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Science, technology, engineering and math education versus collaborative higher education methodologies: challenges, opportunities and limitations

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Abstract

This article evaluates the challenges, opportunities, and limitations of the implementation of Science, Technology, Engineering and Mathematics (STEM) education in the Mozambican context, considering its potential in promoting participatory methodologies. Using the method of a literature review, the article analyzes the challenges, opportunities, and limitations that the introduction of this practice imposes on the promotion of participatory methodologies in Mozambican education. The results show us the challenges and limitations existing at various levels: educational policy formulation, curriculum structure, infrastructure, and the faculty training, on the one hand. On the other hand, they suggest that STEM offers some opportunities for reframing the act of teaching/learning, leading to increase the quality and relevance of teaching. Its implementation in the school territory through project learning or problem solving suggests that this practice can be a valuable tool in the promotion of collaborative methodologies in the teaching/learning process, thus contributing to the improvement of educational practice in the Mozambican school. However, its transposition and application in the Mozambican context must be done critically and reflexively, respecting the socio-cultural specificities of Mozambican society, while preserving the strengths of the current national education system, on the other hand.

Keywords: STEM Education, collaborative methodologies, Mozambique

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Introduction

> STEM has different meanings for different people (…) it is an omnipresent and ambiguous 'slogan', opaque and confusing even for those who use it (Bell, 2016, p. 2)[1].

Our first contact with the subject of Education in Science, Technology, Engineering and Mathematics (STEM, its acronym) was made through a workshop, promoted by the Ministry of Science and Technology, Higher and Professional–Technical Education (MCTESTP), held in the Mozambican capital, Maputo, on August 16, 2019 with the aim of reflecting on the Teacher Training Program in the areas of STEM (Science, Technology, Engineering & Mathematics).

After this workshop, we began to seriously question the purposes, scope, possibilities and limitations that an STEM Education project could represent, in the context of education in Mozambique. This article aims to present the theoretical results of our reflection on STEM, in view of the concept itself, its genesis and its evolution. Taking these aspects as presuppositions, we aim, in the end, to assess the challenges, opportunities and limitations that the introduction of STEM imposes on the Mozambican National Education system, in general, and the higher education subsystem, in particular.

STEM is an acronym that represents the set of knowledge learned in the school environment through the disciplines of science, technology, engineering and mathematics (Bell, 2016), whose institutionalization arises, mainly, in response to a Western political agenda, based on professional and economic imperatives, allied with the need to maintain hegemony and global economic dominance (Blackley & Howell, 2015)

Education in Science, Technology, Engineering and Mathematics (STEM) emerged at a time when many western countries were dissatisfied with their education systems due to several problems, such as the steady decline in the number of students interested in studying STEM subjects, as well as the number of those who express an interest in working in areas related to this domain in the future.

Therefore, education in STEM is something built by men and women, in a well-defined space-time context. It is an education that seeks to connect knowledge built in the school environment with social contexts and establish links between real-life problems and industry, showing how science, technology, engineering and mathematics are used to improve the society in which we live (Ritz & Fan, 2015).

When it was institutionalized, STEM education was announced as a solution or preventive measure to solve a number of problems of various kinds (environmental, political, social and economic), including economic decelerations in the future, such as the 2008 global financial crisis. However, Blackley and Howell (2015) draw attention to the fact that this optimism and hope in STEM is not based on solid research, but on conjecture and speculation.

With its own history and theoretical framework, STEM is seen in those countries as an adequate alternative for an improved, relevant and contextualized education (glued to real life). A solution to help students develop special literacy that will be needed by many citizens and workers in the 21st century (Ritz & Fan, 2015).

Internally, in Mozambique, the perception or feeling that education, in general, and education in the natural and applied sciences, in particular, offered in Mozambican schools is displaced (out of context) from the reality closest to the students, has been expressed by several entities individual and collective, often complaining about both the lack of relevance and the distance between what is taught and what is experienced.

A little more than four decades after national independence, the lack of men and women with adequate training to meet the need for qualified and trained employees for the hydrocarbon sector, currently on the rise and expansion in the country, as well as the recent mass failures in school re-sit exams in 2019, very much evidenced in the subjects of Physics and Mathematics, constitute another source of concern associated with education in STEM in the country.

It is in this context, in which the Ministry of Science and Technology, Higher and Professional –Technical Education (MCTESTP), through the National Directorate of Higher Education

(DNES), and, with financial support from the World Bank, developed the idea of materializing a broad training program for teachers in General Secondary Education (ESG), Technical Vocational Education (ETP) and Teacher Training Institutes (IFP's) in STEM matters. This program aims, among other aspects, to improve the quality of teaching, whose strategic focus is "to produce graduates who have specific skills, as well as general talents and skills, such as problem solving, reflection capacity, ability to learn, among others" (DNES, 2019).

Education is a powerful and decisive tool in the development process of nations. However, it is determined by the concept of the predominant world that, in turn, establishes the educational objectives that are intended, according to the dominant ideas of the society in which it is established. As such, it can be used to oppress, or to emancipate, to maintain, or renovate, to reproduce, or to transform. It can be "conservative or emancipatory [overcoming alienated forms of existence]; it can only reproduce, or also transform ourselves as human beings through relationships in the world, redefining the way we organize ourselves into society "(Loureiro, 2004, p. 77).

The STEM education that is intended to be implemented in this MCTESTP initiative was created to solve concrete problems, identified in their own cultural, social and geographical contexts, being, in many aspects, different from the Mozambican reality. By the way, Ritz and Fan (2015) draw attention to the fact that, for reasons of a cultural nature and varied beliefs, STEM education may, on the one hand, not thrive in certain countries of the world, and, it may produce results (educational structures and meanings) different in their use and implementation, on the other.

Several authors analyzed in this article teach us that education in general, and education in STEM in particular, cannot be treated in a fragmented way, nor as a panacea valid for any time and place, but, rather, as a social practice located in the time and space, with its own history and theoretical framework, defined according to the social, political, economic and cultural nature of the environment in which it is being developed. Thus, its application in a given geosocial context lacks certain previous actions, one of which is the research to identify the state of the art regarding this practice.

As far as we know, there are no studies published in Mozambique that deal with STEM education. This article is intended to be a simple contribution to the work in progress at MCTESTP, analyzing the state of the art of education in STEM, on the one hand, and assessing the possible challenges, opportunities and limitations that its introduction imposes on the National Education system in Mozambique, on the other. From the analysis of the aspects related to the concept of STEM itself, its origin, the reasons for its institutionalization, and its evolution, the article intends to answer essentially the following question: what are the challenges, opportunities and limitations that the introduction of STEM imposes on the promotion of collaborative/participatory methodologies in Mozambican higher education?

Materials and methods

This article aims to assess challenges, opportunities and limitations associated with the implementation of STEM education, in the Mozambican context, using the literature review technique that essentially consisted of analyzing scientific articles published on Google Scholar in the last five years (2015-2019), based on the analysis of the following key concepts: "The emergence of science, technology, engineering and mathematics education", and "A conceptual framework for STEM education". The use of terms written in English is due to the scarcity of literature on STEM education written in Portuguese and its abundance in English-speaking countries.

Analysis and discussion of results

The search terms adopted in this article were used in Google Scholar to provide a series of peer-reviewed scientific articles, whose reading and analysis of content sparked an initial debate on STEM education in the Mozambican context. Table 6 shows the authors of the analyzed articles.

Table 6. List of authors (articles) analyzed

Authors	**Contribution**
Blackley & Howel (2015)	Origin: National Science Foundation (EUA) x **Judith Ramaley**
Ritz & Fan (2015)	Origin: Second World War, Motivations
Bell (2016)	Origin
Kelley & Knowles (2016)	**Contextualized definition**/STEM: Didactic approach
Nadelson & Seifert (2017)	**Imprecision of concept**; Double motivation
Ntemngwa & Oliver (2018)	**Implementation of education in STEM** **Development of a pedagogic theory**
Thibaut et al. (2018)	Definition of a theoretical framework to underpin educational practices

Concept. Regarding the concept itself, Nadelson and Seifert (2017) call attention to the imprecision of the definition of STEM, due to several reasons that include the need for flexibility, varied contexts and the desire to include a variety of applicable conditions. In addition, the aforementioned authors propose a definition, according to which, STEM represents a continuous and dynamic fusion of contents and concepts from various disciplines, belonging to that domain (Sciences, Technology, Engineering and Mathematics).

Meanwhile, in the same vein, Bell (2016), states that in simpler terms, STEM is an acronym that describes the study of science, technology, engineering and mathematics (STEM). Meanwhile, Kelley and Knowles (2016), describe STEM education as a set of approaches that explore teaching and learning, between two or more STEM areas, and/or between a STEM discipline and one, or more, school subjects. In the same pitch, Kelley and Knowles (2016) present, in our opinion, a more contextualized a definition, in which they refer to STEM education as an effort to combine some, or all four disciplines of Science, Technology, Engineering and Mathematics, in a class, unit, or lesson, which is based on the connections between subjects and world problems.

The definition by Moore et al. (2014) is contextualized because, in it, the authors clearly indicate the appropriate contexts, under which STEM education should focus. These are, in this case, the global problems that afflict humanity, among which we can highlight: climate change, resource and waste management, agricultural production, health, biodiversity, depletable sources of energy and water, mining, transport, health, environment, to name just a few, which demand an integrated approach to cope with them, supported by further development in science and technology.

In summary, and resuming the notion of context, Kelley and Knowles (2016) define integrated education in STEM as an approach to teach the content of two or more STEM domains, linked to practices in an authentic context, with the aim of connecting subjects to boost student learning.

Origin. The origin of STEM education can be traced back to the Second World War, when scientists and engineers needed the knowledge of these disciplines to develop war machines, and also to develop, or rebuild, post-war economies (Ritz & Fan, 2015). However, and according to Blackley and Howell (2015); Kelley and Knowles (2016), the concept of STEM, as it is known today, will have been coined by the National Science Foundation (NSF), of the United States of America (USA), in the 1990s. Initially with the acronym SMET, which, after a negative initial return on the initiative, and some reformulations, adopted the current designation. Bell (2016), corroborating Blackley and Howell (2015), places the origin of STEM education in the American government initiative, and ascribes the originality of the term to Judith Ramaley, a North American biologist and academic administrator.

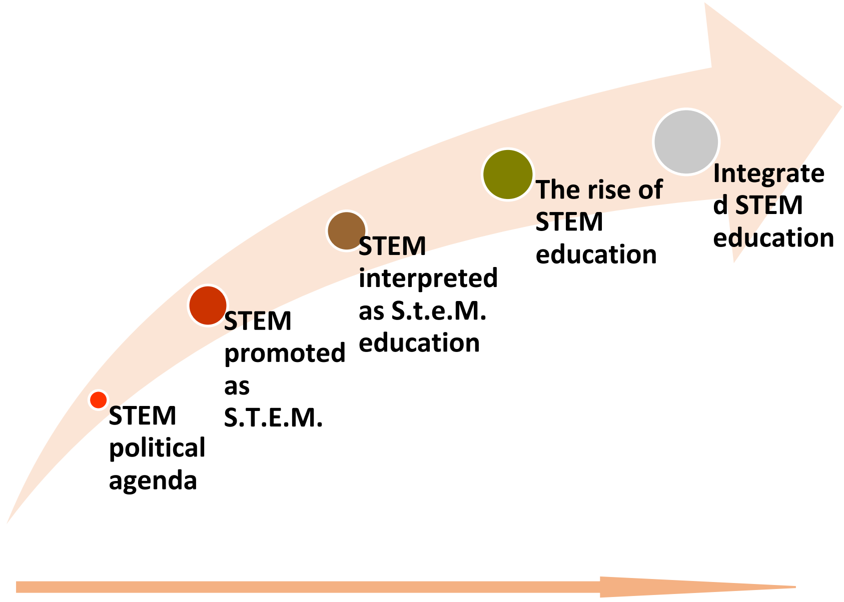
The motivations for its creation and institutionalization in the Western world include: vocational and economic imperatives; pressure from governments to increase the number of students who choose STEM subjects in secondary and university courses; the need for a specialized workforce[2] to respond to the demands of the 21st century; the poor academic performance of students in subjects belonging to the STEM domain; maintaining leadership in a rapidly changing and expanding global economy; the poor performance of students in the STEM subjects, measured by rankings of evaluations (Program for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS)) (RITZ & Fan, 2015).

In summary, paraphrasing Nadelson and Seifert (2017), the motivation, or justification, for the introduction of STEM education in the West, is related to the need to maintain leadership and global hegemony, and to train qualified labor for the challenges of the 21st century, with a view to guaranteeing competitiveness in a globalized world, as well as the search for greater efficiency in the teaching / learning process.

Evolution of the concept. Created due to a political agenda based on vocational and economic imperatives, the Western STEM education agenda is not uniform. While in the USA the rhetoric about STEM is based on maintaining its global superiority, in the United Kingdom, it is conceptualized in terms of human capital (Blackley & Howell, 2015), seen as a means capable of providing a system of science and innovation capable of ensuring high-value goods and services that enable the country to compete in the era of globalization. In the same way that its agenda is not uniform, the evolution of STEM, since its adoption as a state policy until today, has also occurred in a different way in different countries. Figure 3 shows, as an example, the metamorphoses through which the concept of STEM education in Australia has gone through.

1

Figure 3. Timeline of the evolution of education in STEM



Source: Adapted from de Blackley and Howell (2015)

As shown in the figure above, since its creation, as part of a political agenda, STEM education has gone through different stages. Since the isolated application, in which the four subjects that make up the acronym were treated in the school in an equally isolated way (hence the separation by points), passing through the one in which S.T.E.M. was misinterpreted in terms of S.t.e.M (with a greater emphasis on Science and Mathematics at the expense of Technology and Engineering). To explain this misconception Blackley and Howell (2015) state that, at that stage in the evolution of STEM, teachers focused on traditional science and mathematics teaching, practically ignoring the technology and engineering components, justifying this practice with the lack of curricular guidelines to guide teaching practice.

An interesting fact, highlighted by the aforementioned authors, at this stage of evolution, was demonstrated by the difference in the approach to STEM, between the school environment, and the professional (business) environment. In school STEM was represented as S.t.e.M.

[1] These workers need to develop special skills so that they can better understand STEM issues and integrate this knowledge, using team work, communication and leadership skills, which must also be designed and integrated into educational systems (Ritz & Fan, 2015)

(with emphasis on Science and Mathematics in isolation), while out of schools (in the professional context), it was promoted as s.T.E.m. (with emphasis on technology and engineering in isolation). For Blackley and Howell (2015), this discord between schools and professional contexts about the promulgation of STEM and its meaning was the first point of crisis in the STEM narrative. To this point, the authors add the second point of the STEM education crisis, related to the mismatch between the curricular structure and the level of competence and/or the preparation of teachers to act in STEM education. For Blackley and Howell (2015), the two points mentioned above represent the two main reasons for the failure of STEM education.

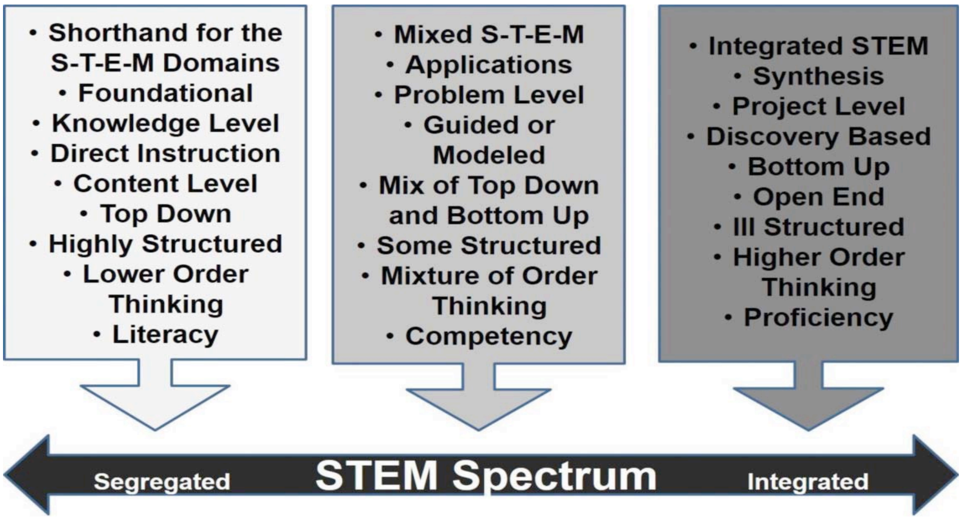
The next phase appears, exactly, as a way to correct the above-mentioned mistake, consisting basically of the integration of the substantive education, to highlight the role that educators have in the conduct of the political/educational agenda (Blackley & Howell, 2015). The next chapter of the evolution of STEM in Australia was related to the integrated approach to education in STEM, representing, then, the highest stage in the STEM timeline, as shown in Figure 3.

According to Nelson and Seifert (2017), the integrated STEM, as opposed to the disintegrated[3] STEM, occurs in such a way that the knowledge and the process of the specific STEM disciplines are considered simultaneously, without taking into account the discipline itself, but rather the context of a problem, project, or task. The problems that require an integrated STEM approach are typically poorly structured, with several potential solutions, and require the application of knowledge and practices from various STEM disciplines.

In the school environment, integrated STEM is usually associated with project-based learning, or problems where the results can vary widely, and the knowledge necessary for their solution is distributed across the STEM disciplines. The aforementioned authors emphasize that the integrated STEM is compatible with the era, or age, of synthesis (Nadelson & Seifert, 2017). This is the age towards which humanity is heading, coming from the digital age, or information, involving conditions that require the application of knowledge, and practices, of various STEM disciplines in order to learn, or solve, transdisciplinary problems.

The concept of segregated STEM (as opposed to integrated STEM) allows us to introduce the notion of STEM spectrum, comprising three vectors, which include STEM approached in isolation (S.T.E.M), the mixed, and the integrated (see Figure 4).

Figure 4. STEM Spectrum



Source: NADELSON and SEIFERT (2017)

The teaching of a school subject (Physics for example), in which the context of approach is the subject itself, belongs to the segregated extreme. While the teaching of the same subject, linked to a concrete problem, which represents the context of the teaching process/ongoing learning (solid and urban waste management, for example) would be in the domain of integrated STEM.

Nadelson and Seifert (2017) elucidate and broaden the notion of integration, stating that education in integrated STEM is materialized through a teaching /learning process, involving two or more STEM disciplines, or a STEM discipline, and a non-belonging discipline to this domain, like the arts, for example. Indeed, the authors show that integrated education in STEM goes beyond the integration of disciplines belonging to this domain, in order to integrate others external to themselves, such as art, public health, entrepreneurship, design, among others.

Nadelson and Seifert (2017) using the notion of spectrum relating STEM inside and outside the school, show that STEM education that takes place in research, industry and society is tended to be at the integrated end of the spectrum, while most of the STEM education that takes place in schools is more in line with the segregated end of the STEM spectrum (see Figure 2).

Outside Australia, in the global context, the attention of governments, the public and the media has been concentrated around STEM education in schools with a focus on the following aspects (Nadelson & Seifert, 2017):

- Curriculum;
- Pedagogical approaches;
- Teacher skills level;
- Student motivation and discipline selection.

Still in the global context, Nadelson and Seifert (2017) point to four geo-social areas, characterized by different approaches to STEM education: (1) English-speaking countries, (2) Western European countries, (3) Asian countries, and (4) developing countries. ANNEX1 (page 13) presents the dominant characteristics of STEM education in the four groups of countries identified above.

With a non-uniform agenda, and a different evolution that varies from one country to another, from one geo-social context to another, in the set of nations interested in the topic, it is possible to identify some variations in the application of STEM education (Ritz & Fan, 2015). Indeed, some countries have merged the contents of science and technology education (for example, France, Israel, the Netherlands), while others prefer the development of engineering programs for their schools, in an effort to create learning contexts for science and mathematics. Other nations are integrating engineering content into the technology education curriculum (Canada, Sweden, United States). As a consequence of these variations, STEM education, in terms of its use and implementation, produces different meanings and different educational structures (Ritz & Fan, 2015).

In terms of application in the school environment, STEM education is typically associated with project-based learning methods, or problem solving (Nadelson & Seifert, 2017), where the results can vary widely, while the knowledge needed to solve the problem in question is distributed among the STEM disciplines. For Nadelson and Seifert (2017), with greater exposure to STEM in classrooms, students' learning experiences would be more similar to those they will face when living, learning, and working as productive citizens, involved in issues, problems, and projects related to real life.

As we saw earlier, education in STEM was created in its own spatio-temporal context, with the purpose of solving specific problems identified in a specific location. Therefore, the transposition, and subsequent application, of this practice in the Mozambican context must be done in a critical way, strictly and scrupulously respecting the socio-cultural, economic, and political specificities, typical of today's society, preserving the values and strengths that characterize the current national education system.

The relatively smooth transposition of STEM into the Mozambican reality necessarily involves mapping the challenges, opportunities, and requirements that the introduction of STEM education into the national education system imposes. Annex 2 summarizes, without intending to exhaust, the possible challenges, opportunities, and limitations, related to STEM education. The mapping activity must be continued and based on field research, the results of which will serve not only to identify challenges, opportunities, weaknesses, and threats, but also to guide the definition of action strategies, with a view to implementing STEM in the national context.

Final considerations

This article aims to analyze the origin, evolution, and state of the art of education in STEM in order to assess the challenges, opportunities and limitations that the introduction of this practice imposes on the Mozambican education system, in general, and to the higher education subsystem, in particular. According to the methodological framework adopted, the study suggests that, as a localized social practice, education in STEM represents an emerging approach, a new teaching /learning strategy, with its own history and theoretical framework that give it a certain potential to motivate and attract students to include STEM subjects in their training path.

Having been created in a specific space-time context, with the purpose of solving concrete problems identified in that context, its transposition and subsequent application in the Mozambican context must be done in a critical and reflective way, respecting the sociocultural, economic and political specificities, typical of society Mozambican, on the one hand, while preserving the values, achievements and strengths that characterize the current national education system, on the other.

As a teaching/learning strategy, STEM education has its own history, theoretical framework and trajectory and, as such, its transposition and application in the Mozambican context entails challenges and limitations (see Annex 2) that are situated at various levels: formulation of educational policy, curricular structure, infrastructure/material resources, and training/ qualification of teaching staff.

In addition to the challenges and limitations mentioned above, STEM education can be seen as an opportunity to reframe the act of teaching/learning, leading to increased quality and relevance in the teaching of disciplines linked to STEM, in particular, and of all curricular subjects in general.

Its implementation in the school environment through project learning, or through problem solving, suggests that STEM education can be a valuable tool in promoting collaborative methodologies in the teaching/learning process, thus contributing to an improvement in educational practice in the Mozambican academe.

Subsequent research, which takes into account the challenges, opportunities and limitations, intrinsic to STEM education, as well as the crises it has undergone, since its institutionalization to the present day, would be the indicated path to obtain a clear definition of adequate strategies for the implementation of education projects, that are sufficiently realistic and robust to reduce, as much as possible, the various types of damage that affect our education system.

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ANEXES

Annexe 1. Global educational approaches to STEM

Geo-social domains	Representatives	Characteristics
Anglophone countries	UK and USA	STEM crisis discourse predominates USA Maintaining global superiority UK: Human capital decisive for competitivity
Western European countries	France and Germany	Integration of STEM in the National Education and Industry Policy Focus on the apparent "shortage of STEM" instead of "crisis" Promotion of a positive image of science Increased public knowledge of science Improving student performance in science and mathematics; Growing interest in STEM subjects in schools and higher education;

		Increased workforce in STEM.
Countries in Asia	China, Japan and Taiwan	High-performance education systems Top in international rankings[4] Fast-growing economies; Well-structured national policies around STEM; R&D driven by academia and industry; They value careers for meritocracy Excellence in teaching STEM subjects STEM taught by highly qualified teachers Long-term planning Broad and deep consensus (population and government) on the importance of STEM Confidence reigns over STEM Respect / valorization of the teacher Student-centered and problem-solving teaching
Developing countries	Brazil, South Africa	Emerging economies Low supply of qualified teachers STEM is addressed in terms of improving participation in basic education and the development of qualified teaching staff

Source: Adapted from NADELSON; SEIFERT (2017)

[2]

ANEXE 1. Challenges, opportunities and limitations related to education in STEM

Challenges	Opportunities
• Compartmented x Integrated Curriculum • Rigid x Integrated Curriculum • Subject-based x Problem-based teaching • Teacher's mentality • Teacher knowledge about STEM • Detachment from traditional pedagogy practices (Exit our comfort zone) • Lack of (evidence) in proof of concept • Change of focus: Reproduction → Real-world application • To problematize the PEA using: • Problem-solving learning • Project learning • Restructure the curriculum and introduce significant changes in instruction	✖ Developing skills for the 21st century: Adaptability; ✖ Social skills; ✖ Troubleshooting complex problems ✖ Systemic thinking, etc. ✖ Approach to critical, liberating and emancipatory pedagogy in the conduct of teaching/learning processes ✖ Coping/Solving global challenges (Kelley & Knowles, 2016). ✖ Offers opportunities for students to learn through more relevant and stimulating experiences (Kelley & Knowles, 2016) ✖ Encourages the use of higher-level critical thinking skills ✖ Improves problem solving skills and increases retention (ditto). ✖ Use the content and principles of science, mathematics and engineering to enhance students' learning about complex concepts (Nadelson & Seifert, 2017) ✖ Develop knowledge, attitudes and skills to identify real-world problems ✖ Exploration of the multiple facets of knowledge, as well as their transfer, improving the significance and relevance of the content learned, raising the motivation and involvement of students in learning
Limitations	

[2] The focus should not be centered on the student's capacity to reproduce what is learnt, but on how well the student can extrapolate the knowledge acquired to apply it to unknown situations inside and outside school (OCDE, 2014 apud (Nadelson & Seifert, 2017)

- Programs must include rigorous curriculum, instruction and assessment; Integration of technology and engineering in the science and mathematics curriculum; Promotion of scientific research; Strong conceptual and fundamental understanding of how students learn and apply the learned content (Kelley & Knowles, 2016);
- Teachers should focus more on student-centered learning, and on other innovations, and less on the transmission of knowledge;
- Promotion of teaching as guidance and facilitation, rather than simple knowledge transfer
- Requirement in the identification and use of appropriate contexts (NADELSON; SEIFERT, 2017: p.222)
- The individual must develop knowledge, attitudes and skills to identify problems