*Bulgarian Chemical Communications, Volume 54, Special Issue B2 (pp. 102-105) 2022 DOI: 10.34049/bcc.54.B2.0426*

# Analysis of problem-based learning in physics from the perspective of integrated STEM education

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November 17, 2021; July 04, 2022

Problem-based learning is a specific instructional strategy that applies to the teaching of a variety of scientific content in school. In this article, we analyze the main characteristics of problem-based learning and argue that it is one of the most appropriate practices for integrated STEM education. Our arguments are based on several key concepts and principles that are common to problem-based learning and the integrated approach to STEM. In addition, we find common difficulties in the implementation of problem-based learning and the integrated approach, which are also discussed. This offers new perspectives for problem-based learning in connection with the future development of integrated STEM education.

**Keywords:** problem-based learning, integrated STEM education, physics

## INTRODUCTION

Recently, in science education, the focus has been on the world-famous STEM (science-technology-engineering-mathematics) education. As a result of several years of research on this phenomenon called STEM, we have gained a very thorough knowledge of its origin, its impact on education, and the approaches and models through which it is applied in education. The modern analysis of the approaches and models in STEM education reveals a tendency towards the improvement of the integral approach. In recent years, the integral approach in STEM has been developing under the pressure of influential international organizations of engineers and technologists. The question of where "T" and "E" are in STEM education is quite fair and standards for technological literacy are consequently developed [1, 2]. Let us remember that the ideas of active learning and learning by doing are inherent in technology education and let's admit that problem-based learning began to develop in the early 20$^{th}$ century through the work of John Dewey precisely in connection with technology education [3]. So it's no surprise that we're looking for intersections between problem-based learning (hereinafter referred to as PBL) and integrated STEM (hereinafter referred to as I-STEM).

PBL is the focus of many universities, which aim to modernize their curricula and programs and shift the burden from teacher-centered instruction to student-centered learning. Other reasons to focus on PBL are, that learning is more enjoyable with PBL. PBL helps you learn 'how to learn' and critical skills for the workplace are developed with PBL [4]. It is also interesting, "what employers want to see from new graduates entering the workplace" [4]. The author George Watson refers to a Sigma Pi Sigma Survey of "*Skills Used Frequently by Physics Bachelors in Selected Employment Sectors, 1994*" and although it was done in the distant 1994, the listed characteristics are even more relevant: high level of communication skills, ability to define problems, gather and evaluate information, good teamwork skills and the ability to work with others, and the ability to use all of the above to address problems and find solutions in a complex real-world setting. It is interesting that in the list of self-reported skills used frequently by physics bachelors in selected employment sectors - industry, government laboratories, and high school teaching, knowledge of physics is placed just before advanced mathematics in one of the last places, and not surprisingly, problem-solving is put in the first place [4].

## METHODS OF RESEARCH

This is primarily an exploratory report, the purpose of which is to analyze PBL in physics education but from the perspective of I-STEM education because PBL and context-based real-life problems in themselves or the interdisciplinary approach are not a novelty to physics education [5-10]. This implies a good knowledge of the characteristics and trends of both the PBL and the integrated STEM. Based on the available sources in PBL and STEM education (not all of them are cited here), we have formed our point of view on some current issues of physics (and STEM) education in general.

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In the analysis, we also take into account two additional facts - that PBL and I-STEM intersect with the new 21$^{st}$-century paradigm in education, namely the emphasis on developing certain skills on the one hand, and the highest taxonomic level in Andersen's taxonomy – creativity, on the other hand.

*Characteristics of PBL*

The basis of PBL is the research of a problem most often through teamwork. Problems can be clearly defined by the teacher, or unstructured by defining different levels of problem definition [11]. Problems are also divided into routine (with a clear decision procedure) and non-routine (without a clear decision procedure). They can be in only one subject area or they can be integral - combining knowledge from different areas. PBL is a student-centered approach in which, instead of memorizing knowledge and solving such problems, oriented to the use of this knowledge, a real problem is posed and information necessary to solve this problem is collected by the students. This approach also forms skills for teamwork and research and develops critical thinking and lifelong learning skills [12]. The motivation to learn increases due to the challenge of finding the necessary information, not just applying what is learned in class. Seeking information also contributes to strengthening the motivational element in learning, strengthening the student's self-confidence and building a sense of competence. The reflection related to the self-assessment of the student's activity and the evaluation of the work of the other students is also brought up. Communication skills, skills for presenting and defending positions, defined as soft skills, are formed at the stage of presenting decisions and sharing with others their own decisions.

Some authors determine that the use of PBL has the following main advantages: the student's responsibility for his own achievements increases, the learning also has an emotional character, the skills for group activity in the distribution of roles in the team improve, the comprehension of content is facilitated [13].

The most difficult thing for the teacher when applying PBL is to determine within the studied curriculum a real significant problem suitable for research. It must be consistent with the age of the students and the competencies declared in the curriculum. A preliminary analysis of the problem is needed regarding the difficulties and challenges that students may encounter. The different roles in the teams, as well as the resources available to the students should be defined. It is also necessary to plan feedback with students at each stage when solving the problem.

*Characteristics of I-STEM*

In the integrated approach in STEM, the disciplines are studied as one discipline, without barriers between them. This approach requires the integration of at least two disciplines, and in recent years there have been models of integration in all four areas of STEM [14, 15]. This is made possible by the entry of engineering design into curricula and the understanding, supported by the Next Generation Science Standards (NGSS), that the study of practical applications of science can provide a framework for integrated STEM education. This new generation of standards has three dimensions involved in teaching at all levels: (1) basic ideas derived from the specific content of individual disciplines; (2) scientific and engineering practices (students are expected not only to study content but also to understand the methods that scientists and engineers use in their practice); (3) crosscutting concepts applicable in all areas, such as *pattern, cause and effect, scale, proportion, quantity, systems and system models, energy and matter, structure and function, stability and change* [16].

We see that an important element of these standards is the integration between content and scientific and engineering practices. It should be noted that NGSS focuses equally on engineering design and scientific inquiry. The entry of engineering and technological design greatly changes the landscape of STEM education. While in science education students learn ideas about the world previously accepted by science, this is not the case with technology and engineering. Technology and engineering acquire knowledge through design starting from a technological problem and there are elements of trial and error in this process. Technological knowledge is predetermined by the nature of the problem. The information needed to solve a technological problem constitutes this new knowledge, which must be acquired and which is therefore not known before an analysis of the problem is made. Hence the conclusion is that content cannot be studied without a design problem [17].

The different epistemologies of science, technology, engineering, and mathematics are the biggest challenge to I-STEM [17]. This predetermines the different connections that science, technology, engineering, and mathematics can have in pairs. This must be taken into account in any model of the integral approach [14]. Yet integration can be achieved based on the goal that has been set and the goal is not only to acquire knowledge but also to develop certain skills.

*Intersections with 21st century skills*

Both PBL and I-STEM have intersections with 21st-century skills. The skills of the 21st century, which are fundamental to shaping the prosperity of future generations, are defined by the National Research Council of the United States and more specifically, by the Board on Science Education at a workshop in May 2007 as follows:

- *adaptability* - sustainable behavior in a changing and uncertain environment;
- *social and communicative skills* – a manifestation of tolerance, empathy, and acceptance of the different;
- *non-routine problem solving* - recognizing and defining the problem, developing a strategy for solving it, searching for new solutions;
- *self-control* - exercise of reflection, need to learn, self-assessment;
- *systems thinking* - the ability to understand how things work, how the parts are connected to the whole, how they interact and how they change, and how to improve and refine the system [18, 19].

Two of these skills - systems thinking and non-routine problem solving - are related to science education, in particular physics. The PBL strategy can be integrated to achieve effectiveness in terms of these two qualitative characteristics of personal behavior. Systems and non-routine thinking are the basis for the formation of the cognitive level of creativity in physics education.

Systems thinking is formed in science education as a system of knowledge that is classified in the process of its creation and is based on the use of conceptual apparatus, models and laws – the core of science. Systems thinking requires knowledge of the structure of scientific theory, the limits of the models we use, and the methods of scientific research. This is knowledge of epistemological and procedural nature, defined in the PISA programs [20].

Scientific knowledge, part of which is studied in school, is structured - there is a system of concepts, laws, models, and theories. It has a collective character and develops by changing models. Its purpose is to reach a conceptual description, explanation, and prediction of facts and phenomena. Through systems thinking we can distinguish the different categories of knowledge - facts, concepts, laws, and models, which are in different relationships and different degrees of generalization. For example, physical laws have great predictive power, and the theory explains the facts. The formation of systems thinking in the study of physics is also presupposed by its object of study - natural phenomena and processes that take place in different systems [21].

The conditions in which the systems exist determine the causes and consequences of natural phenomena. Understanding how changing conditions affect consequences is an important element of systems thinking and is the basis for understanding how systems work. Nature itself teaches us to think systematically when we study it. It sustains life by creating and operating systems. Understanding that the behavior of systems in nature depends on all its parts, and that the lack or imbalance in one part of the system affects the normal functioning of others, is a basic idea in the formation of systems thinking in students. Important concepts here are the modeling and visualization of systems, as well as defining the boundaries within which they exist.

PBL is an approach through which systems thinking can be formed by organizing learning so that in the process of solving physics problems clearly distinguish the individual elements of scientific knowledge - fact, concept, law, model, theory, etc. This also forms competencies related to the application of procedural and epistemological knowledge, defined as important in the study of natural sciences.

Non-routine problem solving requires researching a wide range of information, recognizing existing models and developing a strategy, integrating seemingly unrelated information, as well as generating new solutions, and switching to another strategy if the developed one works no longer [22]. It also requires creative thinking, which is the highest cognitive level in Anderson's taxonomy [23].

In connection with I-STEM and creativity, some authors believe that Anderson's taxonomy is more relevant and helpful for engineering and technological education because “creating lies at the heart of engineering and technology” [24]. We further agree that developing metacognitive knowledge which is the fourth category in Anderson & Krathwohl’s knowledge dimension is a basis for active learning not only in engineering but in I-STEM and PBL as well. Both Bloom’s and the revised Bloom’s taxonomies are appropriate to develop the levels in the PST – the problem-solving taxonomy [24, 25]. We can also refer to a PPST – a physics problem-solving taxonomy presented as a useful instructional tool to teachers [26].

## CONCLUSION

Both PBL and I-STEM are rooted in constructivism which means developing new knowledge rather than learning by heart. But other characteristics connect PBL in physics education and I-STEM. These are teamwork and developing other 21st-century skills. PBL is sometimes described as an instructional strategy in which students confront conceptually ill-structured problems and this type of task is very typical for engineering and consequently for I-STEM. Ill-structured problems are very often rooted in real-life situations and require meaningful solutions (not always unambiguous). Strategies for solving this kind of problem are developed in both PBL and I-STEM.

Both PBL and I-STEM have great potential to improve education in general but there are some challenges to their implementation. As oriented towards higher cognitive levels, they require new strategies at the policy and management level and flexible curricula that provide the time needed to accomplish goals and objectives. Certain changes in the educational space are necessary to facilitate teamwork regarding PBL and cooperation with communities of practice regarding I-STEM. Content that covers different areas of knowledge and competencies is based on both PBL and I-STEM and has to be found and included in cognitive problems. This also leads to changes in teachers' professional development and implementation of new instructional methods, like design-based methods, for example. Despite these difficulties, the challenges of the 21st century make us think that PBL and I-STEM should and will develop and the trends we notice prove it.

***Acknowledgement:*** *This work was supported by the Research Fund of Sofia University under contract number 80-10-142/26.03.2021.*

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