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IDEARR Model for STEM Education—A Framework Proposal

David Aguilera [1,*], José Luis Lupiáñez [2], Francisco Javier Perales-Palacios [1] and José Miguel Vílchez-González [1]

[1] Department of Science Education, University of Granada, 18071 Granada, Spain; fperales@ugr.es (F.J.P.-P.); jmvilchez@ugr.es (J.M.V.-G.)
[2] Department of Mathematics Education, University of Granada, 18071 Granada, Spain; lupi@ugr.es
* Correspondence: davidaguilera@ugr.es

Abstract: This article proposes a theoretical framework for STEM education. It begins by determining the epistemological (based on the Model of Educational Reconstruction and General Systems Theory) and pedagogical (grounded in Situated Learning Theory and co-teaching) alignments. Once these issues are established, a pedagogical model is proposed to facilitate the implementation of the STEM approach in the classroom. This is the IDEARR model, consisting of six phases (Initial, Deconstruction, Explanation, Application, Review, and Reporting) to address an ill-defined problem. This article concludes with a reflection on the educational implications that arise from adopting this theoretical framework for working on STEM education in classrooms, particularly those related to the organization and operation of educational institutions and the initial and ongoing training of teachers.

Keywords: STEM education; STEM literacy; STEM identity; STEM thinking; educational model

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1. Introduction

The STEM movement has permeated the educational policies of numerous countries in recent years. Examples of this can be found in the USA [1], Chile [2], Mexico [3], Australia [4], South Korea [5], and other European countries, which have formed the STEM Alliance, consisting of 33 Ministries of Education through the European Schoolnet [6]. Given this global proliferation, it is essential to construct theoretical frameworks and didactic models to articulate the implementation of STEM education in classrooms. However, a certain imbalance has been detected between its theoretical development and practical application [7].

Most of the pedagogical models proposed for STEM education come from Southeast Asian countries and the United States of America, with none originating from Iberoamerica or Europe [8]. Many of these models focus imprecisely on the methodological dimension of the STEM approach, making it necessary to develop a robust epistemological and pedagogical framework that allows for the design of a coherent and viable didactic model [8].

The absence of a clear theoretical framework in which to place the growing momentum of the STEM educational movement is creating a profound gap between research and the contribution it could make to the advancement of Science, Technology, Engineering, and Mathematics education. This "orphaning" hinders, and at times, entirely prevents the interpretation of the generated results, risking a descent into pure empiricism [7], something criticized by contemporary philosophy of science as a hallmark of science itself. For this reason, we shall endeavor, drawing from general references such as General Systems Theory [9] and the Model of Educational Reconstruction (MER) [10,11], to construct a unified theoretical framework that enables researchers, educators, and other interested groups to understand (1) what STEM education is, considering epistemological aspects; (2) what roles can be expected from both students and educators in STEM education; and (3) how STEM education could be applied in the classroom.

This article thus pursues two objectives: (1) to establish the epistemological and pedagogical foundations for STEM education, and (2) based on this theoretical framework, to provide methodological guidelines that direct the implementation of this educational approach in the classroom (IDEARR model).

2. STEM Education and Its Epistemological Fit

STEM education has been defined, with a certain consensus, as "an educational approach that integrates knowledge and/or skills from various disciplines appearing in the acronym, oriented towards the resolution of problems and contextualized in situations with different levels of authenticity" (p. 112) [12]. It is not, therefore, a didactic methodology [13], but an educational approach aimed at (1) guiding the integrated teaching of the four disciplines involved in the acronym (Science, Technology, Engineering, and Mathematics), and (2) promoting competency-based learning [7,14]. This conceptualization aligns with the recommendations for lifelong learning by the European Union [15].

On the other hand, the epistemological debate on the Nature of STEM (NoSTEM) has revolved around the role that Science, Technology, Engineering, and Mathematics play in an integrated teaching and learning process. Various authors who have sought to clarify the epistemology of STEM have arrived at very similar general conclusions: (1) STEM is not a discipline, and (2) as a result, NoSTEM does not exist [13,16–18]. Faced with these conclusions, different interpretations have been made:

- Ortiz-Revilla et al. [18] argue that NoSTEM should be understood figuratively to ensure proper disciplinary integration and to teach an "integrated nature of integrated STEM". Thus, while they acknowledge that NoSTEM does not exist in theory because STEM education is not a discipline, it does have a practical expression that underlies the transdisciplinary integration of STEM disciplines.
- Quinn et al. [17] understand that, also in a figurative sense, NoSTEM is manifested through the Nature of Engineering (NoE).
- McComas and Burgin [16] assert that NoSTEM does not exist and also question the relevance of Technology in the acronym, as they do not consider it a discipline.
- Akerson et al. [13] assume that NoSTEM does not exist but admit that there are individual natures (NoS, NoT, NoE, and NoM) that interact to construct an integrated educational approach.

In summary, various approaches have been provided to explain the epistemological relationships between the STEM disciplines. According to Radder [19], the convergent model for NoSTEM by Quinn et al. [17] could correspond, a priori, to a primacy model—in which Engineering acquires greater relevance than the other disciplines—but it also exhibits characteristics that would place it close to a two-way interactive model—in which each discipline is considered an independent entity but in constant interaction with the others. Akerson et al.'s [13] epistemological reflection clearly aligns with a two-way interactive model, while Ortiz-Revilla et al. [18] establish a "seamless web" model for NoSTEM, assuming that interdisciplinary relationships are so strong that they cannot be distinguished in action.

In this landscape, STEM education undoubtedly faces a significant risk that simultaneously concerns the specific didactics involved (Science, Technology, Engineering and Mathematics education): that of distorting the forms of knowledge inherent to each discipline [16,17]. This is such the case that the STEM educational approach should offer opportunities for analysis and reflection in which students distinguish the disciplines present in the integrated teaching and learning process [17]. Specifically, STEM education must address both the forms of shared disciplinary knowledge and practices and those specific to each discipline in order to promote the simultaneous development of STEM literacy and the unique literacy of each discipline. This pedagogical practice would ensure that the singularity of each discipline is not devalued, without surrendering the didactic potential of interdisciplinary integration [17]. Therefore, the epistemological reasons outlined, along with student difficulties in identifying both the STEM disciplines in integrated projects and the interactions that occur between them [20], invite the promotion of nested, multidisciplinary, or interdisciplinary levels of integration [21]. Regardless of the level of integration, educational proposals based on the STEM approach should focus on social, political, cultural, and environmental challenges [22]. This would enable teachers to blur disciplinary boundaries—without "erasing" them completely—while students experience a certain "epistemic disobedience" [23], interpreting these challenges through different disciplinary lenses [24].

STEM education must be understood from a systemic perspective and interpreted within the educational framework. From General Systems Theory [9], a system needs to be understood as a set of interacting elements that, while being susceptible to division into parts, acquires entity precisely to the extent that these parts are integrated. In any system, we can distinguish components, or composition, and a structure, or network of relationships, which enables the interconnections between the parts to provide unity. Thus, in the educational context, three systems can be established: (1) the disciplinary system; (2) the school system; and (3) the social system. Furthermore, considering something as a system implies understanding that it is both more and less than the parts that constitute it. It is more because from it emerge constructs such as STEM literacy, STEM thinking, and STEM identity (Table 1), which are established as distinct qualities and afford it entity; these qualities, which are not contained in the parts, have the capacity to retroact on the system and its parts. Nevertheless, it is also less than the parts because the organized whole imposes limits and restrictions on them, as they cannot always fully demonstrate all their potential. Hence, not all scientific, technological, engineering, and mathematical knowledge and practices can satisfactorily conform to the STEM educational approach.

Table 1. Emergent constructs of the STEM approach.

Concepts	Definitions
STEM literacy	The ability to identify, apply, and integrate concepts from Science, Technology, Engineering, and Mathematics to understand complex problems and to innovate in order to solve them [25]. Bybee [26] specifies that this involves the following: • Managing scientific, technological, engineering, and mathematical knowledge to identify problems. • Acquiring new knowledge, the product of the integration, and applying it to the solving of problems. • Understanding the characteristic features of Science, Technology, Engineering, and Mathematics. • Recognizing how STEM disciplines shape our material, intellectual, and cultural world. • Becoming involved in subjects related to Science, Technology, Engineering, and Mathematics as committed, active, and critical citizens.
STEM thinking	"As purposely thinking about how STEM concepts, principles and practices are connected to most of the products and systems we use in our daily lives" (p. 8) [27]. Therefore, this construct can be considered as part of STEM literacy.
STEM identity	As the extent to which a person sees themselves and is accepted as a member of a STEM discipline or field [28]. Therefore, it consists of four dimensions: (1) personal interest in STEM disciplines; (2) the ability to perform a task in the STEM field; (3) self-efficacy or beliefs about one's capabilities to carry out a task in the STEM field; and (4) professional, academic, or personal aspirations in the STEM field [29].

Nevertheless, we also need to consider the characteristics of the MER, as it is a model aimed at the teaching of the sciences, with a constructivist epistemological orientation [11], which assumes that such teaching involves a multitude of disciplines that serve as references during the teaching and learning process [10]. Our model for STEM education is based on this principle, so the identified elements (Figure 1) make different contributions to the educational approach:

- The philosophy and history of Science, Technology, Engineering, and Mathematics, along with the body of knowledge of each, provide thought patterns that allow for a critical analysis of the role that each STEM discipline can adopt in the resolution of an authentic and complex problem.

- Psychopedagogical elements, both general (e.g., educational theories, cognitive development. . .) and specific (e.g., science education, technology education. . .), enable the didactic transposition of disciplinary elements.
- The curriculum provides legislative support for the implementation of STEM education.
- Social elements participate in the construction and resolution of the problematic situation, which has been identified as a key characteristic of STEM education [12]. This encourages other disciplines to be linked to this approach in a crosscutting manner. For example, Linguistics can provide frameworks for analyzing discourse and preparing research reports; Ethics provides a framework for interpreting the moral aspects inherent in the chosen issue; and Art can offer a framework for evaluating the choice among different alternatives for a product based, for instance, on aesthetic aspects.

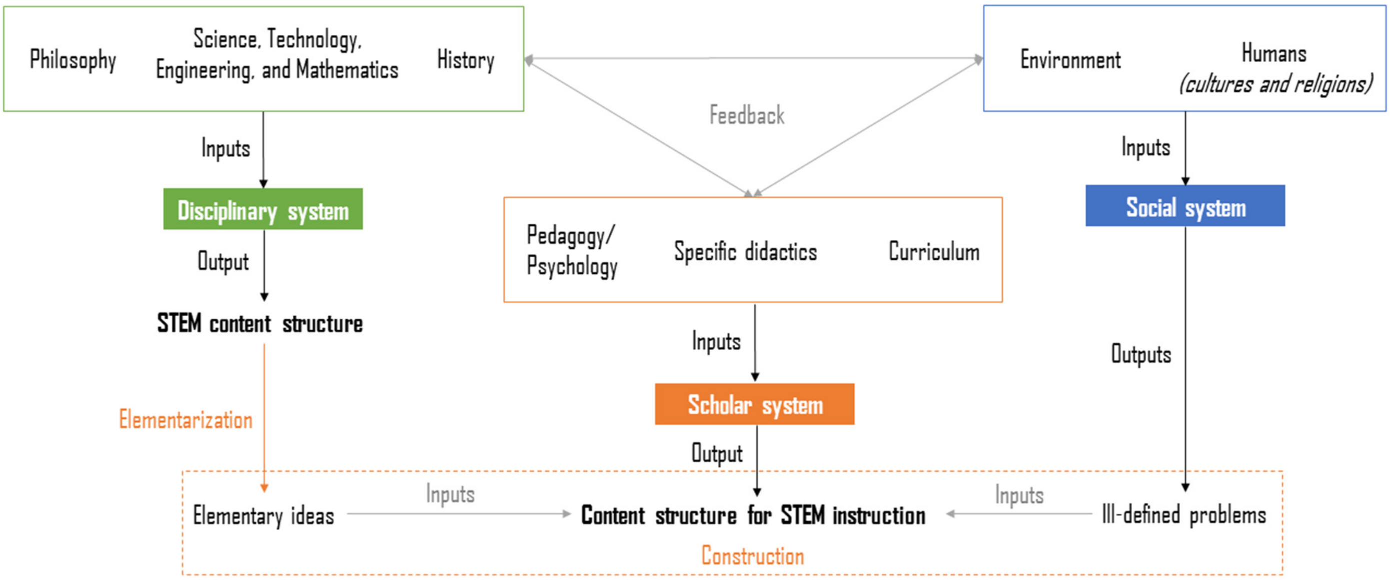

Figure 1. Systemic model for STEM education.

Once the theoretical references of our systemic model of STEM education have been established, it is appropriate to define each of the systems, as well as the interaction between them (Figure 1).

2.1. Disciplinary System

This system is composed of the four STEM disciplinary domains, each of which contributes its epistemology, history, philosophy, as well as its body of knowledge. All of these elements form the STEM content structure. The competency-based orientation of the STEM approach has already been emphasized; therefore, the body of knowledge in each discipline encompasses concepts, procedures, and attitudes because (1) instruction should pay attention to all three perspectives of disciplinary knowledge [10]; and (2) STEM education must be involved in the acquisition of knowledge and skills as well as the promotion of positive attitudes toward learning in the four STEM domains [7].

Our proposal for the STEM content structure aligns with a two-way interactive model [19], providing each discipline with its own identity based on its knowledge and practices while describing the relationships or interactions that take place between them (Figure 2). It is worth noting that Davis et al. [22] have approached the role of each discipline within STEM from a narrower perspective: Mathematics (calculation and modeling), Technology (usage and designing), Engineering (application and innovating), and Science (method and inquiring). In contrast, we take the proposal of MacKinnon et al. [30] as a more general starting point:

- Science as a "form of knowledge" that seeks to understand the world around us.
- Technology as a "form of adaptation" that necessarily considers social impacts.
- Engineering as a "way of designing/creating devices" to respond to real problems.
- Mathematics as a "way of expressing an understanding/analysis of the world and problems through numbers".

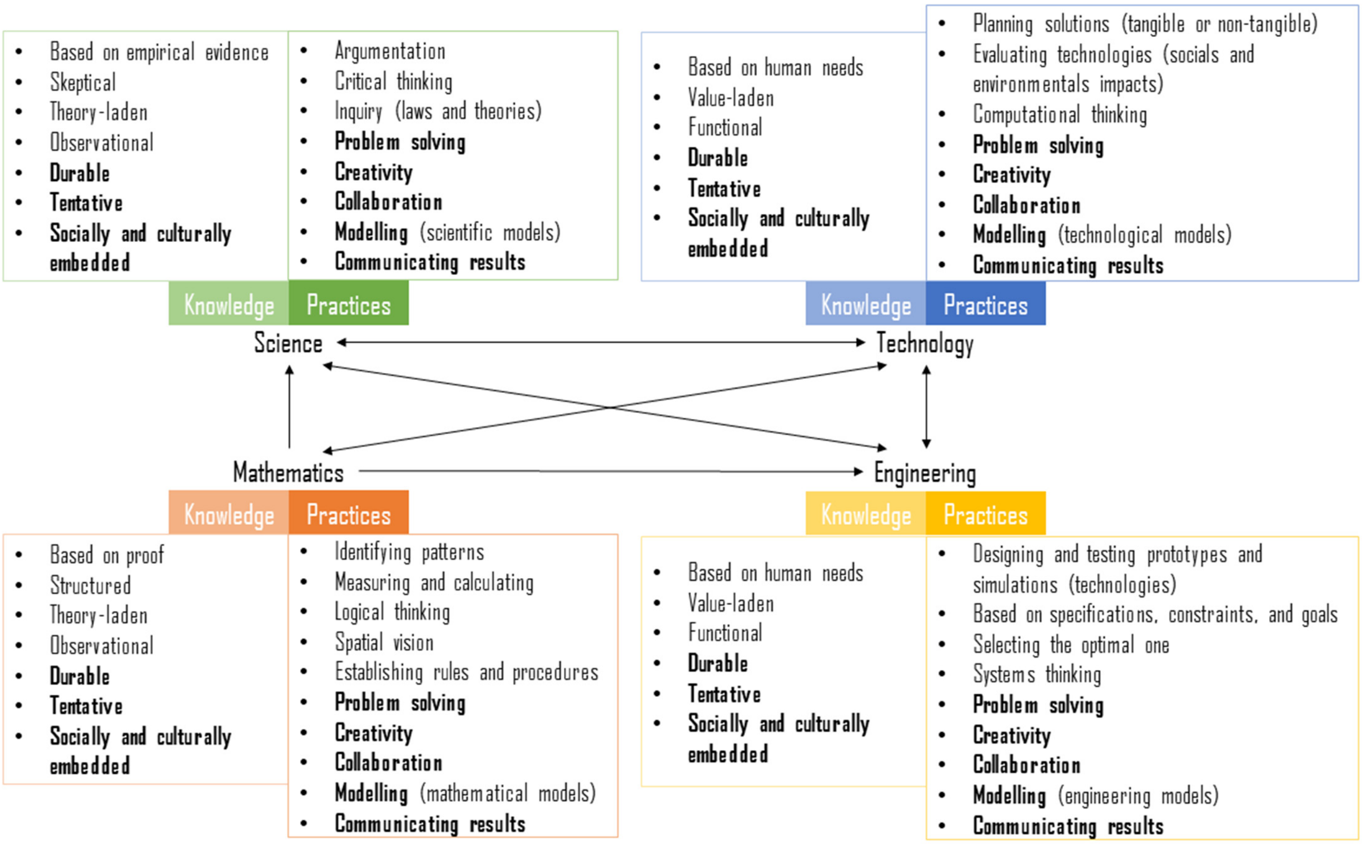

Figure 2. Characterization of STEM disciplines and their relationships. Note: Practices and knowledge common to the four disciplines are highlighted in bold (overlaps).

Figure 2 is based on theoretical references that address the nature of STEM disciplines [13,16–18,22,30–36]. Thus, our model highlights various issues identified in the literature:

- STEM disciplines share some characteristics in their knowledge and practices (overlaps) while also displaying peculiarities [17,18]. This facilitates their integration but also presents a challenge. Therefore, when implementing STEM education, the practices and characteristics of knowledge specific to each discipline should not be neglected.
- Technology and Engineering exhibit significant overlaps that make their disciplinary distinction challenging [17], to the extent that some authors do not consider Technology a discipline [16]. However, Technology has nuances, albeit few and still lacking consensus, which differentiate it from Engineering. While Technology focuses on assessing the social—we extend it to environmental—impact of technological elements and systems [35], Engineering is centered on producing them [17,32]. Thus, Technology constitutes a discipline linked to the study of human needs within a specific social and environmental context, while Engineering is a discipline aimed at the production of artifacts to solve real, specific problems based on human needs [30].

- Science, Technology, and Engineering constantly interact (bidirectional relationships), which is why the development of one is linked to the others [37,38]. In contrast, Mathematics does not have such a high level of interaction (unidirectional relationships) with the other STEM disciplines. This could explain, a priori, the support role that Mathematics tends to play when integrated with the other STEM disciplines [7,39–41] and the inclusion of mathematical content in STEM educational proposals that require low cognitive demands [42]. Becker and Park [43] suggest that sequential integration, guided by a thematic axis or context, leads to better performance in Mathematics and a better understanding of NOM, compared to parallel or total integration of the disciplines. Therefore, it is advisable for the STEM approach to highlight the contribution of Mathematics to the other disciplines and problem solving [42], which also provides an applied perspective on Mathematics as opposed to its abstract societal image. This didactic approach is desirable and can be extrapolated to the other STEM disciplines.
- Mathematics and Technology demonstrate an interaction justified through computational thinking, closely related to logical–mathematical thinking and pattern recognition [44], and the contribution of different technologies (artificial intelligence, software. . .) to the development of mathematical knowledge [17,41].

2.2. Social System

This system serves as a source of complex problems for which more sophisticated or simpler solutions are sought through the STEM approach. It is also responsible for contextualizing the integrated teaching and learning process.

Three dimensions can be distinguished: familiar, local, and global. Thus, the problem can focus on (1) a familiar everyday situation directly related to one of the students, another person, being, or thing; (2) an issue of a local nature that has occurred or is occurring in a specific population; or (3) a matter of global nature, the repercussions of which may affect different populations. It should be noted that any complex and authentic problem can simultaneously manifest in all three dimensions. As an example, the sustainable development goals [45] constitute the most relevant global problem source of the 21st century, although these can be approached from local or familiar perspectives.

2.3. Scholar System

The school system receives inputs from both the disciplinary system, through elementary ideas, and the social system, through the provision of ill-defined problems. Along with the other didactic actions by the teacher, these constitute the content structure for STEM instruction a term based on the MER [10,11]. Within this structure, two didactic processes converge:

1. Elementarization, a process by which the teacher extracts key ideas, concepts, and principles from the STEM content structure, developing a didactic transposition thereof and generating elementary ideas suitable for working with students. This is made possible to the extent that the teacher—or teachers cooperating in the design of the learning sequence—has mastery of the pedagogical knowledge of STEM content. In this process, the mobilization of psychopedagogical elements of the school system is also crucial.
2. Construction, a process that links the elementary ideas obtained in the previous phase with the ill-defined problems provided by the social system. It is here where the authentic problematic situation is generated, which the students will have to face based on the learning sequence designed by the teacher. In this process, it is important to highlight that for non-formal and informal educational actions, the curricular elements will not be relevant; in contrast to formal contexts, where the curriculum is the legal and structuring support of the school system. In this sense, Montés et al. [46] offer a curriculum analysis methodology that could be a valid option for the construction process. Specifically, the "Forward" variant methodology presents seven phases aimed at (1) analyzing the contents of each STEM area in the

curriculum and (2) identifying connections between contents from different areas. The final choice of the "opportunity areas" in the curriculum would facilitate their alignment with the elementary ideas and the selected ill-defined problem.

In conclusion, the school system acts as a connecting axis between the disciplinary and social systems. This enables the formation of an active and informed citizenship capable of engaging with the global problems that currently concern us [47]. This should lead us to reflect on the need to transform educational action in the quest for the construction of more effective, and why not, affective knowledge, to produce knowledge more closely aligned with environmental, social, and cultural realities. Consequently, in addition to the well-known objectives of STEM education, related to promoting a positive STEM identity and developing STEM literacy and specific disciplinary competencies [12], we can move toward a broader and more ambitious goal: to educate citizens with a critical spirit, capable of adapting and successfully participating in a changing society that is closely tied to Science and Technology.

3. Pedagogical Foundation for STEM Education

In this section, STEM education is linked to the situated learning theory, which, given its characteristics, appears to be the best option. Key elements of the STEM approach have been established as the resolution of authentic problems, the contextualization of the teaching and learning process, and interdisciplinary integration (primarily through knowledge and practices) [12]. This section also addresses teaching within the framework of STEM education.

3.1. Situated Learning (Lave and Wenger's Theory)

Situated learning theory is closely linked to Vygotsky's socio-constructivism, Kolb's experiential learning, and Bandura's social learning theory [48]. Lave and Wenger [49] conceptualized socially situated learning with the purpose of establishing two key axes for learning: (1) the context, which engages students and provides a medium in which to apply their learning; and (2) the socio-interactional component, which is necessary and essential for generating learning. In this sense, the authors state that "persons, actions, and the world are implicated in all thought, speech, knowing, and learning" (p. 52) [49]. Consequently, they speak of "legitimate peripheral participation" as a transformative process in which all authorized agents are included in the same community of practice, which Wenger [50] characterized based on three components: (1) mutual engagement; (2) joint enterprise; and (3) a shared repertoire (tools, artifacts, ways of knowing, etc.).

STEM education enables the creation of a community of practice in the classroom, in which (1) educators (teachers, family members, and other external agents to the educational community such as scientists, engineers, NGOs, etc.) and learners participate; and (2) the element responsible for situated learning is the ill-defined problem (social system). Thus, this community can be characterized by the following:

- It is oriented towards preparing learners for active and critical citizenship, capable of participating in the resolution of real and complex social problems. Its success lies in the quality of the learning acquired by all members, as well as in the actions developed by the participants and their impact on their environment. While educators take on the role of moderators and guides, they, along with the learners, develop actions that result in benefits for the community and their immediate environment, at the very least (joint enterprise).
- Educators are responsible for stimulating curiosity in learners and encouraging them to take action. However, the resolution of the problem will depend on the commitment of all parties and mutual support (mutual engagement).
- During the problem-solving process, cooperative or collaborative work is required, involving consensus on decisions and procedures (shared repertoire).

3.2. Co-Teaching

Managing a community of practice is not a simple task, especially when its purpose is purely educational and it requires a sound command of multiple disciplines. Therefore, the implementation of STEM education should consider co-teaching, which has been defined as the instructional process directed at a group of students that has been designed and/or implemented by two educators in the same physical space [51]. However, considering the characteristics of STEM education, this concept can be applied more flexibly. Thus, it is possible for more than two educators to participate in the instructional process, and it could also be carried out in different spaces. This would allow the creation of multidisciplinary teaching teams that could implement the STEM approach with different levels of disciplinary integration (nested, multidisciplinary, and interdisciplinary) [21].

This teaching model, while recognizing its limitations—primarily related to situations and environments lacking resources—has various educational implications, including (1) more personalized teaching and learning processes; (2) improved academic performance for students who face difficulties, as well as those with high capabilities [52]; (3) reduced student–teacher ratios [53]; and (4) the possibility for pre-service teachers to gain experience, as they could engage in joint professional practice with in-service teachers experienced in STEM education [54].

The plurality of professionals who could be involved in co-teaching makes it essential to analyze the factors that determine the effectiveness of this teaching model (Table 2), as well as the relationships between them (Figure 3).

Table 2. Moderators of co-teaching effectiveness.

Factor	Definition
Cooperation	Teacher and co-teacher should collaborate and help each other [54].
Co-experience	Teachers should share their knowledge about contents and related pedagogic experience, in order to enrich instruction with different teaching styles [55].
Co-generative dialogue	Teachers should talk prior to class and during class. These talks should be aimed at solving problems related to the instructional process [56].
Co-respect	Teachers should accept the presence, opinions, and help of peers [57].
Co-responsibility	Teachers should feel involved in teaching planning, a fact that implies agreeing on content, strategies, and procedures (co-planning) [58].
Co-leadership	No one should hold the role of main teacher or, on the contrary, subordinate [51].

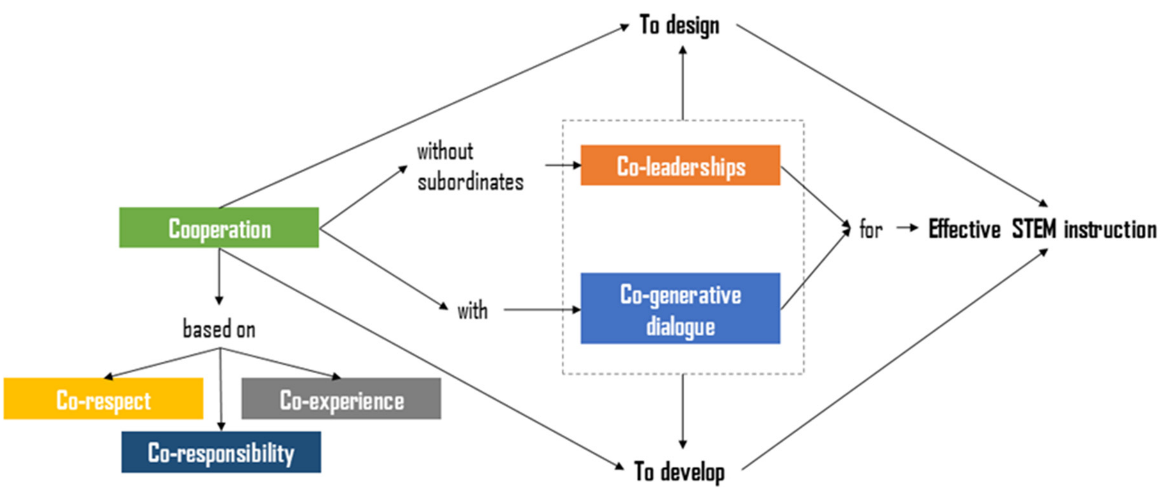

Figure 3. Relationship between the moderators (Table 1) that determine the effectiveness of co-teaching.

Finally, we need to consider how co-teaching can be implemented in the classroom. According to Cook and Friend [51], two models are established for its implementation:

- STEM station teaching: Groups of students are attended to simultaneously by the co-teachers at different stations, different spaces within the same classroom, or sequentially in different spaces or classrooms. Each teacher is assigned a station or space (laboratory, classroom, etc.) based on their knowledge, skills, and/or preferences. The student groups rotate through the various stations or spaces.
- STEM team teaching: The co-teachers deliver the lesson in a coordinated manner, interacting with each other and with the students. Therefore, it will be essential to clearly and equitably define the roles and responsibilities of the co-teachers, encouraging them to take on different roles throughout the sessions [58,59].

4. IDEARR Model—A Methodological Proposal for STEM Education

Once the epistemological and pedagogical foundations have been established, it is time to present our proposal: the IDEARR model (Figure 4). Based on the problem-based learning (PBL) cycle [60], it constitutes a methodological approach to implementing STEM education in the classroom. This responds on the one hand to the fact that most problems addressed in science, technology or engineering education do not have a single solution and, given their interdisciplinary nature, require a complex, non-linear problem-solving process [61]. On the other hand, PBL is a general teaching and learning methodology that does not give priority to any of the STEM disciplines [21], as it focuses the teaching and learning process on a practice common to all four STEM domains: problem solving (Figure 4).

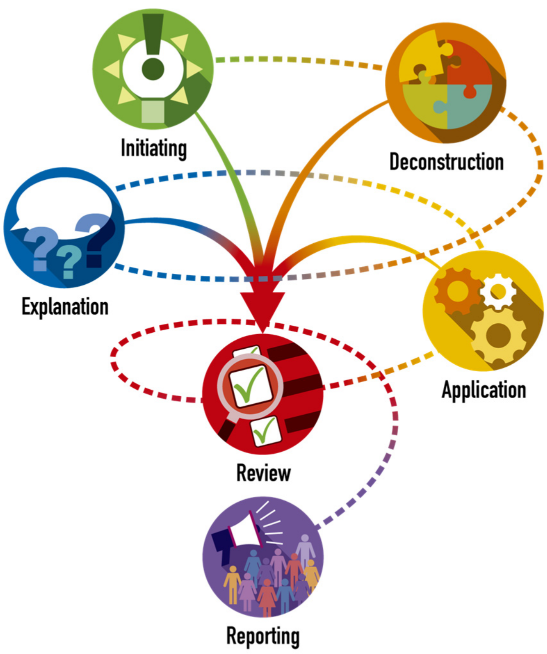

Figure 4. Graphic representation of the IDEARR model for STEM education.

The IDEARR model focuses on the problem-solving process, assuming that there are multiple pathways for solving (open-ended) problems and that they will largely depend on the actions taken by the students. Therefore, it is advisable to avoid a complete and meticulous advance definition of the product expected at the end of the process. This would prevent predicting—and inducing—decision making and actions that students would take to solve a complex problem. In this sense, it has been found that such predictions on the part of teachers are not reliable [61], as they often turn out to be inaccurate and undervalue students' capabilities.

4.1. Initial Stage

This first stage includes presenting the ill-defined problem, exploring the problem scenario, and creating working teams. Therefore, in this phase, sufficient stimulation and curiosity should be generated to create an intrinsic commitment to problem solving, fostering the identification of prior knowledge of students, as well as personal and/or educational experiences useful for finding solutions.

According to Lynch et al. [62], "a problem is ill-defined when essential concepts, relations, or solution criteria are un- or under-specified, open-textured, or intractable, requiring a solver to frame or recharacterize it. This recharacterization, and the resulting solution, are subject to debate" (p. 258). In this sense, an ill-defined problem, which is to be applied for educational purposes, could be characterized based on the following elements [60,63]: (1) there are few guiding elements in the problem, allowing for different solution strategies; (2) the underlying objective is unclear or ambiguous; (3) there are several feasible solutions; (4) it generates uncertainty about which concepts, procedures, rules, or principles are relevant during the resolution process; and (5) it is essential for students to formulate and defend judgments about the problem at hand. Additionally, Le et al. [64] establish that the solution to an ill-defined problem—class 5 according to their continuum—cannot be verified automatically and immediately. Instead, it requires a validation process by all interested parties who, based on criteria, will assess the adequacy of the solution achieved.

As an example, consider the following ill-defined problem: Our local transport company is implementing a comprehensive improvement proposal. This involves creating a new, more sustainable and environmentally friendly package collection and delivery plan. We are going to help them with this task. This example presents concepts with broad interpretation (open-texture), such as "more sustainable" and "environmentally friendly". The possible solutions to the problem are numerous, although they all require the mobilization and application of the same knowledge and skills.

4.2. Deconstruction Stage

The second stage aims to "dissect" the problem analytically in order to obtain a plan to solve it and become aware of how each STEM domain can assist in this process (connecting nodes of knowledge). This process can be more or less guided by the teaching staff, depending on their prior experience with the STEM approach, the educational stage, and other cognitive, affective, and behavioral characteristics of the students. At this point, the presence of teachers from different specialties becomes important.

The deconstruction stage should facilitate scaffolding between the presented problem and its resolution, thereby promoting systemic thinking that allows for understanding the ill-defined problem as a system of interacting elements that produce emergent behavior (social and environmental consequences) [65]. To achieve this, it is advisable to use metacognitive strategies to generate a reflective and creative process [60].

We propose two strategies for deconstructing the problem: (1) a divergent strategy, and (2) a convergent strategy. The first focuses on the problem, promoting the formulation of key questions (learning issues) to seek a solution. Therefore, a divergent cognitive process is generated in which an action plan is established to address each learning issue. Figure 5 shows an example of deconstruction following this strategy.

On the contrary, the second strategy focuses on how STEM disciplines could contribute to problem resolution. Therefore, based on the identification of specific learning issues, a general action plan would be established (Figure 6).

In Figures 5 and 6, the "Facts" column would gather relevant information about the problematic situation, such as what the problem is, where it occurs, and who is directly or indirectly involved. The "STEM disciplines" column would simply act as an organizer of information in rows corresponding to the four disciplines. The "Learning Issues" column would record all the questions whose approach and answers will allow for problem resolution. Finally, the "Action Plan" column would outline the process that the work team will follow to solve the problem. If following a divergent strategy, an action plan would be developed for each key question, while applying a convergent strategy would involve outlining a general action plan based on the identified learning issues.

Facts	Learning Issues	Action Plan
Preparing a sustainable and environmentally friendly plan for the collection and distribution of packages. At our location. Stakeholders: transport company and customers.	What parcel collection systems are currently used?	
	What parcel collection system generates the least environmental impact?	
	What impact would sharing the package delivery-collection routes between customers and the company have in terms of atmospheric emissions, economics, and satisfaction?	

Figure 5. Proposal of a panel to deconstruct an ill-defined problem through a divergent strategy.

Facts	STEM disciplines	Learning Issues	Action Plan
Preparing a sustainable and environmentally friendly plan for the collection and distribution of packages. At our location. Stakeholders: transport company and customers.	Sciences	For example, what parts of the Earth can be contaminated?	
	Technology	For example, what environmental impact do transport companies have, directly or indirectly?	
	Engineering	For example, what is the shortest route between the agency and each of the local districts?	
	Mathematics	For example, what is the area that our town occupies?	

Figure 6. Proposal of a panel to deconstruct an ill-defined problem through a convergent strategy.

4.3. Explanation Stage

During the explanation stage, responses are provided to the underlying "Learning Issues" of the ill-defined problem. This phase alternates between guided and autonomous learning processes. In this sense, the teacher(s) involved should aim for an appropriate learning progression for each of the STEM disciplines. Thus, the fact of applying an active methodology such as PBL should not restrict the occasional use of direct instruction in order to overcome obstacles to learning (alternative conceptions, abstract notions, etc.). Therefore, it is a stage oriented toward acquiring and/or developing the knowledge and skills necessary to satisfactorily solve the ill-defined problem.

The output of this phase is the body of knowledge, which can be cross-verified through explanations provided by the students, and the STEM skills involved in the problem. Mastery of these skills will be demonstrated in both this phase and the application phase.

At this point, it is essential to clarify what constitutes an explanation within the context of a STEM learning sequence. Regarding this, Baptista and colleagues [66] have recently addressed this issue. We rely on their theoretical outlines to offer a new version adapted to the epistemological and pedagogical principles presented here. Thus, we must first consider that an explanation takes on different nuances depending on the discipline in which it is developed. Table 3 below illustrates what is meant by an explanation in each of the STEM disciplines, recognizing that this is a concept whose definition has been controversial, particularly in the field of Mathematics.

Table 3. Definition of explanation according to each of the STEM disciplines.

Discipline	Definitions
Science	A scientific explanation arises from the observation of the world around us. Therefore, it is the final product of a scientific process in which a natural phenomenon is described or explained—depending on whether it is a law or a theory—addressing how and why it occurs [67].
Technology	A technological explanation focuses on the functions (behaviors) of the devised solution (prototype) for a specific problem, understanding it as part of a system. Therefore, it must consider its purposes and its impact (expected and/or verified) at the social and environmental levels [68].
Engineering	An engineering explanation is oriented towards the functions (behaviors) of the devised solution (prototype) for a specific problem, arguing its creation based on the decisions made, project constraints, and limitations [69].
Mathematics	A mathematical explanation is usually constructed from the observation of phenomena. Hence, it has traditionally been linked to scientific explanations, although explanatory processes also emerge within the discipline (e.g., the description of mathematical symbols). In essence, a mathematical explanation constitutes a repository of evidence describing a reality in the simplest and most truthful way. These pieces of evidence can consist of describing the rules of a specific calculation, analyzing a pattern or a variable, graphically representing patterns (e.g., graphs) or variables, statistical and probabilistic deductions, or structural descriptions (geometry) [70].

Baptista et al. [66] coined the term "STEM explanation" to refer to explanations that involve knowledge from two or more STEM disciplines, distinguishing "I-STEM explanation" (with "I" for integration) as those that integrate all four disciplines of the acronym. As can already be inferred from our theoretical stance, we believe that the term "STEM explanation" is sufficient and should exclusively refer to explanations of natural and/or induced phenomena—generally by humans—that integrate knowledge from all four STEM disciplines (we do not use the concept of "STEM phenomenon" proposed by Baptista et al. as we find it confusing and erroneous from an epistemological perspective, as phenomena are not owned but rather studied by disciplines). Therefore, a STEM explanation should include the disciplinary nuances provided in Table 3.

Continuing with our example, at the end of this phase we might become aware that our company's major sources of pollution are atmospheric and solid waste (scientific explanation), the former due to delivery vehicles and the latter to packaging materials (technological explanations), which can be discarded and managed either within the company or at the destination households, or with the collaboration of third parties (engineering explanation). There could also be an optimization of the routes used for delivery, which could be achieved for example by studying the areas resulting from marking concentric circles with the delivery vehicles' starting point as the center, so that the circular sectors cover the same area, or by dividing the area to be served using equal angles with vertices at the company's location (mathematical explanation).

4.4. Application Stage

The application stage, which is intertwined with the explanation stage, involves mobilizing all the worked knowledge and applying the developed skills for a specific purpose: solving the problem. Consequently, it can be described as a convergent and highly active learning process, culminating in the resolution of the problem. The output of this stage will be the generated product or prototype.

In our example, one could decide to replace delivery vehicles with more fuel-efficient alternatives, such as bicycles or electric scooters recharged with photovoltaic panels, at least for closer areas or those with dedicated lanes for such vehicles, and as long as the package size and weight permit it. Simultaneously, replacing adhesive materials with less polluting alternatives would be considered. All these decisions would necessitate market research, as they could impact pricing and carry the risk of losing customers by becoming less competitive. Additionally, publicizing these decisions would be crucial for the company to be seen as environmentally responsible, potentially aiding in obtaining funding for implementing these improvements (corporate social responsibility).

4.5. Review Stage

The review stage has a cross-cutting nature in the IDEARR model. Thus, it is expected that small adjacent cycles are generated to refine the outputs obtained in each of the phases. Specifically, the following is expected:

- Conduct explorations of the problem scenario (initial stage) at different moments. These can be in-person and/or virtual.
- Monitor the modification of those alternative conceptions identified (initial stage) during the stages of explanation and application.
- Update the "Learning Issues" and the "Action Plan" (deconstruction stage), if necessary, according to experiences arising during the learning processes developed in the explanation and application stages.
- Enrich the provided STEM explanations (explanation stage) based on the experiences gained in the application stage.
- Test the functionality of the solution achieved (application stage).
- Become aware of the limitations of the solutions achieved, leading to future lines of work (review stage).

4.6. Reporting Stage

Finally, the learning process must conclude with the presentation of the developed process and the solution achieved for the ill-defined problem addressed. This final communicative process can take place in multiple forms and formats, but the most relevant aspect is that the findings and enjoyed experiences reach the community. Likewise, we must ensure that all students actively participate in communicating their results. In this phase, there should be a presence of external agents who could assess the final product from non-academic perspectives, and peer co-evaluation within the group class is also important.

5. Educational Implications

The educational implications arising from adopting the IDEARR model as the most suitable for implementing STEM education in the classroom must be analyzed from three axes: the ontological (how it understands educational reality, assuming a competency-based approach), the epistemological (how a STEM sequence is produced or constructed, considering interdisciplinary relationships and the nature of each discipline), and the methodological (how it could be implemented in the classroom).

From the ontological perspective, the IDEARR model incorporates elements of situated learning and co-teaching, the latter under two modalities (STEM station teaching and STEM team teaching). While Kelley and Knowles [71] had already established the theory of situated learning [49] as the most suitable for implementing the STEM approach in classrooms, the emerging community of practices and the roles of the involved agents had not been sufficiently described until now. Likewise, the teaching challenge of integrating STEM disciplines was addressed by providing a conceptualization of STEM education that was somewhat inconsistent (integrating two or more instead of all STEM disciplines). In our theoretical framework, we embrace this challenge by advocating co-teaching; thus, in addition to ensuring coherence in the number of integrated disciplines, we aim to foster a culture of cooperation among teachers similar to that applied among students (cooperative learning).

Regarding the epistemological axis, the IDEARR model assumes the Responsible Education Model (MER) and General Systems Theory, considering three elements in continuous interaction: the disciplinary, the social, and the school. The disciplinary system of the model (Figure 2) provides the framework of knowledge and practices of STEM disciplines (the STEM learning sequence will be defined according to the elements it addresses from this system); the social system provides the appropriate context to implement STEM knowledge and skills; and the school system gives educational meaning to the resolution of the addressed problem, considering diversity and the curriculum.

Similarly, the IDEARR model itself can provide answers to methodological questions by establishing the phases to follow for the development of the proposal and the actions to be taken in each. Table 4 shows the scientific, technological, engineering, and mathematical practices that predominate in each phase of the model. Those highlighted in bold in Figure 2 would correspond to STEM practices (present in all phases of the IDEARR model, except for "communicating results", which aligns with the reporting phase), as they are disciplinary practices common to all four domains. However, this proposal should be understood as general, and a process of personalization should be applied taking into account factors such as the selected ill-defined problem, the infrastructure, and the organization of the specific educational institution.

Table 4. Predominant disciplinary practices in the different phases of the IDEARR model.

IDEARR Stage	Practices	Justification
Initiating	Based on specifications, constraints, and goals; spatial vision	Once the problem is presented, it is advisable to establish the objectives and explore the scenario. As a result of these actions, specifications and constraints arise that will apply to the possible solutions to be achieved.
Deconstruction	Systems thinking; computational thinking; planning solutions; establishing rules and procedures	A holistic understanding of the problem is sought, so that it becomes part of a system in which different elements interact. Ultimately, to plan its solution, it will be necessary to establish "steps to follow", along with alternative measures as contingency. All of this within the framework of pre-established or agreed-upon rules and general procedures during the planning.
Explanation	Inquiry; argumentation; logical thinking	An inquiry process begins, which could be empirical and would have its corresponding impact on the application phase. This process is aimed at obtaining explanations for the learning issues from the previous phase. Thus, logical thinking will be essential for linking simpler explanations and building complex (STEM) explanations.
Application	Designing and testing prototypes and simulations; selecting the optimal one; measuring and calculating	Prototypes are produced, selecting the option that best fits the established objectives.
Review	Critical thinking; evaluating technologies; identifying patterns	The cross-cutting nature of this phase creates small adjacent cycles that allow refining the outputs obtained in the other stages. Thus, a reflective process begins, aiming for improvement through critical and objective judgments. The produced technologies are evaluated, and patterns are analyzed to make better decisions.
Reporting	Communicating results (STEM practice)	

To implement STEM education effectively, it is important to break away from rigid subject schedules and replace them with intervals not associated with specific subjects for solving the ill-defined problem. Additionally, creating spaces where students have the necessary resources to face challenges is advisable. Both issues are, in principle, the responsibility of education authorities, which must legislate in this regard and provide schools and teachers with the necessary resources. In this respect, many countries are moving towards more flexible and interdisciplinary educational models. In Europe, we can cite the education systems of Finland [72], Portugal [73], or Spain [74], which include in their curricula the creation of interdisciplinary educational modules or projects aimed at solving real problems. Certainly, this educational renewal is still in its early stage on a global scale. Therefore, we must be cautious about generalizing the implementation of STEM education. Although there is evidence of significant convergences in education systems worldwide [75], it is also worth looking at non-formal learning environments, such as museums, summer camps, or after-school programs, as opportunities to test the IDEARR model.

One other crucial aspect for the success of STEM education is teacher training. Both initial and ongoing training should focus on shaping teaching–learning processes by designing learning situations that mobilize students' knowledge through interdisciplinary integration. In this regard, there should be support for an initial teacher training curriculum emphasizing content knowledge centered on learning domains broader than classical sciences, and a didactic knowledge of content with a more interdisciplinary orientation is essential. Disciplinary integration is a key aspect for the development of STEM literacy and, at the same time, responsible for some limitations inherent in this educational approach. Not all STEM discipline contents are suitable for integrated educational perspectives, either because they present difficulties in linking them with other STEM domains or because they cannot be placed in authentic contexts. It can also act as a performance limiter in some STEM disciplines, especially in mathematics. These are all considerations to keep in mind.

6. To Sum Up

This work proposes a theoretical framework for STEM education. The proposal culminates in a didactic model that addresses not only methodological but also epistemological and pedagogical aspects. Given the lack of research that combines the theory and practice of STEM education, these actions are becoming increasingly necessary. The objectives are (1) to establish an epistemological and pedagogical fit for STEM education, and (2) to provide methodological guidelines for overseeing the implementation of this educational approach in the classroom.

Regarding the first objective, the epistemological fit is based on the Model of Educational Reconstruction (MER) and General Systems Theory. Three systems in continuous interaction, both internally and between them, are considered and defined (Figure 1): the disciplinary (with content and practices of STEM disciplines—Figure 2), the social (with family, local, and global dimensions), and the school (connecting the first two). For pedagogical fit, Situated Learning Theory and co-teaching are used (Figure 3).

The second objective is addressed through the proposal of the IDEARR model, consisting of six phases corresponding to the letters of the acronym: Initial, Deconstruction, Explanation, Application, Review, and Reporting (Figure 4). It is a model that allows the implementation of STEM education in classrooms based on ill-defined problems, in line with the presented theoretical framework. Once the educational implications and limitations of the model are understood, as outlined at the beginning of the article, it enables us to comprehend (1) what STEM education is; (2) the expected roles of students and teachers; and (3) how it can be applied in the classroom.

The definition of these theoretical frameworks and didactic models is a way to bridge the gap between research and the contribution it can make to the advancement of STEM discipline teaching. In other words, it helps overcome the criticized gap between research and instruction. To this end, the next step will be to test the IDEARR model in formal learning contexts, which will be carried out through a recently initiated research project led by the authors: STEMgame "https://stemgame.ugr.es" (accessed on 5 February 2023). This will make it possible to assess its effectiveness in real environments and make the appropriate methodological adjustments.

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