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Stem Integration as A System

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ABSTRACT

This article focuses on STEM integration as an important aspect of applying this approach in education. It presents the author's concept of its planning and implementation on the basis of systems theory and the systems approach. In this context, the components of STEM education are viewed as a system that emerges and operates "under the influence" of the so-called "system-generating factor." This leads to the distinction of two types of STEM integration: knowledge-based and skill-based, each defined as a primary component of the system-generating factor. The research methodology involves the conceptualization of this idea through literature review, definition, and critical analysis. The main goal of the literature review is the investigation of theoretical sources concerning different models of STEM integration and those that focus on the application of the systems approach in education. The main concepts in the proposed model are defined. The critical analysis of the author's model refers to discussing the opportunities for implementation in real pedagogical practices, its strengths and weaknesses, and also the potential opportunities for future scientific research.

Keywords: STEM; STEM Integration; system; systems approach; system-generating factor.

INTRODUCTION

Most researchers studying the nature and specifics of STEM application consistently emphasize its interdisciplinary character. This aspect is directly related to integration in education – a significant and ongoing pedagogical issue that dates back to Comenius. In the current educational context, the concepts related to integration are increasingly examined through the lens of this new approach as well, with discussions centering on STEM integration. This topic has become an integral part of STEM research as a whole and its implementation in modern education systems.

Concurrently, the application of the systems approach is gaining prominence in contemporary education studies. This paper builds on this concept and proposes an original framework for applying the systems approach to STEM integration. The scope of the research comprises three main aspects: 1) a brief overview of existing concepts and models of STEM integration; 2) identification of the core ideas related to the systems approach's application in education; 3) outlining the theoretical foundations for applying the systems approach to STEM integration.

METHODOLOGY

This study is theoretical in nature and aims to conceptualize the application of the systems approach to STEM integration. For this purpose, the methods of literature review, definition, and critical analysis have been employed. The first method provides an overview of the leading concepts and models of STEM integration, thus forming a basis for positioning the proposed approach within the existing body of research (Chowdhury & Shil, 2021). In addition, key concepts related to the implementation of the systems approach in education are identified. From this perspective, two specific types of integration have been defined. A critical analysis of the proposed approach to STEM integration is also conducted, focusing primarily on its potential advantages and limitations.

RESULTS

Basic Concepts and Models of STEM Integration

Just as the topic of integration itself remains a perennial issue in education studies, there are numerous divergent views regarding its implementation in STEM education. In their review of a substantial body of work on the subject, Tamara Moore et al. synthesize several key ideas through which researchers define the essence of STEM integration: 'STEM problems and lessons should be based on the real world; STEM disciplines are connected by ideas and skills, degrees of integration, which include number of disciplines, implementation strategies, defining levels of integration; structures for integrating the disciplines, which include role of individual disciplines, specific pedagogies' (Moore et al., 2020). Within the framework of this paper, particular interest lies in the idea that STEM integration is justified through the definition of levels, approaches, and models for its implementation. Rodger Bybee summarizes understandings of STEM from the perspective of the disciplines it encompasses, outlining the following interpretations: 'STEM equals science (or mathematics); STEM means science and incorporates technology, engineering, or math; STEM equals a quartet of separate disciplines; STEM means science and math are connected by one technology or engineering program; STEM means coordination across disciplines; STEM means combining two or three disciplines; STEM means complementary overlapping across disciplines; STEM means a transdisciplinary course or program' (Bybee, 2013).

Based on the classification above, several approaches to STEM integration can be identified. The first one 'maintains STEM 1.0 as a traditional discipline while integrating another STEM discipline' (Bybee, 2013). It can be achieved through strategies such as coordinate, complement, correlate, connections, and combine (Bybee, 2013). The second model involves the integration of two disciplines, allowing for the following combinations: science and technology; science and engineering; science and math; technology and engineering; technology and math; engineering and math. The third model entails the integration of three STEM disciplines with possible groupings such as: science, technology, and engineering; science, engineering, and math; technology, engineering, and math; math, technology, and science. The final model represents the 'full integration of the four STEM disciplines' (Bybee, 2013).

Another approach to the analysis of STEM integration and the development of models for its implementation focuses on determining which discipline assumes a leading role, while the others provide support. Based on a review of an extensive body of research, Hussima et al. (2024) identify five models explored by various scholars: *"The first model separates the STEM disciplines into different teaching and learning sessions, which is the current practice in most schools (Dugger). The next integrated STEM model focuses on all four disciplines but strongly focuses on one or two disciplines. This model type can be seen in McManimon's study, which only focused on science and engineering. McManimon also implicated a third model, where one of the disciplines was integrated into the other disciplines. Thus, the study integrated technology into science and engineering. Many studies applied the fourth model, where technology, engineering, and mathematics disciplines were integrated into science, as studied by Khanaposhtani et al., Shahali et al., Smith-Jackson et al., and Struminger et al. Other than that, Ayar, Maiorca et al., Roberts et al., and Üçgül and Altıok studied robotics modules in which science, technology, and mathematics were integrated with engineering. This integrated STEM model was known as total integration, based on Hobbs et al. Then, Anand and Dogan, Kim and Keyhani, as well as Kwon et al. practised the last model, in which all four disciplines are distributed into separate subjects."*

Other models of STEM integration examine it in relation to the positioning of STEM education not only within the broader education system of a given country and its objectives, but also in the context of the wider social environment and the specific skills it currently demands or is expected to demand in the future (Morais et al., 2025; Shagrayeva et al., 2025). One such model is described by Frank Banks and David Barlex, namely the STSS model (Society–Technology–Science–Society). As the scholars note, 'this model serves as both a conceptual and a curriculum framework for dealing with social and environmental issues' (Banks & Barlex, 2021). STEM integration is also viewed from the following perspectives: K–12 education (English, 2016; Honey et al., 2014; Davis, 2014); specific types of skills such as 21st-century skills, problem-solving skills, and social-emotional skills; interdisciplinary integrated powerful knowledge; and the Next Generation Science Standards (Moore et al., 2020; Jenkins, 2020; Bybee, 2013; Ersozlu., 2022; Felder & Brent 2016; Ge, 2024; Rogovaya et al., 2019).

Before presenting the concept of applying the systems approach to STEM integration, it is essential to address some of the fundamental understandings related to its use in education and training more broadly.

The Systems Approach in Education Studies

It is well known that the principles of the systems approach[1] are built upon the General Systems Theory, to which a number of scholars have contributed—most notably Ludwig von Bertalanffy and Ilya Prigogine (System approach is 'a scientific research approach based on the premise that any more or less complex object is regarded as a relatively autonomous system with its own characteristics of functioning and development' (Surmin, 2003). On this solid foundation, an extraordinary number of theories, concepts, and studies emerged during the 20th and early 21st centuries, focusing on the application of the systems approach across virtually all scientific domains. Education and training are no exception to this trend. Given the large volume of work in this field, it is impossible to cover the full scope of studies related to the application of the systems approach to education studies in this paper. Instead, the focus is on identifying the general conceptual foundations of this trend in pedagogy, based on the contributions of educational researchers over the past two decades.

The reason for the increasingly intensive application of the systems approach in pedagogy and education studies is that 'the systems approach has given birth to such a method the fundamental principle of which is to think, not in small parts, but as a whole. This approach presents a detailed and effective picture of problem and its solution.' (Bhaskar & Lajwanti, 2019).

Within this framework, education, along with pedagogical phenomena and processes, is viewed as a system in which the structural components of which are strictly interdependent (System is 'a set of elements that are interconnected with one another and with the environment, forming a specific whole and unity' (Surmin, 2003). This perspective allows for a deeper exploration of the cause-and-effect relationships that exist or may arise between these components (Component – 'a smaller, self-contained part of a larger entity; it often refers to a manufactured object that is part of a larger device.' (Available at: https://en.wiktionary.org/wiki/component (Accessed 10 October 2024). For these reasons, the systems approach proves particularly effective in presenting and analyzing pedagogical phenomena and facts, as it encompasses all their components (and, to some extent, certain features of the broader environment in which they operate). Consequently, the approach provides a "comprehensive picture" of their internal structure.

According to Gupta and Gupta (2013), some of the key advantages of applying the systems approach to education include: '*a framework for planning, decision-making, control, and problem-solving; sheds light on the dynamic nature of management; provides a unified focus to institutional efforts; helps to view the institution as a whole rather than as separate parts; en ables managers to identify the critical subsystems and their interactions; contributes to institutional improvement; enhances efficiency in school administration and management; supports systematic educational planning; ensures maximum utilization of resources; assists in improving the examination and evaluation system; supports the maintenance, control, and enhancement of guidance services; contributes to the design, control, and improvement of non-formal and adult education systems; enhances the quality of education; and improves teacher training programmes – both in-service and pre-service'*.

Since the terms "system" and "systems approach" are used across various scientific fields, there are no universally accepted definitions for them. Given the purpose of this article, a brief explanation is necessary to clarify how these terms are understood in the context of education. According to Mat et al. (2012), who employ the systems approach to present their own educational model, 'the system consists of component parts, or elements in which they are intimately linked with one another. Therefore, any change in one or more elements may affect the overall performance of the system either beneficially or adversely (Mat et al., 2012).

In addition to the aforementioned points, it is emphasized that 'educationists define the systems approach as an approach which aims at finding the most efficient and economically cost-effective methods for solving educational problems scientifically. The system approach provides a framework for all the factors that influence the solution of educational problem or the achievement of objective. Systems approach is a rational problem-solving method of analyzing the educational process and making it more effective.' (https://ugcmoocs.inflibnet.ac.in/assets/uploads/1/43/1126/et/LECTURE%204%20TEXT200220080802021111.pdf (Accessed 10 October 2024)).

As a result, the terminology used in pedagogy has been expanded to include notions such as "pedagogical system," "theory of pedagogical systems," "systems analysis," etc.

According to Maria Belova, 'the pedagogical system is a social system whose regularities stem from the nature of the interaction between its components, occurring in the pedagogical process and pedagogical activity, both of which are aimed at achieving a pedagogical goal' (Belova, 1997). The scholar emphasizes that in order to understand the specific characteristics of a pedagogical system, one should take into account those of social systems. In her view, the latter are characterized by goal-directedness, which in their case is determined by the human being as the object of study; complex hierarchical structures and interdependencies; a wide range of variability; the capacity for self-reproduction, self-modify, and self-develop; a specialized management system; and the nature of complex dynamic systems (Belova, 1997).

As far as the focus of the application of the theory of pedagogical systems is concerned, Härkönen (2009) states: *"The new pedagogical systems theory is going to consist of pedagogical views. It will deal with philosophical, educational and pedagogical values, aims, goals, subjects, and methods. It will show links to different sciences and knowledge areas and it will also show how different curricula and programs can be well planned and evaluated. These kinds of phenomena have been and are pedagogical by their nature."*

Research related to the theory of pedagogical systems has also been conducted by scholars such as Sidik (2022), Maxwell et al. (2021), Exter et al. (2004), and Ural & Öztaş. (2021). Some of the specific features of applying the systems approach in education will be addressed in the following sections.

Essence of the Concept of STEM Integration as a System

Considering all of the above, the presentation of the concept of STEM integration as a system is based on two essential points: **1)** STEM education, along with all its components, is viewed as a system in this article; and **2)** the concept of implementing STEM integration is presented through the systems approach. The arguments for applying this research approach are as follows:

1. STEM education, like (traditional) subject-based education, comprises the same components (which will be discussed below) that exist in specific functional interrelationships, thereby creating a system (that constitutes a subsystem of the broader education system). Despite the differences between them, both types of education encompass four main *elements/parameters* characteristic of any system: '*input, process, output, and environment*' (Bhaskar, Lajwanti 2019: 105).
2. The components of both (traditional) subject-based education and STEM education are closely interconnected, both structurally and functionally.

The first step in employing the systems approach is to identify the components of the system (Jackson et al., 2010). Bulgarian educationist Plamen Radev highlights that every system for organizing and implementing education consists of the following components: 'input; educational institution; learning content; learning objectives; teaching and learning; teaching and learning techniques; learning methods; external forms of the learning process[6]; learning outcomes; output' (Radev, 2015). The term 'forms of the learning process' is primarily used in Bulgarian pedagogical literature. In general, it refers to the specificities of the teaching and learning process, which are determined by factors such as the type of session (lesson, seminar, excursion, training, etc.), the location where it takes place (at school, out of school, etc.), the number of students involved (small groups, large groups, etc.), and its function (acquiring knowledge, developing skills, measuring and assessing students' knowledge and skills).

As previously mentioned, the main parameters of any system are input, process, output, and environment (Parameter – a variable that describes a property or characteristic of some system (material, object, event, etc.) or some aspect thereof.' Available at: https://en.wiktionary.org/wiki/parameter. (Accessed 10 October 2024). The author refers back to them to emphasize that "process" and "environment" contain certain components. The term "environment" encompasses 'all the circumstances in which the system operates' (Bhaskar & Lajwanti, 2019). This includes the component of the "educational institution," but it may also incorporate additional components depending on the goals of studying the respective system and which components take precedence. On the other hand, the process 'associated with a person or machine unites all the activities through which raw materials are transformed into products, using all available technological knowledge' (Bhaskar & Lajwanti 2019). Therefore, the process within the education system includes the following components: learning content, learning objectives, teaching and learning, teaching and learning techniques, learning methods, external forms of education, and learning outcomes.

The concept presented here focuses exclusively on the parameter of "process" as it encompasses the primary components of any learning process, including those associated with STEM integration. **Table 1** elucidates these primary components in relation to STEM education.

Table 1. Clarification of STEM Education Components

Learning objectives	Global objectives of STEM education, outlined in the theoretical foundations of the approach and defined as 21st-century skills. Specific learning objectives defined in curricula.
Teaching and learning	Based on the philosophy of constructivism in education.
Teaching and learning techniques	A facilitative approach along with associated learning methods and techniques. Both interactive and individual learning are incorporated.
Learning methods	Individual learning methods and interactive methods.
External forms of the learning process	Predominantly group forms of education are featured.
Learning outcomes	Applying the principles of formative assessment.

Some researchers dealing with the General systems theory argue that the interaction between a system's components is not sufficient on its own to account for the system's emergence and scientific validation as such. The so-called "system-generating factor" is also required (System-generating factor – 'the force, program, active principle, or subject that attracts and retains, for a shorter or longer period, the elements, structures, functional entities, or objects that possess system compatibility and are capable of forming a structured whole of one kind or another' (Gradinarov, 2019). This factor is tasked with the role of 'coordinating, organizing, and arranging these interactions in such a way that, ultimately, a (systemic) whole emerges, exhibiting a new quality that cannot be reduced to the qualities of the individual elements it comprises' (Gradinarov, 2019). Without delving further into this issue, it should be noted that, in the same study, Borislav Gradinarov proposes a definition of this factor in the context of the social sciences and the study of social phenomena and processes, one of which is education. He states that 'the system-generating factor is the force, program, active principle, or subject that attracts and retains, for a shorter or longer period, the elements, structures, functional entities, or objects that possess system compatibility and are capable of forming a structured whole of one kind or another' (Gradinarov, 2019). It is also worth mentioning that the system-generating factor consists not of a single component but of multiple system components, as seen in the definition of "system factor" provided by the same scholar (Gradinarov, 2019).

In Bulgarian literature on pedagogy, it is widely accepted that the system-generating components of the pedagogical system are 'the paradigm, the goal (further broken down into specific objectives), and the principles' (Belova, 1997). This concept is also supported by the prominent German sociologist Niklas Luhmann, who asserts that the fundamental component of any education system is 'the transfer of knowledge and skills' (Baraldi & Corsi, 2017). In fact, this points to two key components of teaching and education: the transfer itself, or the methods and means by which it occurs, encompassing the paradigm, principles, and methods of teaching. On the one hand, knowledge and skills form the core of any educational content (curriculum), while at the same time, their acquisition by students represents the primary goal of all teaching and educational processes.

In this sense, within the framework of the concept presented here, knowledge and skills serve as the basic components of the system-generating factor in STEM integration and represent its primary goal. On the basis of this function, two types of STEM integration can be distinguished: knowledge-based and skill-based.

Knowledge-based STEM integration is a type of integration in which knowledge is regarded as the primary component of the system-generating factor. This knowledge must pertain to at least two STEM fields, and its acquisition or application serves as a primary didactic objective. This objective, in turn, determines the specific characteristics of the other components of the system.

In this case, the teacher is guided by what knowledge students need to acquire and how they achieve it. This in turn influences the choice of teaching approach (e.g., project-based learning, problem-based learning, etc.), learning methods (e.g., analysis, synthesis, modelling, etc.), tools, and so on. In fact, these choices also affect all other aspects of the learning process, which touch on the broader theoretical concepts related, for instance, to the competence-based approach in education, constructivism, facilitation, and so forth.

Skill-based STEM integration is a type of integration in which skills are considered the primary component of the system-generating factor. These skills must pertain to at least two STEM fields, and their mastery or application serves as core didactic objective. Based on the latter, the peculiarities of the other system components are then defined.

The planning of this type of STEM integration is guided by the skills the students are expected to develop through the task assigned.

DISCUSSION

First of all, a clear distinction is made between the terms "parameter," "component," and "system-generating factor." The parameters of a system (input, process, output, and environment) are inherent characteristics, independent of the type of system or the scientific field to which the systems approach is applied. In other words, these parameters are intrinsic to all types of systems—social, chemical, biological, and others.

In contrast, components refer to the specific phenomena, processes, or objects studied and analyzed within the particular scientific domain where the systems approach is employed. In this study, for instance, elements such as "learning content," "educational objectives," "teaching and learning," fall within the scope of pedagogy. However, when considered within the framework of STEM education integration through the systems approach, they assume the role of components within the pedagogical system. Each of these components may also serve as a system-generating factor. Hence, this factor cannot be identified unless the system's components have first been determined. In this sense, components represent the structural parts of the system, while the system-generating factor can be one (or more) of these components that performs a specific function relative to the others and to the study of the system itself.

The author's approach presented here addresses two main stages in the implementation of STEM integration: planning and outcome evaluation. Planning STEM education has received considerable attention in pedagogical literature. Notable studies in this area include those by Berland (2013); Felder, Brent (2016); Liston (2018); Trevallion & Trevallion (2020), Özkan, Topsakal (2020); and Meadows et al. (2024). Some of these scholars describe approaches that rely on a set of questions intended to help teachers structure their STEM lessons. Most often, such models begin with the formulation of a real-world problem situation such as: '1. Does the lesson present a real problem (an engineering challenge)?; 2. Will students relate to the problem?; 3. Does the lesson allow students multiple acceptable and creative approaches and solutions for successfully solving the problem?; 4. Does the lesson integrate and apply important science and math grade-level content?; 5. Does the lesson clearly use the engineering design process as the approach to solving problems? …' (Liston 2018: 35). Other models, by contrast, take as a starting point the identification of specific knowledge and skills that students are expected to develop: 'review the knowledge you want your students to acquire and the skills you want them to improve in the course' (Felder & Brent, 2016). The author's approach belongs to the latter group. Applying the systems approach to this conceptual framework transforms knowledge and skills not merely into the primary instructional goal but into a system-generating factor. This means that the organization of all other components is structured around them. Of course, this approach also incorporates project- and problem-based learning; however, the problem situation or project is formulated by the teacher based on the specific knowledge and skills that students are expected to apply or acquire through their work. From a curricular perspective, this approach offers a more effective strategy for overcoming the lack of systemic structure in the acquisition of learning content – an issue frequently considered a major shortcoming of integrated education models in general.

Planning STEM integration as a system would enable teachers to consider all relevant components from the outset and to reflect on potential ways of combining them effectively. This process can be guided by the framework outlined in the left column of Table 1, which may also serve as a planning matrix.

As previously discussed, existing concepts and models of STEM integration focus on different approaches to synthesizing the four STEM disciplines, along with the skills associated with each of them, as well as on those arising from contemporary educational priorities. The approach presented here – conceptualizing STEM integration as a system – does not operate on the same plane as the ones already outlined, but rather at a higher, meta-level in relation to them. In describing the features of the General Systems Theory, Bertalanffy (1972), makes two crucial observations: '1) there is the realm of systems philosophy, that is, the reorientation of thought and world view following the introduction of 'system' as a new scientific paradigm (in contrast to the analytic, mechanistic, linear-causal paradigm of classical science)'; '2) hence an object (and in particular a system) is definable only by its cohesion in a broad sense, that is, the interactions of the component elements'.

Therefore, the model presented in this paper is founded on the view of STEM integration from specific epistemological standpoints. Its object of analysis is the interaction among the components of the system responsible for organizing and delivering instruction and, by extension, for implementing STEM integration. These components, however, are constant, i.e., they are always present, regardless of whether the integration among STEM disciplines is inter-, multi- or transdisciplinary in nature, how many disciplines are involved (two, three, or four), or which specific types of knowledge and skills the instruction aims to develop. Because of this, the concept of viewing STEM integration as a system can be applied to the planning and implementation of any of the models outlined earlier in the article through the specific methodological foundation it implies.

The meta-level at which the systems approach operates enables not only the analysis of specific models of STEM integration, but also a broader examination of STEM education as a distinct educational concept, especially in terms of the outcomes of its planning and implementation. In this context, the term "outcomes" refers to both students' academic performance and the overall effectiveness of STEM in achieving general and specific educational goals. It further allows for the comparative positioning of STEM education (through comparative analysis) in relation to its variants (e.g., STEAM, D-STEM, STREAM), as well as to other educational approaches. All of this highlights the critical importance of refining the procedures for assessing and measuring student outcomes, as these outcomes serve as key indicators in examining STEM education as a whole and in finding ways for its further development.

The term "integration" is defined as 'the act or process of combining two or more things so that they work together' (https://www.oxfordlearnersdictionaries.com/definition/english/integration?q=integration. (Accessed 10 October 2024)). From the perspective of the systems approach, however, this combination is associated with the emergence of new characteristics of the system, which have not been observed in any of its components before. As Ryan Alex notes: 'while the systems approach recognizes the existence of emergent properties it nevertheless seeks to explain them in terms of how their constituent parts are organized. (…) … systemism aims to demystify emergent properties by providing scientific understanding that utilizes analysis as well as synthesis' (Ryan, 2008). In light of the above, conceptualizing STEM integration as a system opens the possibility not only of accounting for the expected learning outcomes, but also of identifying outcomes that emerge unexpectedly from the specific combination of goals, methods, teaching approaches, and other factors. For example, in a STEM lesson integrating mathematics, science, and technology, there is a real chance that students will develop skills traditionally associated with engineering. This is one of the essential aspects that distinguishes the cognitive philosophy of the systems approach from that of the other paradigms. By its nature, this issue is highly complex, and any in-depth exploration of it will inevitably lead to questions regarding the application of Synergetic in education.

The rationale for distinguishing between the two types of integration lies in the fact that knowledge and skills are core components of competencies, and the competency-based approach is a key element of contemporary educational policy. Knowledge and skills are also central to Bloom's taxonomy, where they are identified as fundamental educational objectives (Bloom et al., 1956). Its significance in the context of STEM education has been highlighted by several scholars (Torres-Velásquez et al., 2014; Felder & Brent, 2016). In the revised version of this taxonomy by Anderson et al., four major types of knowledge are distinguished: 'Factual knowledge – the basic elements students must know to be acquainted with a discipline or solve problems in it; Conceptual knowledge – the interrelationships among the basic elements within a larger structure that enable them to function together; Procedural knowledge – how to do something, methods of inquiry, and criteria for using skills, algorithms, techniques, and methods; Metacognitive knowledge – knowledge of cognition in general as well as awareness and knowledge of one's own cognition' (Anderson et al., 2001). Thus, the information/facts that students acquire relate primarily to the first two types of knowledge, while skills correspond to the third type. In this sense, *procedural knowledge* represents the practical application of *factual* and *conceptual knowledge* through various activities, methods, procedures, etc. These practical activities are a defining and inseparable characteristic of the STEM approach as a whole. It should also be noted that 'the result of using procedural knowledge is often factual knowledge or conceptual knowledge' (Anderson et al., 2001). Hence, solving problems (problem-based learning), completing projects (project-based learning), or engaging in other types of tasks can simultaneously lead to the acquisition of knowledge and the development of skills. This constitutes the foundation on which the two types of integration are proposed, while also acknowledging some potential challenges in their practical implementation—issues that will be addressed later in this paper.

A comprehensive and accurate description of the proposed approach to STEM integration requires an attempt – albeit at a theoretical level – to outline its potential limitations, which arise primarily from the application of the systems approach itself. First and foremost, it is widely accepted in academic circles that the systems approach, although increasingly applied across a range of scientific disciplines, often remains at a conceptual or theoretical level, i.e., it proves difficult to operationalize. In the field of education in particular, there are several reasons for this. Operationalizing the systems approach demands expert proficiency in mathematical and statistical methods and procedures. This means that teachers and researchers often need to consult specialists in these domains. From the perspective of the General Systems Theory and Synergetic, pedagogical systems as a subset of social systems are classified as complex nonlinear systems characterized by intensive dynamics; their components are subject to frequent and sometimes abrupt and unpredictable changes. This is because the core of any education system is the human being (the learner), who represents the most dynamic and complex type of system. Studying such systems necessitates the use of even more sophisticated methods and procedures. All of this stems from the fact that with social systems, unlike the ones studied by natural sciences, 'the difficulties are not only in the complexity of phenomena but in the definition of entities under consideration' (Bertalanffy, 1972). For the same reasons, the approach to STEM integration proposed here may prove challenging for teachers to implement in practice, as it requires familiarity with and the ability to apply a specific conceptual and terminological framework.

Another challenge in applying the proposed approach concerns its two variants: knowledge-based STEM integration and skill-based STEM integration. Assigning knowledge and skills the role of a system-generating factor requires that they be clearly distinguished from one another—a task that can be problematic. As Anderson et al. point out, 'the problem of how to characterize knowledge and how individuals represent knowledge is a classic and enduring question in philosophy and psychology' (Anderson et al., 2001). In this regard, teachers may find it difficult to construct an adequate system, i.e., to design a problem situation or select appropriate teaching strategies and methods, specifically aimed at developing skills such as analyzing or synthesizing. The manifestation of these skills on the part of the student may vary considerably in both form and outcome. Nevertheless, no 'bits of information' (Anderson et al., 2001) or individual skills are acquired or developed entirely in isolation from other knowledge and skills, even within the framework of the traditional classroom-based teaching and learning model.

The primary aim of this article is to present the theoretical foundations for viewing STEM integration as a system. Future research on this topic should focus on testing the practical applicability of this concept in two key aspects: the planning of STEM integration and the evaluation of its outcomes. With regard to planning, further studies could examine the extent to which the matrix presented in Table 1 can support teachers in planning STEM integration more effectively. In terms of outcome evaluation, future studies should aim to test procedures for operationalizing the approach proposed here. This includes developing methods for measuring the parameters of "input," "process," and "output," as well as for assessing the interrelationships among the individual components of the STEM integration system. Of course, additional directions for future investigation may also be identified, such as applying the approach to different student types or at different educational levels. However, the author considers the first two research directions to be of primary importance for advancing the development of this idea.

At the end of this study, an attempt is made to provide a general hypothetical example, intended to illustrate how the proposed approach could assist teachers in planning STEM integration and, consequently, their STEM lessons.

In this example, a teacher plans to implement knowledge-based STEM integration. The first step in the process is to determine the STEM fields from which the knowledge will be drawn. Let us assume that he/she selects biology (science), technology, and engineering. The next step involves designing a student task, which typically presents a certain problem (problem-based learning) or requires the completion of a project (project-based learning). For example:

Mario lives in a village and has a house with a yard. Since his house is in the outskirts of the village, snakes frequently enter the yard and threaten his livestock. He wants to design a trap that will capture the reptiles safely without harming or killing them. What ideas for a trap can you suggest to Mario?

This formulation of the task presupposes a problem-based learning approach, where students will need to apply their existing knowledge or discover new facts about what snakes eat, the times of day when they are most active and hunt, what materials could be used to construct the trap, and how these materials can be assembled into a cohesive structure, etc. In this case, students will be acquiring and applying only knowledge, since the task does not require actual creation of the trap but only the description of the idea for it. The skills that students will utilize are general cognitive ones, but not specifically linked to the three STEM fields which the teacher aims to address through this task. In other words, this again highlights the role of the primary component in the system-generating factor, which consists of specific knowledge from the curriculum. Nevertheless, the author of the article is far from denying the fact that the knowledge formation process involves skills and vice versa. The distinguishing criterion is their so-called "didactic status," namely whether they are general cognitive skills or skills from a specific subject area or field.

Based on the planning conducted so far, the teacher identifies the remaining components of the system, namely objectives, teaching and learning strategies and techniques, learning methods, external forms of the learning process, and outcomes. The planning of STEM integration concerning the task presented is illustrated in **Table 2.**

Table 2. Planning Integrated Knowledge-Based STEM Education

Integrated Knowledge-Based STEM Education	
Learning content	Biology (Science), Technology, Engineering
Objective	Acquisition of new knowledge and application of already obtained knowledge from the selected STEM fields
Teaching and learning (educational approach)	Problem-Based Learning
Teaching techniques (facilitative), learning techniques, learning methods (interactive). (Here, the techniques and methods are combined into a single category to avoid unnecessary complexity in the example.).	Discussion, brainstorming
External forms of the learning process	Group-based learning (in groups of three students)
Outcomes assessment	Oral or written description of the idea proposed

In a similar way, the teacher could also plan skill-based STEM integration.

CONCLUSION

The concept presented in this paper is based on the premise that perceiving knowledge and skills as primary components of the system-generating factor can significantly enhance both the planning and implementation of STEM education. It is a fact that integration in education poses certain challenges as regards goal setting and structuring learning content, especially in terms of the systematic acquisition of the content and the sequential achievement of learning objectives (as outlined in various educational taxonomies). At the same time, integration is one of the broadest and most complex topics of research in pedagogy for a number of reasons, such as the vast range of possible approaches to implementing it in real-world practice. This very fact alone greatly complicates the identification of its principles and methods. In this regard, the author's concept presented here, with all its strengths and weaknesses, represents only one possible approach to planning and implementing STEM integration.

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