Ciències – TRANSLATED PAPER
Received: 2nd May 2022 • Accepted: 30th June 2022
eISSN: 1699-6712 • https://doi.org/10.5565/rev/ciencies.470

Approaches, methodologies and technologies for advancing STEM education

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Cite as: Couso, D., Domènech-Casal, J., Simarro, C. López-Simó, V. & Grimalt-Àlvaro, C. (2025). Perpectives, metodologies i tecnologies en el desplegament de l'educació STEM. [Approaches, methodologies and tecnologies for advancing STEM education. Translated paper]. *Ciències: Revista del professorat de primària i secundària,* (44), 56 – 67. https://doi.org/10.5565/rev/ciencies.470

Abstract • STEM education is often presented as an innovative and exciting proposal that has gained traction in our country's educational landscape, both as a means to foster STEM vocations and to enhance scientific and technological literacy among the general population. However, when it comes to classroom implementation, STEM education is frequently reduced to specific methodologies—such as project-based learning—or to particular technologies, like programmable devices. This narrow focus overlooks the fact that any educational perspective, methodology, or technology that contributes to developing students' scientific and technological competencies, as well as their engagement with these domains, can be appropriate. As with any educational approach, what matters most in STEM education is the thoughtful selection of what to teach and how to teach it, in alignment with the underlying educational goals.

Keywords • STEM, STEAM, methodologies, approaches, technologies, STEM identity.

Perspectives, metodologies, i tecnologies en el desplegament de l'educació STEM

Resum • L'educació STEM es presenta sovint com una proposta innovadora i excitant que, tant al servei de l'augment de vocacions com orientada a millorar l'alfabetització de la població en aquest àmbit, ha arribat amb força al panorama educatiu també del nostre país. Quan ens preguntem, però, com fer-ho a les aules, veiem que sovint les propostes d'educació STEM es vinculen de forma reduccionista a certes metodologies concretes (com per exemple l'aprenentatge basat en projectes) o a certes tecnologies (com ara les tecnologies programables). En fer-ho, s'està obviant que qualsevol perspectiva, metodologia o tecnologia educativa que serveixi per a millorar tant les competències de l'àmbit científic-tecnològic de l'alumnat com el seu posicionament respecte el mateix serà adient, i que en educació STEM, com en totes les propostes educatives, és important la tria de què ensenyar i com fer-ho al servei de per a què ho volem fer.

Paraules clau • STEM, STEAM, metodologies, perspectives, tecnologies, posicionament STEM

INTRODUCTION: UNDERSTANDING STEM?

In the field of education, the term STEM—referring to science, technology, engineering, and mathematics education—has gained significant prominence. Today, unlike ten years ago, it is rare to find a teacher, particularly one in science, technology, or mathematics, who has not heard of STEM education or who lacks at least a basic understanding of what it entails. Numerous STEM-related initiatives are making their way into schools, including necessary professional development opportunities, but also numerous offerings related to the purchase of materials and equipment (such as robotics kits, programmable boards, or curriculum packages) or an increasing number of science and technology outreach activities (such as talks by scientists or projects to raise the visibility of engineering). At the same time, society at large is increasingly surrounded by initiatives branded with the STEM acronym—from non-formal education settings (such as after-school robotics clubs or STEAM summer camps) to toys and recreational products for children (including programmable toy robots and construction sets).

Despite this, there is deep confusion about what we actually mean when we talk about STEM education. To begin with, something that might seem straightforward—given the acronym—such as which disciplines are included, already presents the first difficulty. What sciences are we referring to with the "S" in STEM? Are we talking about the prototypical school subjects such as biology, chemistry, physics, and geology, or should we also include fields like nanoscience, bioengineering, or medicine, among others? Which branches of engineering are we referring to? Would we include agricultural or food engineering, or are we rather referring to computer science, telecommunications, and industrial design? Is the "T" for technology understood as a discipline, a subject, or simply a set of tools? Are the mathematics in STEM the same mathematics as always, or are they mathematics at the service of the needs of science and engineering?... A significant portion of the literature in the field revolves around these questions, and depending on the context, it is said that there are more than 70 different disciplines associated with STEM. And that's without even considering how the scope broadens when the "A" is introduced in the increasingly common STEAM proposals. This "A" might stand for the visual arts (drawing, painting), for a broader conception of the arts (performing arts, music, dance, theatre...), or for *all* disciplines altogether. It might represent creativity or design (as if STEM without the "A" were not inherently creative!), or serve as a much-needed reference to the liberal arts or the humanities. And if the picture wasn't already complex enough with STEAM, we now hear about STREAM proposals, in which the "R" might stand for computational thinking (Robotics), literacy and literature (Reading), or even Religion. Or proposals like iSTEM (STEM with imagination) or STEEM, with the extra "E" standing for environmental education... If we go by the wide range of initiatives labeled with some version of the STEM acronym, it becomes difficult not to fit in any educational proposal that has been conveniently rebranded.

Given this context, it is not surprising that in a recent review of international STEM education studies conducted by Martín-Páez and colleagues (2019), the authors point to inconsistent use of terminology, a lack of clear definitions, and, more broadly, theoretical frameworks that make it difficult to understand what STEM education actually is. In fact, more than half of the studies analyzed do not include any specific conceptualization of STEM education—that is, they do not define what they mean by education, curriculum, literacy, identity, or STEM competence, among other key concepts. According to the authors, this leads to what they describe as a "blurred projection" of STEM education. This blurred projection is also evident at the practical level. A quick global image search on the internet for STEM education activities reveals a wide variety of educational scenarios: children building artifacts using everyday materials; programming apps, video games, or robots with computers and/or tablets; conducting small experiments or scientific observations; working on mathematical concepts with hands-on materials; visiting technology centers; meeting professionals in the field, and so on. The result is a colorful amalgam of activities—often group-based, hands-on, and involving sophisticated technological resources—in which students appear to be enthusiastically engaged in creatively overcoming some sort of construction-based challenge.

The lack of a clear projection and definition of what STEM education entails also becomes evident when examining how different professionals involved in the field—particularly STEM teachers—conceptualize it (Simarro & Couso, 2018). From the very first STEM teacher training session held in our context in 2017 as part of the STEMCat Plan, we have encountered recurring questions from in-service teachers during conferences, panel discussions, and professional development courses that reveal genuine uncertainty about the "what" and the "how" of STEM. It is therefore common for questions such as the following to arise:

- "Is STEM about doing engineering projects in the classroom?" (How many of the STEM letters are needed for something to be considered STEM? Is the "E" the new and most important letter in STEM?)
- "If we combine mathematics and science, is that already STEM?" (Does STEM necessarily imply interdisciplinary work? Does doing math calculations during a science activity already count as integrating math? What does it mean to work in an integrated way?)
- "Is playing freely with building blocks a STEM activity?" (Is STEM about explicitly emphasizing the technological process? Is promoting creativity as simple as letting students be creative? Is STEM about playing or gamification? Is it always about building something?)
- "Does STEM mean doing a particular kind of project?" (Does STEM require following project-based learning methodologies? Can you do STEM without a challenge or without group work? In STEM, do we assess the product or the process? Does an activity need to be long-term to be considered STEM?)
- "If we don't include the A, does it no longer count?" (Is STEAM just the modern version of the former STEM? Is the "A" necessary to attract girls? Does the "A" make STEM more appealing to everyone?)
- "Is doing science using a digital whiteboard or augmented reality considered STEM?" (Is STEM about digital competence or about integrating ICTs? Do we need cutting-edge educational technologies to implement STEM?)
- "Do we have to introduce robots to do STEM?" (Are programmable technologies a requirement for STEM? Does STEM necessarily involve computational thinking? Is programming with Scratch enough? If we don't have a 3D printer, can we still do STEM?)

The range of questions is broad, and the level of specificity required to answer them demands a clearly articulated understanding of STEM education. Teachers are asking that, beyond hearing about the supposed benefits of the framework or being shown inspiring STEM project examples, we truly commit to addressing how it can be implemented in the classroom. As can be seen, the questions raised by teachers regarding STEM education are tied to what actual innovation this new framework brings—namely, whether STEM education entails new content, new relationships between disciplines, new goals, new methodologies, and/or new resources for science and technology education, among others. In fact, critical voices in the literature, such as Bodgan Toma and García Carmona (2021), pose the very same questions. To attempt to answer them, however, we believe it is first necessary to reflect deeply on why we might need STEM education—if, indeed, we need it at all. What to do in a STEM classroom and how to do it, whether it involves introducing entirely new practices or simply doing what we already did well in slightly different ways, cannot be separated from the question of why we are doing it.

NEW PURPOSES OF STEM EDUCATION

As we have published previously, specifying what the STEM framework brings and how to implement it in the classroom requires a deep reflection on *why* it is necessary to emphasize or reframe the teaching and learning of science and technology today. This emphasis on the "why" as the engine behind what we do in STEM has been central since the launch of the STEAMCat Plan in our country (Couso, 2017). Far from diminishing in importance, the more we learn about STEM education, the broader the range of goals it must pursue becomes. We now argue that the STEM education we need should ensure two key, distinct—yet deeply interconnected—goals that closely link who we are with what we are capable of doing in STEM.

The first goal of STEM education is to empower and foster scientific-technological literacy for all students. This means enabling them to master and apply the core ideas and idiosyncratic practices of the disciplines of science, engineering, and school mathematics, so they can participate actively and with agency in shaping a more sustainable, inclusive, equitable, and socially just world. This goal is closely related to the definition of STEM competence for all and aligns with values previously outlined in this journal (Couso, 2017). It emphasizes the importance of STEM education as a way of seeing the world through specific lenses—the lenses of STEM disciplines—while also recognizing when to switch lenses and the limitations each has in understanding and acting upon the world. Achieving literacy in the STEM field requires us to define the key ideas and the social, cultural, and discursive practices unique to each discipline. For example, the scientific idea that matter is composed of particles arranged in various ways at the micro level, leading to different macro-level properties, or the engineering practice of developing and testing prototypes and simulations. Some of these core elements are well established in the literature—such as the key ideas and practices of science as detailed in the Next Generation Science Standards (NRC, 2012). Others are less developed or lack consensus. Recently, in response to the need for more concrete classroom tools, we have focused on developing the didactics of lesser-explored areas like engineering. For instance, we have proposed definitions of its key ideas (Simarro & Couso, 2022) and its idiosyncratic practices (Simarro & Couso, 2021), and have compared the core practices of science, mathematics, and engineering while reflecting on the limited role often given to mathematics in many STEM projects (Couso, Mora & Simarro, 2021).

The second goal that all STEM education should pursue is to foster in students a critical—but not initially negative—stance toward the themes, actors, and initiatives of the scientific-technological field. This goal aims to achieve real equity in access, participation, and aspiration toward the STEM world—something that, both research and experience show, does not occur automatically, regardless of students' actual abilities. The concept of a STEM stance allows us to address the influence of affective and social aspects—such as interest and perceived self-efficacy—on students' STEM identities, as we have discussed elsewhere (Grimalt-Álvaro & Couso, 2022). While some students see themselves as “STEM people,” we know there is significant gender bias in these perceptions and preferences (Grimalt-Álvaro et al., 2022). Likewise, many students do not see themselves in STEM for the wrong reasons: because they feel it is not meant for people like them (based on their gender, race, ethnicity, religion, socioeconomic background, personal history, or their intersections), or because they believe they are not “smart enough”—a perception shaped by the dominant culture of whiteness, masculinity, wealth, academia, and brilliance, coupled with an elite view of science (Grimalt-Álvaro & Couso, 2019). Both patterns are rooted in pervasive social stereotypes around STEM and must be addressed through high-quality STEM education that understands that developing STEM competence begins with feeling explicitly invited to participate.

Following the formulation of this second goal, the authors have proposed a redefinition of the idea of STEM competence initially outlined by Couso (2017), aiming to highlight the significance of addressing stereotype, bias, and identity as core challenges in the STEM field. For many—including ourselves—this is the fundamental justification for engaging with STEM education. Thus, we redefine STEM competence (Couso, Grimalt-Álvaro & Simarro, 2022) as:

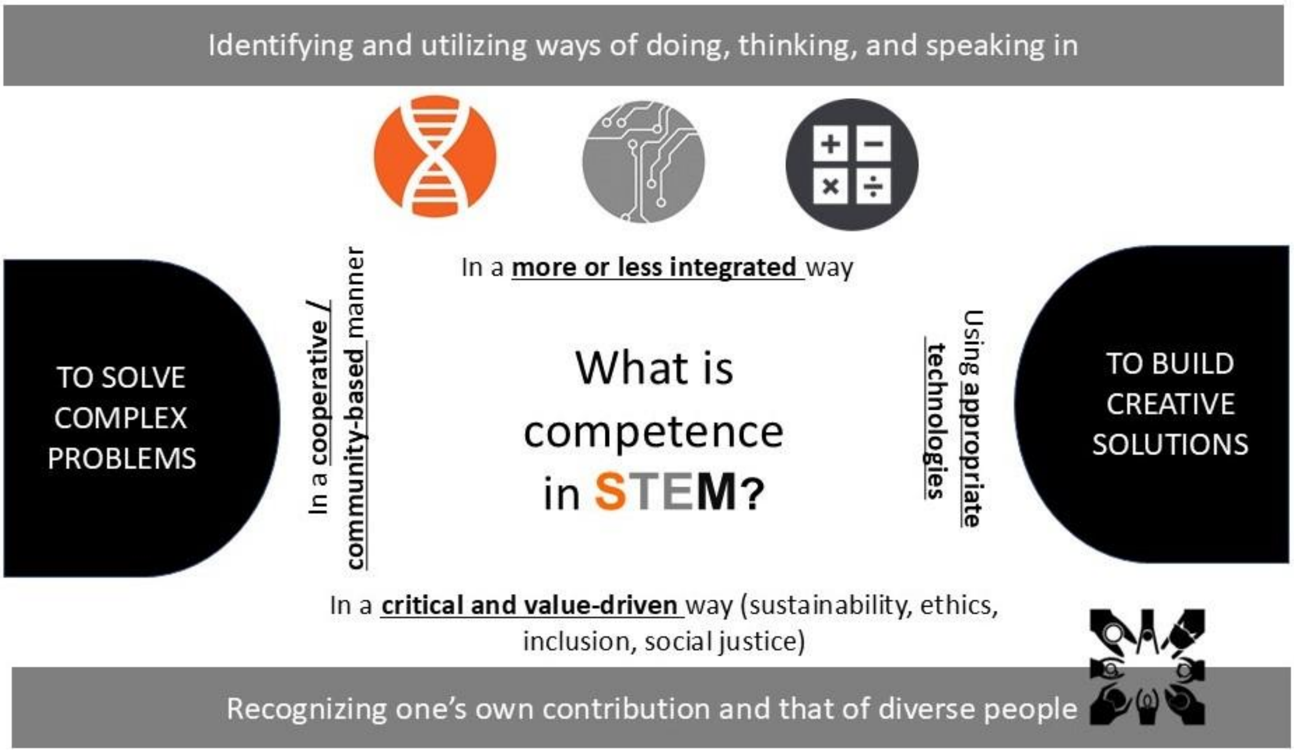

Figure 1. Definition of STEM competence that includes a goal of scientific-technological literacy for everyone and a goal of improving STEM identity and stance.

The ability to identify and apply both key knowledge and characteristic ways of thinking, doing, speaking, and being in science, engineering, and mathematics—in a more or less integrated fashion—to understand, make decisions about, and act upon complex problems, and to build creative solutions, by drawing on both personal synergies and appropriate technologies, in a critical, reflective, and value-driven manner. This includes recognizing one's own contributions and those of diverse individuals to the STEM field, in order to reduce existing inequities.

Figure 1 attempts to visually synthesize this definition.If we agree that the two interrelated objectives of STEM literacy and appropriate STEM stance should be **non-negotiable foundations** for a truly empowering and values-driven STEM education for all, then we can let this definition of STEM competence—or any other that encompasses these aims—guide us in determining which educational perspectives may be favorable, which pedagogical methodologies appear promising, and which educational technologies may be appropriate. In doing so, we place the *what* and *how* of STEM education at the service of the *why*, recognizing that our concern lies not so much in what is new in STEM education, but rather in what—new or not—can help us attain the two aforementioned goals of meaningful STEM literacy and positioning.

In the following paragraphs, we will speak in the plural about each of these elements (perspectives, methodologies, and technologies), which are so often reduced to singular notions, with the intention of highlighting that, in STEM education—as in education more broadly—there are no magic formulas or universal step-by-step methods. There are, however, certain ingredients or underlying didactic principles that help us achieve the intended effect of our educational proposal.

PERSPECTIVES THAT FAVOR QUALITY STEM EDUCATION

Quality STEM education must be approached from high didactic-value educational perspectives that foster and enhance the spirit of disciplinary, critical, and community dialogue embedded in the earlier definition of STEM competence. This entails using educational approaches that require examining a problem through multiple disciplinary lenses, that encourage critical thinking and evidence-based argumentation, and that do so within a context of community participation that is as authentic and real as possible, where the agency and involvement of all students are genuinely necessary.

The notion of cross-disciplinary perspectives, or those fostering some integration among STEM disciplines or with others, that we advocate here differs significantly from the conceptions of multi-, inter-, or transdisciplinarity often found in STEM education literature. For us, STEM is not a separate discipline, nor does it entail the globalization or dissolution of existing disciplines as if their distinct contributions were insignificant. Unfortunately, STEM has often been presented merely as a context, suggesting that a project is STEM simply because it includes a STEM-related element, like a river-cleaning initiative. Sometimes, it is considered that a STEM project must include all STEM disciplines equally and in a balanced way, which, within a reasonable timeframe, can only lead to superficial and often forced engagement with each discipline (e.g., S: study the river; T: design a litter picker; M: calculate the volume of collected litter; A: design a "cool" t-shirt to go with it!). Projects are also frequently referred to as globalized, where "everything is done" at a shallow level, applying what students already know and focusing only on transversal competences without working on specific STEM or disciplinary competences. As a result, students seldom engage deeply with what they actually need to learn through the project—something that can't be learnt simply by participating and they likely wouldn't learn elsewhere.

For us, whether an activity or sequence qualifies as a good STEM project does not depend on the topic, how many letters of the STEM acronym are included, or how fun it is, but rather on which key ideas and disciplinary practices are explored in depth. Thus, the school project "clean the river" can become a good STEM project if it uses the river to deeply explore the concept of an ecosystem and involves students in core STEM practices (e.g., systematic observation and data collection of litter types). Here, one discipline (science) leads, while others may enter at different times and to varying extents, depending on necessity. For instance, if time permits, students might prototype a litter picker, develop an app to document the process, or create a public performance or campaign to share findings, using art to foster engagement. However, disciplines should only be included if they are genuinely needed and can be addressed in depth, with explicit learning objectives. In reflective STEM education, the emphasis is less on including various disciplines and more on making students aware of the shifts in perspective that each discipline enables and how each empowers them. Looking at a river through the lens of engineering helps envision material solutions. Through science, it invites inquiry and explanation. Through art, it prompts emotional and aesthetic engagement.

The argument that the phenomena of the world are interdisciplinary in nature, often used in STEM education, does not justify not going in-depth with disciplinary knowledge and competencies in each STEM proposal, appropriately selecting which ones will be learned. The phenomena of the world, in reality, are neither disciplinary nor interdisciplinary: they exist, regardless of our intent to address them. What is divided into disciplines is our current knowledge, making it possible that in the real professional world we can approach complex phenomena from different perspectives. This requires collaboration among professionals with different disciplinary expertises who are able to dialogue with each other. In the classroom, we could emulate this reality by involving students in activities that require different perspectives and expertises, making it explicit when we put on the glasses of science or mathematics. Also, distributing these expertise among students, making different students in a given topic become experts in one of these perspectives. Perhaps not everyone needs to do everything all the time, but what they do should be done thoroughly enough to give them a sense of expertise, that is, the ability to act with knowledge and confidence in the value of their contribution.

There are several educational perspectives that support respectful disciplinary engagement while also fostering navigation and dialogue among disciplines. In STEM education, one prominent perspective (often confused with STEM education itself) is the STEAM perspective. We find it particularly appropriate because it allows students to view problems from traditionally separate perspectives, challenging the entrenched division between the scientific-technological and the artistic-humanistic fields ("two cultures"). The crucial importance, however, that we give to all disciplines, whether STEM or not, leads us to be very critical of many proposals labeled as STEAM that only focus on decorating or beautifying what has been built. The "A" in STEAM should represent serious integration of philosophy, literature, history, economics, geography, and the arts—when and how needed. It is better not to do STEAM at all than to append art superficially to a science or engineering project. Nor should we add an aesthetic component simply to attract girls to STEM, as we can hardly overcome stereotypes by applying them intensely. Students from all backgrounds do not need glitter on a robot they have designed to find meaning in the task; they may instead need to reflect and discuss the personal or social need the robot addresses and the ethical dilemmas it poses.

Other perspectives that help us achieve STEM competence as we envision it are those that, while not new, have proven powerful in developing students' reflective and critical capacity without avoiding values. An example is the framework of socially relevant issues or socio-scientific controversies (SSI) (Díaz and Jiménez-Liso 2012) that invite students to weigh, evaluate, and decide, in an argued and justified manner, between among often conflicting alternatives. Through SSIs, students recognize the complexity of the world around them, identifying the different interests present in each situation and experiencing how scientific-technological knowledge is necessary to understand, decide, and act, but at the same time, not the only source of knowledge to consider. Well-researched approaches such as environmental education and the STS (science-technology-society) perspective are also valuable. Some argue they offer a more appropriate foundation for relating society, science and technology than STEM does. Both perspectives are highly contextualized and give relevance to values, emphasizing that the relationship of humans with the world around us should be viewed from a critical stance. Currently, visions such as school eco-feminism or STEM education for global justice are heirs to these perspectives, but with a more incisive activist and transformative stance (and therefore better suited to today's climate and social crises!). Other proposals promote respect for the scientific and mathematical knowledge of traditionally marginalized groups, such as ethnomathematics or indigenous science. Drawing on these perspectives for a reflective, critical, and values-driven STEM education—which explicitly includes engineering and mathematics, often absent from such socio-historical and cultural reflections—may help develop a more ethically attuned STEM competence.

Other promising recent STEM perspectives include citizen science and community engineering proposals. These lie between Responsible Research and Innovation (RRI) and Service Learning (SL), and engage students in real, professionally led research efforts (e.g., instrument design, data collection, data analysis) or in co-designing solutions (e.g., space planning, testing). Though often not designed for education and lacking a didactic foundation, they can be highly educational when implemented in schools with tailored pedagogical materials. They also help students realize they can take part in real research as they are, especially if the scientists and messages presented to them are carefully selected. This can allow students to see that real STEM professionals (scientists, engineers, mathematicians) are more like them than they think. One example we have worked on is the ATENCIÓ project, where students took part in an actual scientific experiment on pollution's cognitive effects while conducting school-based research on pollution near their school, all under the guidance of scientists who also shared their personal interests beyond science.

METHODOLOGIES CONDUCIVE TO QUALITY STEM EDUCATION

Defining STEM education as that which serves to develop appropriate STEM literacy and stance, regardless of how it is done, is uncommon. Often, both in curricular documents and in teacher training, STEM education is talked about as a specific and innovative methodological proposal, which involves organizing the teaching and learning of science, engineering, and mathematics in a more active, contextualized, and cooperative way.

Obviously, we have nothing against using active, contextualized, and cooperative methodologies in the classroom, to do STEM or anything else, because educational research in general and in the didactics of STEM disciplines in particular indicate that these characteristics are important for learning. However, what research tells us is that they do not serve per se and are often interpreted in a reductionist way.

For example, when we talk about active methodologies, we should talk about methodologies that enhance students' mental or cognitive-discursive activity rather than methodologies focused on their manual or technical-manipulative activity (Garrido-Espeja and Couso, 2013). What research tells us about the importance of the active student in the process of constructing their knowledge refers, in fact, to activities of a social, discursive, and cognitive nature at the same time, where the manipulative or sensory activity makes sense as support and representation of the cognitive and socio-discursive, to be able to talk about it, do it, and think about it both with oneself and with others. We highlight this idea because often methodologies associated with STEM, such as tinkering or mathematics with manipulative support, are talked about emphasizing the material resources they involve, without realizing that by themselves, these resources have little potential. What makes these resources interesting, which they are, is the fact that we manipulate them based on certain questions or challenges, that we make explicit what we thought at the beginning and what we think now, that we compare different ways of thinking and doing, that we can verify and argue what we conclude from these trials, that we agree on what we have learned by doing this, etc. Thus, rather than talking about active methodologies, we would talk about potentially activating methodologies, where the teacher's role is precisely to activate (Hattie, 2009) (rather than accompany as if it could happen by itself in the right environment) this deeply dialogical, social, and cognitive activity in which we talk, do, and think together. And when it is STEM, the teacher's role is, therefore, to activate the activity of talking, doing, and thinking as it is done in science, engineering, and mathematics (Couso, 2017).

Another point to highlight in active methodologies is that they are often associated with playful activities where students "have fun," either because the methodology invites play (such as in gamification), or because the activity is open and invites experimentation (e.g., a tinkering activity). Regardless of the chosen methodology, what is interesting and common to these proposals is not so much the fun, which in fact may not be present nor directly associated with learning, but the fact that in these proposals the classroom environment and climate are relaxed mainly because mistakes are de-penalized and the activity is detached from the quantitative grade. And these two variables, related to assessment, are variables that enhance learning according to experts (Sanmartí, 2010), just as integrating metacognitive self-regulation into the activity would. At the same time, in these spaces and/or active proposals, the existence of scaffolding and teacher support that enable students to succeed and therefore improve their perception of self-efficacy is also important. In other words, what makes them attractive is not so much the format, but what their format enables when done appropriately. For example, an escape room is not an intrinsically fun activity and therefore conducive to learning. On the contrary, only when the escape room is carried out in an environment where mistakes are de-penalized and in a environment where students can participate and have the scaffolding to do so successfully, does the escape room serve to learn something and become fun.

Continuing with the common characteristics of methodologies conducive to STEM education, one of the most important features is the contextualization of learning, understood as that educational practice that allows giving meaning to what is being learned by situating it in reality. From a psycho-cognitive perspective, contextualizing is necessary to identify students' prior ideas and knowledge, which are usually different from those ideas and knowledge that are activated in the academic context (Pozo, 2020). Considering that the most important thing for learning something is what one already knows about that thing (Bransford et al., 2000), the contextualization of learning in everyday situations or close enough to the real experience of students should be considered a requirement for learning, rather than a methodological option among others. Teaching in context requires not only connecting with students' experiences and emotions but helping them reinterpret them from the new knowledge being learned (Espinet, 2014), while awakening students' interest in acting and intervening in the world from school (Sanmartí and Márquez 2017). Thus, contextualizing is an exercise in connecting with the student's life and perspective, and at the same time, a manifestation of the will to expand it.

Despite the consensus on the importance of contextualizing learning, what we understand by contextualization and how to do it, both within the STEM field and in general, is the product of very different visions of what a good teaching and learning context is. For example, contextualizing has often been related to the supposed goodness associated with the possibility of student choice (e.g., starting the STEM project on animals around the animal chosen by the class), without much consideration of the real learning possibilities the chosen context provides (e.g., if it allows observation or helps test the ideas we have) (Garriga, Pigrau, and Sanmartí, 2012). At the same time, the choice of a good context has been attributed the ability to intrinsically motivate students, for example, believing that doing kinematics in the context of a skate park will be closer and therefore better today than doing it in a more archaic context like billiards. These context choices, however, are based on two erroneous assumptions. The first is that motivation is considered more a prerequisite for learning than the result of successful learning experiences. Thus, it is common to talk about motivating contexts as those that appeal to personal interests and are therefore precursors to learning, although today we know that motivation is more related to the experience of participating successfully in the proposed activities and recognizing that by doing so, one learns (Fernàndez, 2021). Secondly, in choosing the supposedly interesting context for everyone, it is considered that students are more homogeneous than they really are, as if all had common and shared interests that we can uncover and take advantage of. Unfortunately, and as we explain in detail elsewhere, students' interests are never the interests of all students and, fortunately, even what does not generate initial interest can become interesting (Couso and Sanmartí, 2022). Thus, following the proposal of Pérez, Couso, and Màrquez (2021) for choosing appropriate contexts for STEM projects, we consider that appropriate contexts are those that present a balance between different dimensions of the context, including their potential personal, social, and global relevance (the degree to which the context deals with issues that directly or indirectly affect students' lives); their scientific-technological significance (to what extent the context allows learning an important idea or practice of the STEM disciplines); and their authenticity (the degree to which the context is genuine and allows an authentic or at least plausible student activity). Thus, it is not about finding the most interesting context for students, but about choosing between different contexts with the potential to learn idea X or practice Y. And doing so based on what students already know about X or Y and in a way that allows them to think, do, and talk about X or Y as experts in the field do.

The same applies to the idea of cooperative methodologies, in the sense of methodologies that favor learning with and from others. There is extensive discussion in the pedagogical literature about the benefits of cooperative learning, its variants (collaborative learning, peer learning, etc.), and the various ways to promote it in the classroom (homogeneous and heterogeneous groupings, jigsaw technique, co-creation techniques, etc.) (Laal and Ghodsi, 2012). Although it is a well-known topic and often implemented in STEM educational activities (so much so that, in fact, it is not a variable that discriminates between projects according to the research of Pérez, Couso, and Màrquez (2021)), it is worth noting that in STEM education, cooperation among students but also between students and their community becomes not only an appropriate classroom methodology for learning ideas and practices but also a methodology for acting in the world. An example would be the co-creation methodology of design thinking, which is often used in STEM education as a privileged methodology for solving problems and building solutions cooperatively (Albalat, 2017). However, this methodology, while useful in some branches of engineering and social sciences, is not typical of all STEM disciplines. In fact, solving mathematical problems by applying mathematical reasoning, or informal construction with what is available in a tinkering space, does not follow a design thinking methodology, although they are clearly STEM education activities.

Finally, we cannot conclude a section on methodologies conducive to the development of STEM without mentioning the most widely used and linked methodology to STEM everywhere, to the point that STEM education is often defined by mentioning traits of this methodology, such as the need to pose challenges to students. We are talking about Project-Based Learning (PBL), which, although not exclusive to STEM education, is behind its operationalization in most educational centers in our context. Although it is beyond the scope of this publication to detail the potential and limitations that a proposal as powerful and demanding as PBL poses to teachers, we believe it is appropriate to highlight here the need for a certain methodological independence of STEM proposals. The goal is to share with teachers the idea that there is no privileged methodology in STEM education, but many compatible with the desire to improve students' STEM literacy and stance. Although we consider that PBL is in many aspects an appropriate methodology in the context of STEM education, we cannot overlook that other methodologies, such as Inquiry-Based Science Education (IBSE); Model-Based Inquiry (MBI); problem-solving, proposals following the Maker philosophy, the aforementioned Design Thinking, or Service-Learning, among others, can also be conducive methodologies as they are highly contextualized, active, and cooperative. For many, all these methodologies can be developed within a STEM project or STEM PBL that would structure students' activity around posing a challenge, developing a solution, and its final communication. At the same time, however, STEM education also takes place in pedagogical contexts that do not require this sequencing or where the activity is not so structured, such as in ad hoc designed spaces like corners, environments, code clubs, tinkering spaces, or open labs, among others. In any case, we believe that the diversity of available methodologies and the structuring in different times and spaces enriches STEM activity inside and outside the classroom. As long as this activity is actively oriented towards achieving STEM competence and teachers are critical of how contextualized, active, and cooperative the participating students' activity is, we can talk about a diversity of methodologies conducive to STEM education.

TECHNOLOGIES SUITABLE FOR QUALITY STEM EDUCATION

Perhaps the most contested topic in STEM education is precisely the role assigned to technology. Although the T in technology is part of the STEM acronym, we agree with other authors in pointing out the importance of limiting its central role, for several reasons detailed below.

Talking about STEM education or education in the scientific-technological field is talking about the perspective provided by the Scientific, Mathematical, and Engineering disciplines, which are distinct disciplinary bodies with objectives, validity criteria, spheres of activity, and diverse and rich forms of knowledge (Couso and Simarro, 2021). While the differential objective of science is to build data-based explanations, that of mathematics is to solve mathematical problems, and that of engineering is to materialize solutions (Couso, Mora, and Simarro, 2021), technology does not have an objective in itself as a discipline because it is a product or tool aimed at facilitating human activities. Thus, technology facilitates the activities of science, mathematics, and engineering, and also those of other disciplines such as history, philosophy, politics, economics, or the arts. This is why some authors talk about SEM education, an acronym with which STEM education was actually born (Couso, 2017), to refer to the type of education that develops competence in the scientific-technological field. From this perspective, which understands technology as a product of engineering and at the same time a tool for engineering and all other disciplines (Simarro and Couso, 2022), technology can have as secondary or prominent a role in STEM education as in the education of any other field, and as would happen in any other field, using technology is not inherently positive. This vision of technology as neither exclusive nor central in STEM education, however, should not be misunderstood. Limiting the role of technology in STEM education does not mean, for example, that the technology subject should be split off, nor that it should be oriented to studying the history of our tools. On the contrary, if STEM education has done anything, it is to claim the important role that engineering as a discipline should have in compulsory education, involving students in engineering practices such as delimitation, prototyping, or testing (Simarro and Couso, 2021).

Regardless of whether we consider technology as a STEM discipline or not, STEM education has often received legitimate criticism about its dark side precisely in relation to the world of technology (Garcia, 2020). These criticisms refer to its relationships with the political-economic power of large high-tech companies, more interested in the existence of many and diverse (and therefore cheap) STEM vocations, particularly in the field of computing. Also, in the interest of selling educational technologies and products for the classroom of the future by these same global companies and many other local ones, often in the form of sophisticated technologies with such high potential as rapid obsolescence. Unfortunately, this link between the world of STEM education and global technology providers results in many STEM education proposals suffering from deep techno-optimism, favoring a techno-solutionist perspective towards the world's problems and involving, in schools and educational centers that want to start in this perspective, a syndrome of unreflective technology purchase, such as 3D printers, robots, and many other devices, without knowing if they really need them.

From our perspective, however, STEM education must be balanced between the prominence given to the different disciplines, and therefore, not centered on engineering (Couso and Simarro, 2021). At the same time, the technologies that allow working on engineering practices and supporting science and mathematics do not always have to be digital or highly sophisticated technologies, as demonstrated by the learning that can be developed with analog and homemade technologies (Simarro, 2019), as well as proposals that recycle technologies or imagine them. Finally, the introduction of STEM education in a school must capitalize on what the school already does well and the values that characterize it, instead of engulfing them. Thus, the STEM education carried out in a forest school or with a tradition of environmental education should not ignore this fact, for example, by filling the school with non-reusable technologies and plastic pieces made with the 3D printer. In fact, this reflection on which digital technologies to use, how, and for what, should be part of any proposal for both STEM education and education in general (López et al, 2020).

Despite the critical view we have on the technology incorporated into schools, and particularly on the unfortunately common association between STEM education and digital technology, we are not saying that technology has no role or potential in STEM education. In fact, the emergence of low-cost programmable technologies cannot be separated from the explosion of interest in robotics, programming, and computational thinking in STEM education from early childhood. The importance of this type of thinking, considered by the EU as a basic competence of the 21st century like creative thinking or critical thinking, lies in how its development can help citizens manage the complex situations typical of our knowledge society (and at the same time of ignorance). Thus, computational thinking goes beyond programming and is linked to ideas such as abstraction, logic, algorithmic thinking, decomposition, debugging, heuristics, iteration, and automation, among others (Peracaula-Bosch et al, 2020). And although computational thinking can be introduced in the classroom in an “unplugged” way, and there is no one-to-one relationship between computational thinking and robotics (e.g., robots can be used without developing them), nor between computational thinking and programming, it is obvious that with appropriate use of creative and programmable technologies, its development is favored. In summary, although we think that both computational thinking and especially robotics and programming should have a limited role in STEM education that does not reduce STEM competence to this aspect of it, we value as a positive contribution of this proposal the fact of making this type of thinking visible as one more to work on in the STEM classroom (López et al, 2020).

The same happens with other digital technologies, which although they have their role, have focused more on the tool for its attractiveness and novelty than on the learning that this tool allows. An example is 3D printers, augmented reality, or programmable construction blocks like Lego Mindstorms. Although all these tools have clear potential and can be used in the context of STEM projects and/or activities that serve to learn some concept or key practice of the STEM disciplines, often the focus has been on the technical mastery of the technology itself, looking for which world problem can be appropriate to solve with these tools that we want, yes or yes, to introduce in the classroom. In doing so, the old saying “when all you have is a hammer, everything looks like a nail” is fulfilled. This can lead to inconsequential and forced uses of these tools, such as printing keychains with students’ names instead of pieces that we cannot get in any other way. Considering the technical difficulties and the learning curve associated with many of these tools, it is important to carefully select which ones we need and when, based on the real value that the technology brings to the solution of the problem and deciding realistically which part of its use is necessary for students to master and which perhaps not. In summary, it is about deciding which technologies are affordable, both economically and pedagogically for students, while promoting the use of programmable technologies that foster creativity and incorporate certain values (such as the Open Access culture or technology recycling) over others that are less interactive, flexible, and ethical.

SUMMARY AND FINAL REFLECTIONS

STEM education is understood and carried out very differently everywhere, becoming an overly large and indeterminate umbrella that encompasses everything “innovative and exciting” happening in scientific-technological education (Kelley and Knowles 2016). In fact, under this umbrella, we find business initiatives that only seek to influence labor market training to meet their needs, and also commercial strategies that only seek to make money with education by selling “STEM devices.” At the same time, however, we also find many other educational initiatives closely linked to educational equity and more democratic access to STEM knowledge, as well as feminism and the perspective of gender, social justice, or environmental education. To stop disputing and ceding the meaning of STEM to the former would not only be a renunciation of those who conceive education in the service of the common good, equity, or global justice, but it would also further invisibilize the advantages and opportunities that this perspective has brought us in recent years in our educational context. Examples include the incorporation of engineering practice already in primary school, awareness of existing inequities in this field, the visibility of computational thinking as a basic competence, cooperation between teachers of various disciplines in the design and implementation of educational proposals, the opening of schools to STEM professionals, or the provision of long times and specific spaces for the integrated learning of key ideas and practices of science, engineering, and mathematics, among others.

Safeguarding what it brings us and improving what does not work in STEM education requires a critical vision of STEM education guided by its purpose, which for us is twofold. On the one hand, achieving sufficient literacy in the scientific-technological field in the sense of the ability to use in context and with values the key ideas and practices of the STEM disciplines. On the other hand, the development of a STEM stance that overcomes the influence of stereotypes and reconciles with one's own identity.

Achieving two such demanding objectives requires eclectic and diverse STEM education that promotes the use of different proposals and didactic tools according to the learning objective and the specific context of action. At the same time, we need STEM education that takes advantage of our extensive knowledge about teaching and learning in the field and connects with our didactic and cultural tradition. Thus, we need to collect and incorporate into STEM education the reflections, knowledge, and tools existing in the didactics of the involved disciplines, because although STEM is new, we cannot ignore that the didactics of science and mathematics, and to a lesser extent engineering, have more than a century of development.

To do this, we have proposed STEM education guided by the variety of favorable perspectives, conducive methodologies, and appropriate technologies that we consider can serve us to propose quality STEM education (Figure 2). The choice of blocks of perspectives, methodologies, and technologies to describe what STEM education brings us and what it does not is not arbitrary: we have often heard STEM education talked about as a specific educational perspective (instead of any perspective that promotes STEM competence); as an idiosyncratic methodology (instead of any educational methodology that promotes STEM competence); and even as the introduction of certain technologies in the classroom (instead of working with any technology or without that serves to develop STEM competence). By attributing certain characteristics to these perspectives, methodologies, and technologies, such as being cross-disciplinary, critical, active, contextualized, affordable, or creative, among others, we want to emphasize this idea that, just as many roads lead to Rome, many ways of doing STEM lead to quality STEM literacy and stance.

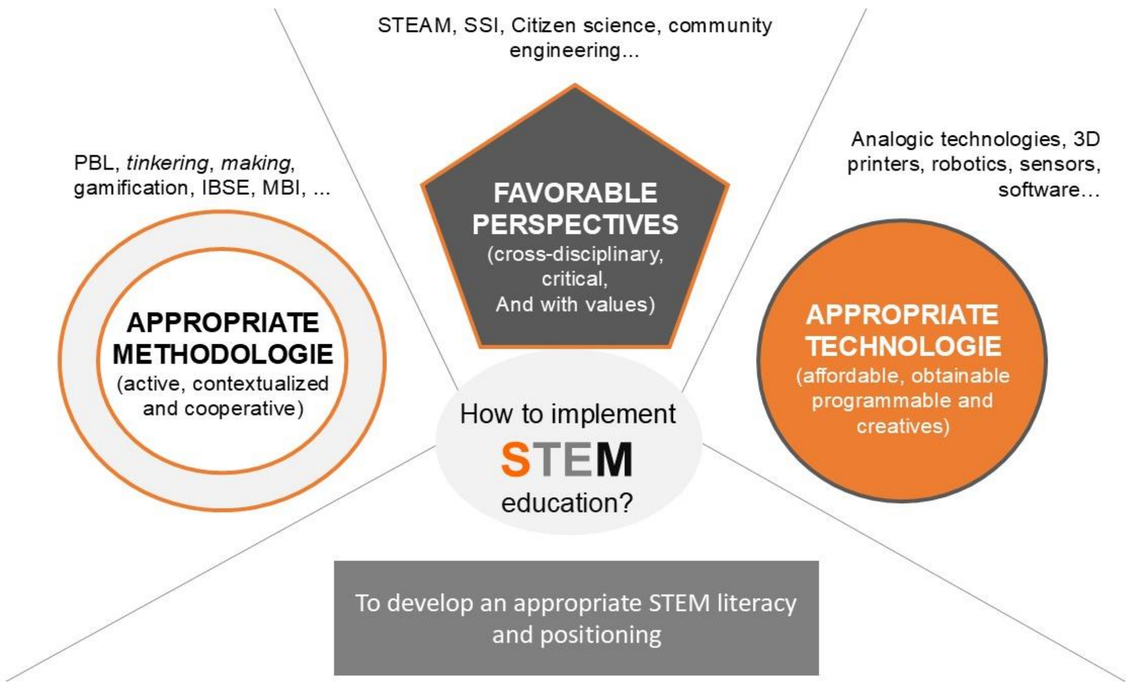

Figure 2. Example of the diversity of favorable perspectives, enabling methodologies and appropriate technologies for developing STEM competence.

Considering that the length of this article is limited, we have left out important characteristics both in STEM education and in general, such as promoting students' metacognitive self-regulation or using measures to promote inclusion, among others. Thus, the goal has not been to be exhaustive in identifying everything that makes a STEM proposal of quality, but to point out the most limiting and common traits in STEM education that we observe around us.Finally, it should be noted that in the article by Albalat et al (2022), published in this same issue, it is shown how this framework of favorable perspectives, conducive methodologies, and appropriate technologies has been operationalized in the training and specific tool package that the Department of Education of the Generalitat de Catalunya has prepared within the framework of the STEAMCat program in our context. It introduces different examples of perspectives, methodologies, and technologies while providing access to the toolbox or STEMtools that have been developed to help teachers introduce them in the classroom. We hope and wish that, among the reflections present in this article and the considerations included in the next one, teachers will find answers to the questions with which we started this writing, as well as others they might have. However, we know that the future of STEM education will be full of new questions that will arise as we encounter more dilemmas and challenges. Our will is to continue reflecting and researching in this field to be able to answer them with knowledge and in community, involving teachers and students in the shared challenge of promoting STEM competence.

NOTES

[1] ATENCIÓ project webpage: https://projecteatencio.cat/

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