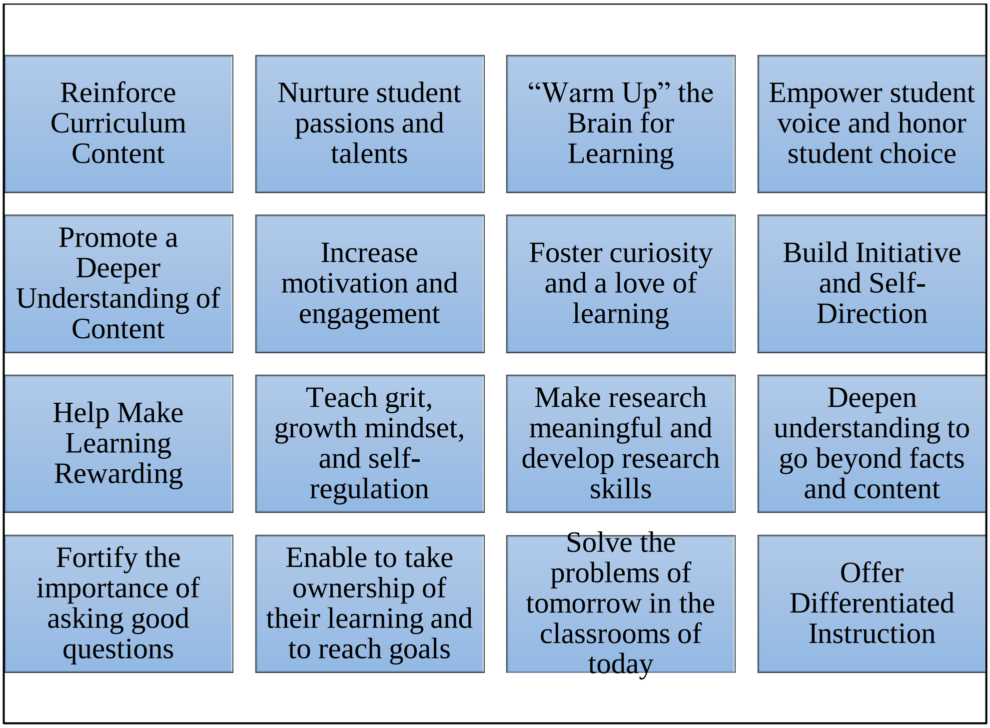

Figure 6. Benefits to implementing inquiry-based learning programs

Source: Gladun, Buchynska, 2017

Inquiry based learning will be much more beneficial for students, because involvement in learning results in improvement of the skills and attitudes possessed that permit you to seek resolutions to questions and issues while you build your new knowledge. There are many web tools that support inquiry based learning which teachers can use effectively to make all the students involve in the interaction.

In this article we have assembled a collection of some useful web tools and apps that support inquiry-based learning (Figure 7). Using these tools will enable students to engage in a wide range of learning tasks that are all driven by a sense of inquiry and questioning.

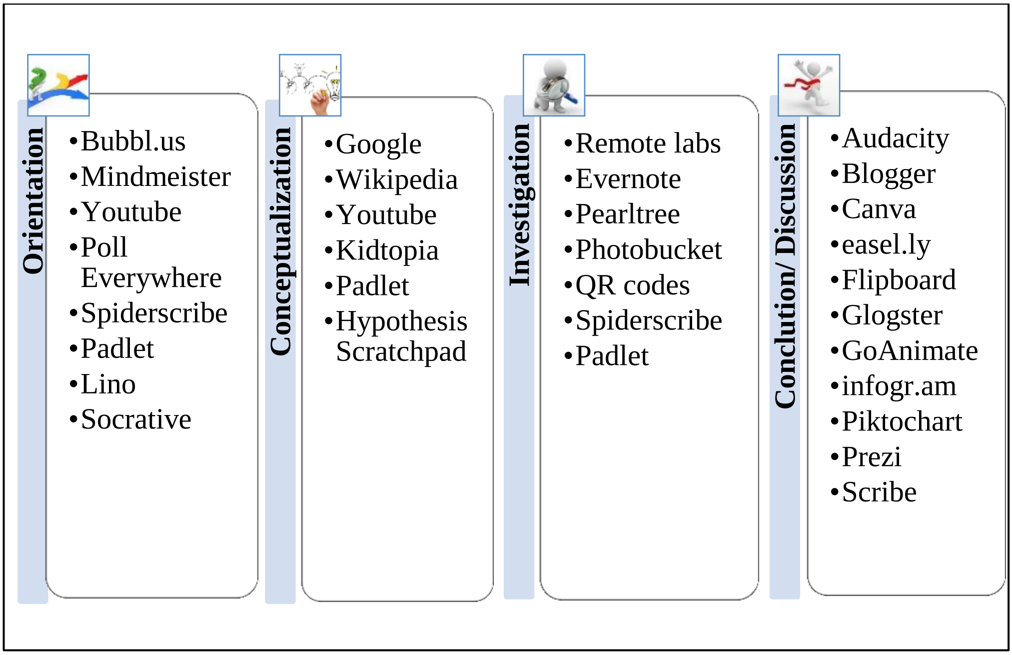

Figure 7. A collection of web tools and apps that support inquiry-based learning

Source: Own work

In our article, we mention the educational portal Go-Lab (web address: http://www.golabz.eu), which offers a unique and comprehensive set of remote and virtual laboratories. The online labs aim at supporting inquiry-based learning and providing the opportunity to conduct scientific experiments in a virtual environment. The Go-Lab project provides access to scientific databases, tools, and resources supporting student learning activities.

The educational portal Go-Lab is designed for creative and modern teachers who are eager to bring their students to the world of science, knowledge and discoveries through a comprehensive development of research tasks. Leading experts from more than 15 countries of the world have been added to the portal. When creating a learning resource, experts are added to its generation, which can competently make suggestions for improving it and only after official confirmation the development appears in free access and occupies the appropriate place in the rating.

In order for the teacher to fully use the educational portal, share experiences, participate in discussions and create a quality education product in the category Support on the site presented: User manuals, Video tutorials, Tips & Tricks tutorial, Community forum, Online course, Forum.

In order to create a complete space for research training, it is necessary to complete three stages:

1. Find the online labs aim at supporting inquiry-based learning using Go-Lab repository (web address: http://www.golabz.eu).
2. Create a unique environment for your students with a variety of files, links and applications (web address: http://www.graasp.eu).
3. Give access to the resource.

Online Labs has 1500 online laboratories (remote and virtual) dealing with Astronomy, Biology, Chemistry, Engineering, Environmental Education, Geography and Earth Science, Mathematics, Physics and Technology, which can be used in their lessons, as well as adapted to their educational needs and goals. Example:

1. Electrical Circuit Lab. In the Electrical Circuit Lab students can make their own electrical circuits and carry out measurements on them. In the circuits the students can use resistors, light bulbs, switches, capacitors and coils. The circuits can be powered by an AC/DC power supply or batteries.

2. *Acid-Base Solutions.* How do strong and weak acids differ? Use lab tools on your computer to find out! Dip the paper or the probe into solution to measure the pH, or put in the electrodes to measure the conductivity. Then see how concentration and strength affect pH.

3. *Star in a Box.* Star in a Box is an interactive webapp which animates stars with different starting masses as they change during their lives. Some stars live fast-paced, dramatic lives, others change very little for billions of years.

4. *Robotic Arm Laboratory.* Each of the sliders controls one of the six services of the robotic arm (Turn on / Turn of a led, move base, move wrist, elbow move, move shoulder, move clamp). Move each of them to define the right mix of movements in which you want to place the robotic arm.

To make your search easier, you can sort online labs using the right side navigation bar. Users have the opportunity to choose the subject area, the age of users, the language of the resource, and so on.

The Go-Lab environment also contains Apps, known as instruments or widgets which are small web applications that support certain training goals and tasks in online labs. Apps can be added to the learning space with online laboratories. The applications are grouped within the survey in the learning space according to their functionalities and goals, and are used to support specific experimental and training activities in online laboratories.

4. DISCUSSION

The major recommendations from the HLG are:

1. There is clearly a need for a common European policy in this area that goes beyond the post-Lisbon open method of coordination of national policies. Europe needs a common policy for human resources.
2. There is a need for novel instruments to measure and monitor human resources for science and technology in Europe, either as a separate entity or as part of a broader European science and technology policy.
3. Reliance on importing suitably qualified workers from outside the EU is not a sustainable, long-term solution, given the global nature of the market and the dynamics at play.
4. A better coordination of national policies and the design of a European policy to attract talented young scientists, with demonstrated potential for original research, from the rest of the world are clearly needed.
5. It is apparent that the shortage of human resources in SET is not felt across the whole of Europe, although it is argued that this in itself is not a steady state and that migration to satisfy demand will surely occur.
6. There is a general hasty conclusion which suggests that the main emphasis on closing the 3% gap lies with industry, and so industry needs to promote careers in a more attractive way to prospective SET employees.
7. The quality of SET training at universities is declining in some institutions.
8. Schools science is often taught by non-experts. All teachers should be offered CPD, and substantial incentives to attend CPD courses by salary structure.
9. Strategies for science popularisation and for the promotion of scientific culture across society are in place in most countries.
10. There is an urgent need for a comprehensive European strategy for enhancing the development of scientific culture across Europe (Gago et al. 2004).

CONCLUSIONS

This article explores aspects of IBL in STEM-education. The survey showed the need to implement IBL in the educational process as a necessary component in the formation of a highly skilled specialist in the modern labour market. Different types of inquiry models were proposed, depending on the degree to which the emphasis is placed on the study, content or study of processes and problems. There are a number of benefits to using IBL.

In recent years, many studies have highlighted an alarming decline in young people's interest in key science studies and mathematics. Despite the numerous projects and actions that are being implemented to reverse this trend, the signs of improvement are still modest. (Rocard et al. 2007)

In the digital age, the integration of technology has become a ubiquitous aspect of modern society. These advancements have significantly enhanced the field of education, allowing students to receive a better learning experience. (Levin, Tsybulsky, 2017).

Inquiry-based learning method as well as inquiry-based science education (IBSE) has proved its efficacy at both primary and secondary levels in increasing children's and students' interest and attainments levels while at the same time stimulating teacher motivation. (Rocard et al. 2007).

Developing and extending the ways in which science is taught is essential for improving student engagement. Transforming teacher practice across the EU is a long-term project and will require significant and sustained investment in continuous professional development (Osborne, Dillon, 2008).

Special instruments are chosen for creating research environment that allow you to complete each stage of the inquiry with the use of interactive techniques. In the Go-Lab environment, students can manage research in remote and virtual laboratories, make self-assessment, communicate and, most importantly, develop their ability to ask questions.

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