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Chapter XX

Problematizing STEM integration from an epistemological and identity perspective

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Summary

STEM education is a global trend, although there is not a convergence regarding the aims, methods and theories behind different meanings given. Within this amalgam of perspectives, the vision of STEM education as an inherently interdisciplinary or integrated framework is usually the most favored. This tacit understanding can lead STEM educational proposals to fail in the acknowledgement of what view of STEM education they hold and diminish the potential behind diversity of approaches. In this chapter we discuss how, regardless of the educational approach, we need to develop and promote both an epistemic understanding of what is STEM and students' identity growth from an equitable and inclusive perspective so that STEM education can successfully achieve its educational aims. To this end, we argue how both an epistemological and identity perspective offer interesting arguments to address important questions within STEM education, such as the supposedly inherent integrative character of STEM education or the existence of a single privileged model of STEM integration. In consequence, we claim for a more critical standpoint in STEM education emphasizing the richness introduced by an idiosyncratic focus regarding both disciplines and people, offering an initial definition of STEM competence that can help to guide STEM education proposals.

Keywords: *STEM education, epistemology, identity, STEM competence, interdisciplinarity, STEM integration*

1. Why do we need an epistemic and identity perspective in STEM education?

There is little discussion on the fact that STEM education is a global trend and "all things STEM" are in fashion. The STEMmania, which M. Sanders described in 2009 [1] is still here, fueled by political, social, economic and/or pedagogical forces around the globe. The acronym has reached not only teachers and educators but also students and parents through a diversity of programs, initiatives, and resources both in and out-of-school. The living proof of a global effort in STEM education is the enormous number of different logos and infographics that can be found in any internet search engine if you look for images related to STEM education, even for different languages and countries.

Despite the existence of a global trend towards designing and investing in STEM education, there is not a convergence regarding the aims, methods and theories behind different meanings given to it [2]. This diversity of views is not inherently problematic: STEM education as a field is richly diverse and different contexts require different STEM education. However, it is worrying that this need for diversity of approaches is not actually acknowledged. In addition, quite often the initiatives, resources and even research pieces on STEM education do not start with a clear positioning on what view of STEM education they actually hold. This is particularly important regarding the goal of any STEM education initiative or resource: *what fo*r is perhaps the most crucial question to bear in mind in STEM education.

According to the influential publication on k-12 STEM [3], there are three major goals for STEM education. These goals are related to the promotion of aspirations towards STEM studies and careers from an equity perspective, the increase in numbers and diversity of the STEM workforce and, more importantly, the development of STEM literacy in all students, independently of their future career choices. Certainly, most STEM education initiatives and resources try to serve one or more of these goals in different ways by applying different approaches and methods (STEM PBL, I-STEM, STEAM, STREAM...) and using different conceptualizations of STEM education (integrated STEM, transdisciplinary STEM...). However, addressing these ambitious goals is a matter of radically transforming the field of science, engineering and/or mathematics education, rather than superficially modifying it. Therefore, quite often, what is needed to fulfill the goals of sound STEM education is not explicit enough.

From our perspective, these three goals of STEM education entail two important needs that refer to epistemic and cognitive aspects of STEM, but also to affective ones. On the one hand, there is the need to develop students' STEM competence so that they become productive, informed and empowered citizens [4] with the potential to become STEM-related professionals. This implies an epistemic understanding of what is STEM and the mastery of how it is done rather than the mere use of STEM concepts and tools, that is, what the literature has discussed as a focus-on-practices vs focus-on-products approach [5]. On the other hand, there is also the need to develop students' identities from an equitable and inclusive perspective so that every student can reconcile who they are with how they consider STEM people are. This implies not only to share a diverse, non-stereotyped model of STEM people, but to act on the affective variables such as self-efficacy, capacity, interest or aspirations, that can guarantee that each student can see themself as a feasible and capable STEM person at their own desired level [6].

To be fulfilled, these two needs require interlinking any epistemological reflection on STEM education with an identity framework for STEM education in such a way that both dimensions of STEM knowledge and competence and STEM feeling and being are mutually supported. However, considering explicitly and coherently both the need to develop an epistemically sound STEM competence and the need to engage adequately diverse STEM identities is undisputedly demanding. From our viewpoint, this is mostly because any interlink with an identity framework implies challenging widespread notions of STEM education, which usually assume an important degree of universality.

An example of this challenge is the vision of STEM education as an inherently interdisciplinary or integrated framework, in which integration among all disciplines is proposed for all students. Hence, the association of STEM education with different ideas of interdisciplinarity or integration is a quite exciting trend in recent STEM education. This trend is referred to as STEM integration, integrated STEM, or even I-STEM. Whatever the language and integrative framework used, the idea behind these I-STEM proposals is to put the integration of different STEM areas to the forefront [7], usually referring to Engineering or Technology as the integrators [8], but without a consistent approach [7]. Despite the many attempts to conceptualize an integrated STEM framework that have emerged in the recent literature [9] and current efforts to review the research in the field [10], we agree with Sgro et al. [11] that integrated STEM is still “whatever someone decides it means”. In practice, claims for integrated STEM could be focused on context or content integration, use of authentic problems, assimilation of STEM practices, development of twenty-first century skills or giving centrality to engineering design or technology, among others [9].

Although integrating disciplines is inherently an epistemological problem (a problem of disciplinary boundary crossing and new knowledge creation), discussions in the field have usually used only pedagogical frameworks. As such, the focus has been more on “how to” do I-STEM rather than what philosophically and epistemically “means” to do I-STEM. It is only recently that the nature of STEM has received an explicit focus [12], and much more developments in this area are needed. The same happens regarding the affective dimension in STEM: even though what it is understood by I-STEM, particularly what disciplines to integrate and the approach to integrate them, have evidenced important implications for which students can be truly engaged [6], the descriptions of I-STEM rarely consider explicitly the identity perspective.

For these reasons, in this paper we want to discuss these two perspectives, the epistemological and the identity ones, in relation to mainstream STEM education and particularly regarding integrated STEM. The purpose is twofold. On the one hand, to show how both perspectives offer interesting arguments to address important questions within STEM education, such as the supposedly inherent integrative character of STEM education or the existence of a single privileged model of STEM integration, for instance, around engineering construction. On the other hand, to claim for a more critical standpoint in STEM education that emphasizes the richness introduced by an idiosyncratic focus on both disciplines and people. As such, we will use epistemic and identity-based arguments to justify the importance of a STEM education that embraces Diversity with capital D: capitalizing on the different and more socially just ways of seeing the world introduced by different disciplines and by different people. In essence, our proposal for STEM education differentiates itself from a uniform, quasi-universal, one-size-fits-all approach, urging caution towards the problems associated with certain ideas of integrated

STEM education that neglect the role of single disciplines and its differential meaning to different people.

2. An epistemological lens applied to STEM education

2.1. Epistemic challenges of an integrated STEM education

Multidisciplinary, interdisciplinary, transdisciplinary, or meta-disciplinary approaches to STEM education are indistinctly presented by STEM education scholars as the way for improving STEM education [13, 14], being the trans-disciplinary approach the most acclaimed one. However, the precise nature of this integration, how should it be done and what its main benefits are do not often get addressed, with difficulties in the literature to propose "*an unequivocal endorsement of integrated approaches to STEM education*" [15]. In this context, challenges to the integrative STEM approach have been found mostly related to two educational factors: the need to deepen students' learning, and the need to guarantee a balanced impact regarding the learning of different STEM areas [16]. According to research, the learning of in-depth STEM knowledge is an obstacle for many integrated STEM curricula [17].

As a strategy to tackle these challenges, many current definitions of integrative STEM education focus on engineering problems as the approach to facilitate STEM areas integration. In this sense, some authors claim that a design, construction, or engineering challenge should be the one that triggers the STEM classroom activity [1, 18]. Justification for this view is the idea that engineering problem solving could be a systematic approach to solve challenges in the STEM field [19] and, consequently, the knowledge and practices of the different areas are at the service of an engineering objective. From this perspective, authors state that STEM education "purposefully situates scientific inquiry and the application of mathematics in the context of technological design/problem solving" [1]. Therefore, this mainstream integrative approach causes an imbalance among the development of students' practices/skills.

Moreover, research points to teachers' difficulties in tackling integration in STEM education due to several reasons, but mainly due to difficulties in the mutual understanding and collaboration among teachers from different STEM areas [20] and, more importantly, limited interdisciplinary understandings [21]. Hence, research has highlighted teachers' limited backgrounds in terms of disciplinary practices, the nature of reasoning in disciplines other than their own, as well as relations among STEM areas [22]. These difficulties can be a source of tensions, especially in secondary and college education.

In our opinion, the problems we have outlined here are related to STEM integration based on the idea of a STEM literacy or competence that goes easily beyond each of the scientific, engineering, and mathematical literacies and competences. However, this perspective of a sort of global competence area [4], if not well addressed, could result in an amalgam of the different well-researched scientific, engineering, or mathematical literacies that has not yet been developed or tested [23]. This is because the conceptualization of STEM as a meta-discipline [14], which unites the normally separated areas to create new knowledge, forces us to establish connections to bridge the gap between disciplines that are closely related but fundamentally different in nature. While we acknowledge that in real-world contexts STEM problems are tackled in an integrative way and that, in fact, STEM areas share important commonalities that allow this integrative approach (such as the crosscutting concepts [24]), we highlight the fact that STEM disciplinary practices are also epistemologically different, and that there are educational benefits associated with this differentiation. For these reasons, we advocate for including an explicit epistemological perspective in STEM education, whether it is integrative or not, for improving STEM education.

2.2. Developing an epistemology for STEM

An epistemological lens that allows to identify the idiosyncratic aspects of each of the STEM areas in terms of their nature and value systems, realizing the similarities and the differences among them, could guide how we face the challenges of STEM integration. By reflecting on the idiosyncratic epistemic features of the different STEM areas, some problems that STEM education research has identified in relation to STEM integration (such as restricted in-depth knowledge, the unbalanced presence of STEM areas or the limited interdisciplinary understanding of teachers) could be more easily problematized, detected, and better equipped for a quality integrative STEM education. Particularly, we argue that developing an epistemological lens can have two major benefits for STEM education, which are described as follows.

On one hand, including an epistemological lens in STEM education would help to develop epistemic knowledge and competence, which are in fact learning objectives of STEM education. Including epistemic knowledge and competence has been agreed internationally in the new PISA framework (OECD's Program for International Student Assessment), and it has been explicitly introduced in most curricula internationally, including the Next Generation Science Standards (NGSS) in the United States. From this perspective, one cannot be considered competent in science, engineering, and mathematics if they do not know what science, engineering or mathematics are about.

On the other hand, the inclusion of an epistemological perspective in STEM education would help to clarify the specific practices, that is, specific ways of doing, talking, thinking, valuing and being [25] of each STEM area. There is global recognition that a disciplinary competence refers not only to the conceptual knowledge and body of practices of that discipline, but also to the epistemic objectives and values underpinning those practices [5, 26–28]. Hence, the relevance given to the inclusion of practices in STEM education will be enhanced and enriched by including this epistemological lens, often neglected.

In a first attempt to reflect these epistemic underpinnings, we propose a set of STEM practices (for science, engineering and mathematics) based on existing proposals [5, 26–28] nuanced by an epistemic perspective. Recognizing the relationship between STEM areas, the nine disciplinary practices have been written in a similar way, led by a core practice encapsulating the aim of each discipline [25] (Table 1).

Table 1

Proposal for the scientific, engineering, and mathematical practices to be developed in STEM education. Core practices from each discipline are placed on grey cells.

SCIENTIFIC PRACTICES Adaptation of NRC [24]	**ENGINEERING PRACTICES** Adaptation of Simarro & Couso [29]	**MATHEMATICAL PRACTICES** Adaptation of NCTM [27] and Niss [28]
Developing and using useful scientific models to predict,	Identifying and/or developing multiple solutions and select the	Developing and using mathematical tools, strategies,

describe, and explain phenomena	optimal one	and concepts to address problems
Familiarizing with the phenomena and formulating research questions	Defining and delimiting engineering problems	Identifying mathematical concepts to generate problems in diverse situations and contexts
Developing hypotheses and making predictions of scientific phenomena	Developing and using prototypes and simulations	Formulating questions, conjectures, affirmations, or hypotheses.
Planning and carrying out scientific research to collect data on the phenomena	Planning and carrying out tests to collect data on the solution	Planning problem solving and carrying it out
Analyzing and interpreting data to improve descriptions and explanations of the phenomena	Analyzing and interpreting data to identify points for improvement	Checking and validating mathematical solutions to problems
Using mathematical reasoning, computational thinking and appropriate technologies when scientifically inquiring, modeling, and arguing	Using mathematical reasoning, computational thinking, scientific models, and available technologies when creating engineering solutions	Using scientific models and technological objects, analog or digital, to adjust and solve mathematical problems.
Constructing sufficiently precise descriptions and explanations of phenomena	Materializing adequate solutions	Constructing useful mathematical knowledge in different contexts and situations
Engaging in argument from scientific evidence	Engaging in argument from test results	Arguing using diverse representations, making deductions, and justifying results in the process of solving

		problems.
Obtaining, evaluating, and communicating scientific information	Obtaining, evaluating, and communicating engineering information	Obtaining, evaluating, and communicating mathematical information

Drawing from our proposal, we argue that in STEM education recognizing the existence of differences among STEM areas, not only regarding their core ideas or practices but also regarding its aims and cultures [30], will not only bring richness to the spectrum of competences able to be developed in STEM classrooms, but also to allow a greater diversity of proposals be more appealing for more diverse people. However, engaging and consolidating diversity adequately in STEM entails further approaches that consider affective aspects. To this end, it is also necessary to integrate an identity lens to STEM education.

3. An identity lens applied to STEM education

3.1. Controversies defining STEM identities

Another important part of the literature related to STEM education has focused on understanding how students can feel that STEM education is "for themselves", especially regarding those students who struggle more because they are from minoritized groups. A promising way to study young people's relationships with STEM is by using the paradigm of identity. Although "STEM identity" has been used in the literature, there is not a clear definition of it [31]. Most research studies characterize students' STEM identity as a conglomerate of students' relationships with any of the different STEM areas: a "socially based identity grounded in the extent to which individuals see themselves and are accepted as a member of a STEM area or field" [32], but the term STEM identity has been also used interchangeably with science identity [33]. Few studies have suggested the existence of a "general" STEM identity characterized as how students view themselves as STEM people, their interest in STEM topics, and their perceived recognition as STEM people from relevant others [34]. These deep discrepancies in how STEM identity is conceptualized led us to question if a general or interdisciplinary STEM identity could actually be developed when students participated in STEM educational activities or not.

3.2. "STEM identity" as an umbrella of different S/T/E/M identities

We approach the characterization of STEM identity from self-identification, as a key process where "people, using the reflexive aspect of the self, name themselves regarding positional designations or labels" [35], such as for example a scientist or a student. When they do so, they invoke socially shared meanings and expectations regarding how a scientist or a student behaves, which becomes internalized as the parts of the self that are called identities [35]. Research has shown that students can self-identify with STEM "as a whole", suggesting the existence of a conscious, explicit "sense of STEM identity" for 12- to 16-year-old students. However, even though students' self-identification expressed something about how students relate to the STEM area "as a whole", interpreting the different ways in which a student can positively or negatively identify themselves as STEM people—and even the interpretation of the meaning of STEM—remains unclear.

The integration of complementary and informative constructs when characterizing students' identity (for example, interest, competence, self-efficacy, and aspirations toward the different STEM areas) allows for a more in-depth interpretation of how students relate to STEM and, especially, which meaning they might be attributing to the term STEM. Hence, although we agree that a general "STEM perception" can exist and act as a general umbrella, we argue that it is a complex and indeterminate entity, which leads us to question the existence of an actual and defined STEM identity as a whole construct, at least from our current social and historical moment. It does not seem to be a clearly shared social meaning of what a STEM person would be and do, but rather, only defined meanings related to the individual STEM areas (e.g., prototypes of what a science or engineering person is and does) or specific subjects and professions within the individual STEM areas (e.g., prototypes of what a physicist, a computer engineer, or a health professional is and does). In sum, the idea that "general" STEM identity, or identifying with STEM "as a whole", is problematic and not considering the different ways in which students identify with STEM has important implications for education.

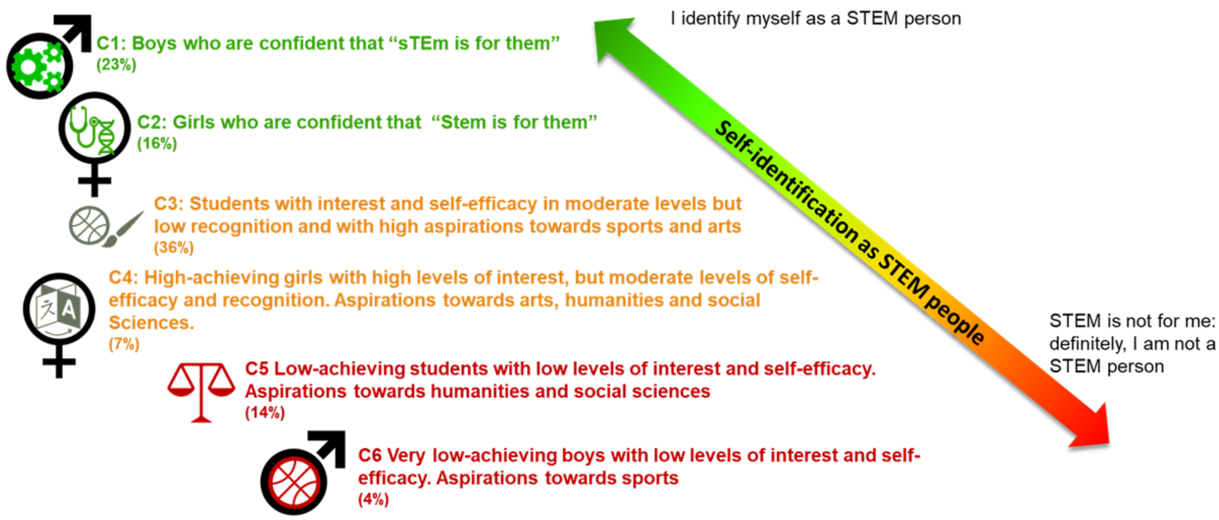
3.3. Deepening into students' possible STEM identity

As an example of how these STEM identities can be characterized, we opted to explore how students both relate to STEM as a unified construct and how they relate to each of the individual STEM areas (Science, Technology, Engineering and Mathematics). In particular, we wanted to know how students' self-identification with STEM related to students' interest, competence, self-efficacy, and aspirations toward the different STEM areas, as all these constructs have been highlighted in the literature to be deeply related to identity formation [31]. We argue that, by doing this, we could begin to better understand if the term STEM seems to have a single meaning or entails different and complementary meanings for different young people.

To answer these questions, we collected data through a questionnaire from 12- to 16-year-old students from different high schools in and around Barcelona (Catalonia, Spain) in 2019, as explained in our previous works [6]. The analysis of student' responses generated six clusters: C1 (234 students, 23% of the sample), C2 (158 students, 16%), C3 (359 students, 36%), C4 (73 students, 7%), C5 (137 students, 14%) and C6 (43 students, 4%), represented in Figure 1. Although overall, more than half of participating students in the study (56%) expressed a very positive or fairly positive identification with STEM, self-identification with STEM among students in C1 and C2 was overwhelmingly positive. For this reason, we interpreted and classified the two first clusters as a group of students with positive self-identification with STEM. This result was of particular interest because, although self-identification was not used to build the clusters, but rather as a target construct, how students in each cluster self-identified as STEM people reinforced the connection between a possible sense of STEM identity and participants' reported interest, competence, self-efficacy, and aspirations.

Figure 1

Conceptual representation of the six clusters based on students' self-identification as STEM people.



When analyzing students' answers in the two clusters displaying positive self-identification as STEM people, we found strong differences. While C1 was overrepresented by students who self-identified as boys, C2 was overrepresented by students who self-identified as girls. Second, students' relation with different STEM areas, showed by their interest, competence, self-efficacy, and aspirations, not only was different, but complementary. Therefore, we observed two notably different ways of how students self-identified as STEM people: Students who self-identified as STEM people were inclined either toward the areas of technology and engineering (C1), or toward science (C2), with mathematics appearing to play a secondary and instrumental role for both groups of students [6].

We argue that each of these two groups of students (C1 and C2) might be giving a different meaning to STEM, based on their preferences toward STEM areas, raising questions about the existence of a single and unified meaning of STEM towards which students can position themselves. The contribution of our results is also showing that we can portray a more complex profile to interpret gender and other personal differences in how students negotiate their allegedly STEM identities, especially regarding their interests, capacities, self-efficacy, and aspirations towards particular STEM areas. Hence, it is reasonable to think that these different identities would benefit from diversity in STEM educational approaches. In other words, promoting a unified STEM education, or narrowing STEM practices to one main STEM area, without explicitly and equally considering the myriad of practices and their epistemological singularities, not only can contribute to maintain these identified inequalities and other existing ones, but widen them.

4. How to include both an epistemic and an identity lens in STEM education?

In the previous sections, we have argued separately the importance of including both an epistemological and an identity perspective in STEM education. Our arguments challenge views of STEM as a transdisciplinary or meta-disciplinary field and fuel the debate about how to address STEM integration in STEM education. However, it is necessary to go a step further in the effort to link the epistemic dimension with the affective one in the context of STEM education for all, taking both dimensions into account at the same time and with the same emphasis if the goals of STEM education are actually to be pursued. In essence, what the previous arguments are showing is that in STEM, as in any other human action, there is no possibility of epistemic and cognitive engagement without emotional engagement. Ignoring this may reinforce and widen inequalities in education and reduce the potential of STEM education for the preparation of all citizens and diverse professionals that take care of their communities and the planet in a knowledgeable, reflective, and critical way.

One possible way of doing so is guiding STEM education by a definition of STEM competence that not only addresses "what of STEM" needs to be mastered and for what, but how STEM is felt differently and why. To truthfully focus the main goals of STEM education we need a definition of STEM competence that is based on the acquisition of mastery regarding the epistemically diverse STEM ideas and practices, but also on the display of diverse STEM identities that reflect a critical but non-stereotyped view of the field. We consider it difficult to make such a definition, but for the purpose of initiating dialogue and a co-creation process in the field, we consider necessary to offer a starting point. As such, and inspired by previous definitions of STEM competence [36], our own definition of STEM competence from an epistemological perspective published in Catalan [37], and including an explicit identity approach, we define STEM competence as being able to *identify, apply and reflect upon the way we think, do and talk in Science, Engineering and Mathematics (in a more or less integrated fashion) to understand, decide and act on complex problems and to build creative solutions, using the appropriate technologies and collaborating with others in a critical, reflective and* *value-driven way*, *through the enactment of the own agency and the authoring of the contribution of diverse people to minimize the inequalities in the STEM field.* Having this (or other better defined STEM competence) in mind, we can ask ourselves if our STEM education interventions do help students to have a critical stance, act with their knowledge of but also about science, engineering or mathematics, or include the values of sustainability or social justice, among others. Despite not all interventions could do all, throughout all the STEM education of a singular student, they should be able to develop this competence progressively. As such, a definition of STEM competence from an epistemological and identity lens can guide our actions as STEM education researchers, trainers, and teachers.

Finally, with this paper we want to emphasize the idea that STEM is not universal: nor in the practices, nor in the knowledge, not epistemologically, not regarding the identities of those who do, like and/or support STEM. STEM is a culturally diverse field, and more diversity should be embraced in STEM education. From our viewpoint, then, any integrative approach to STEM should consider this diversity standpoint and explore different ways of integrating STEM areas and disciplines, in addition to combining STEM integration with none STEM integration. As such, instead of looking for a one-size-fits-all model for STEM integration, we could focus more on what epistemic challenges and identity problems are raised by each particular model of STEM integration, and how to compensate or reflect openly with students on them. For instance, equating I-STEM with interventions only guided by engineering and focused on the creation of technological solutions offers an impoverished view of STEM areas and STEM people, engaging mostly a gendered, particular profile of students. This does not mean that we cannot do this sort of STEM project, but not all I-STEM should look like that: we could offer alternative STEM school interventions guided by mathematics or science, or even projects where students can choose the disciplinary focus, they will use to address them.

Whatever the disciplines leading or involved in a particular STEM educational intervention, we could do so in a way that our students, all of them and each of them, feel welcomed and capable enough. This could be done by explicitly introducing an equity perspective that focus on underrepresented people, indigenous knowledge, and decolonizing practices, among others. But also, by using the research-based didactic and pedagogical tools we have developed in

Mathematics, Science and Engineering education research, such as relevant contextualization, formative assessment, dialogic interaction, adequate scaffolding, and so on. It is by doing high quality, evidence-based, and equity-driven STEM education that we will improve the field of STEM education. In essence, the epistemological and identity perspective to STEM education speaks about high-quality STEM education for all.

Table 1

SCIENTIFIC PRACTICES Adaptation of NRC [24]	**ENGINEERING PRACTICES** Adaptation of Simarro & Couso [29]	**MATHEMATICAL PRACTICES** Adaptation of NCTM [27] and Niss [28]
Aim: Developing and using useful scientific models to predict, describe, and explain phenomena	Aim: Identifying and/or developing multiple solutions and select the optimal one	Aim: Developing and using mathematical tools, strategies, and concepts to address problems
Familiarizing with the phenomena and formulating research questions	Defining and delimiting engineering problems	Identifying mathematical concepts to generate problems in diverse situations and contexts
Developing hypotheses and making predictions of scientific phenomena	Developing and using prototypes and simulations	Formulating questions, conjectures, affirmations, or hypotheses.
Planning and carrying out scientific research to collect data on the phenomena	Planning and carrying out tests to collect data on the solution	Planning problem solving and carrying it out
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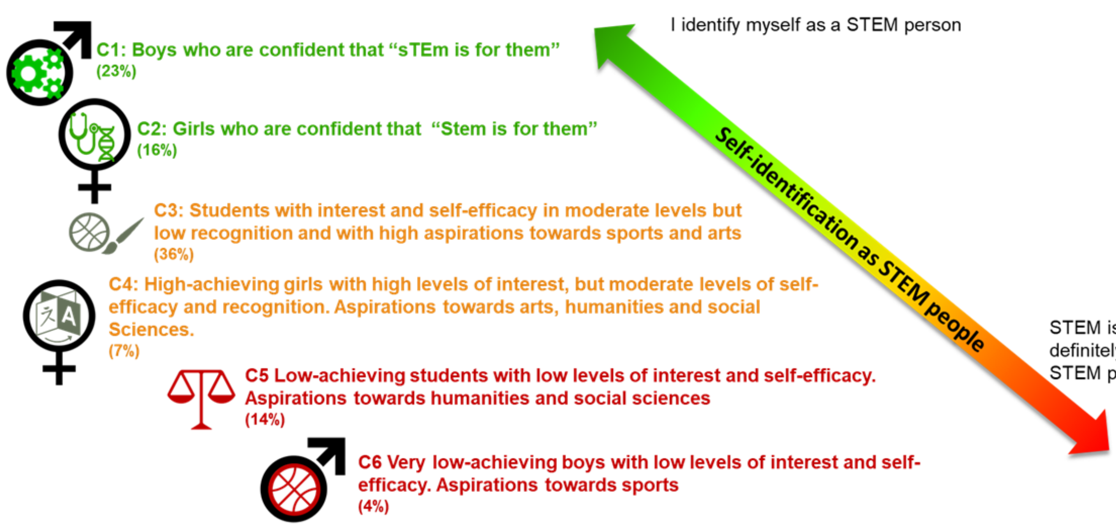
Constructing sufficiently precise	Materializing adequate solutions	Constructing useful

descriptions and explanations of phenomena		mathematical knowledge in different contexts and situations
Engaging in argument from scientific evidence	Engaging in argument from test results	Arguing using diverse representations, making deductions, and justifying results in the process of solving problems.
Obtaining, evaluating, and communicating scientific information	Obtaining, evaluating, and communicating engineering information	Obtaining, evaluating, and communicating mathematical information

Proposal for the scientific, engineering, and mathematical practices to be developed in STEM education

Figure 1



Conceptual representation of the six clusters based on students' self-identification as STEM people.

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