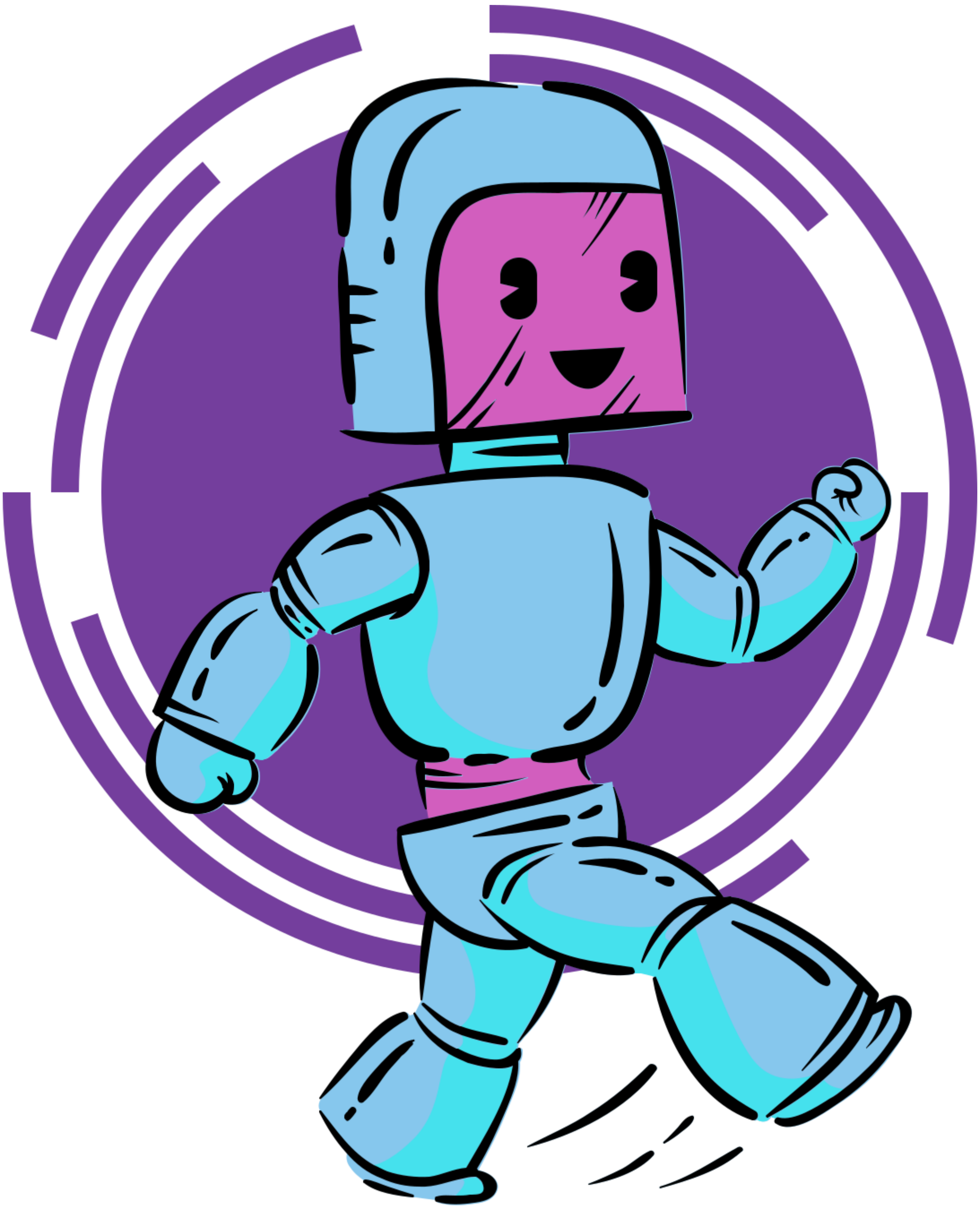
STEMBOT

Co-funded by the Erasmus+ Programme of the European Union

STEMBOT

Introduction Guide



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Introduction

In 2016, The European Union highlighted some key competencies to ensure: “initial education and training offers all young people the means to develop the key competences to a level that equips them for adult life, and which forms a basis for further learning and working life.”[i] Amongst these competencies, we noted ‘Mathematical competences and basic competences in sciences and technology.’ These competences are meant to enable individuals to better understand the advances, limitations and risks of scientific theories, applications, and technology in societies at large (in relation to decision-making, values, moral questions, culture, etc). Indeed, to ensure that all young people are equipped with critical competencies to lead fulfilling adult lives, STEM skills are unavoidable.

Yet, in recent years, statistics have shown that STEM education in Europe is insufficient to equip students with the necessary skills for today’s science-led world. Today, Europe faces a shortfall in science-knowledgeable people at all levels of society. Indeed, only four EU Member States met the ET 2020 benchmark of less than 15% underachievement in both science and mathematics fields. Over the last decades, there has been an increase in the numbers of students leaving formal education with science qualifications[ii].

Different social, cultural, economic, and educational institutional factors can explain why STEM studies and careers are unattractive for young people. Furthered by wide disparities in participation in science education, in formal, non-formal and informal settings, across regions, cultures, combined with gender related issues; all these reasons explain the persisting under-involvement of learners in STEM subjects[iii].

Underachievement in STEM mostly starts to proliferate in secondary education when mathematics and science become abstract. With this project, we hope to bring mathematics and science to life, showing students how STEM is applicable outside of the classroom and give them the practical experiences they crave for
using an innovative approach. With the help of a chatbot, a computer programme using Artificial Intelligence (AI) that can conduct conversations, students will get

access to videos of practical experiments and thus see how science works in the real world, instead of theoretically.
The chatbot developed for this project will help make science more accessible by:

- first showing students how science is applied through experiments,
- then providing them with the explanations behind the shown experiments.

By providing students in secondary education with real-life applications of what they are learning in school, we intend to foster their interest in STEM subjects, so that learners feel confident choosing a career in STEM later.
Therefore, the aim of this guide is to increase the understanding of the importance of practical experiences in STEM and to give leads to educators on how to foster students' interest in STEM subjects at a crucial age, where they usually become more disengaged.

In this project, we will develop a series of additional resources:

- An introductory guide
- The science experiments videos
- The science behind the experiments
- The STEMbot
- The pedagogical guide on how to use STEM in formal learning process
- The creation guide on how to create a chatbot for STEM learning.

Chapter 1: Data on the current situation of underperforming students in mathematics and science in Europe and its consequences for society

Introduction

The performance of students in mathematics and science has a direct impact on society. A tendency to have underachieving students is felt nationwide: poor performance in STEM subjects leads to fewer students in higher education in these fields and consequently fewer professionals in science, technology, health etc.
In order to understand why technological and scientific progress in a country is at a standstill or, on the contrary, is dazzling, it is important to study the problem at its source: what is the level of students in maths and what is the cause of this level?
If we want to have an objective overview of the level of students in Europe, we need to rely on figures. For that purpose, we used the 2019 TIMSS (Trends in Mathematics and Science Study) reports carried out in 8th grade and 4th grade classes in the EU and the OECD.

1.1 Data and Analysis of the situation of students in maths and science in Europe

a. General evolution of the situation over the last few years

If we observe the TIMSS results in mathematics in general, 4th grade students have a similar level (in 23 countries) between 2015 and 2019 or even increase (this is the case for 14 countries). On the other hand, 8 countries, including France, are seeing their results decrease.
In science, the results are more mixed as 10 countries have an increasing score, 25 countries keep a similar score and 10 countries see their results decrease.
Comparing the overall average TIMSS scores of 4th graders in 2015 and 2019, students maintain their level in mathematics and science: in 2015, the EU average in mathematics was 527 and in 2019 it was 527. For science, in 2015 the EU average was 525 and in 2019 it dropped slightly to 522.

TIMSS 2019	Mathematics	Science
Netherland	197	37
Sweden	137	75
Austria	130	78
North Macedonia	131	58
Germany	153	56
France	182	47
Portugal	250	104
Europe	156	67
International	154	75

TIMSS & PIRLS International Study Center at Boston College (2019)
Figure 1: Number of teaching hours per year by teachers and principals [Table].
https://timss2019.org/reports/classroom-contexts/#classroom-math-curriculum

European countries are not in pole position in terms of student performance in mathematics and science, since in both 4th and 8th grade of compulsory schooling. All European countries are being beaten to the punch by Asian countries. Indeed, Singapore, South Korea, Taiwan, Hong Kong and Japan are at the top of the rankings.
In the 8th year of compulsory schooling, the international average (consisting of the results of OECD and EU countries) is 515 in science and 511 in mathematics. Between 1995 and 2019, students in Europe tend to have rather stable results in science. Moreover, girls and boys have performed similarly on average in recent years.
In mathematics, if we compare the results in this same period, over 24 years, the results are more heterogeneous since, out of the 9 countries that took part in this evaluation, 3 countries (including France) have seen their scores fall, while 6 of them have stable or rising scores.

b. An example: analysis of the data for France (PISA / TIMSS)

In 4th grade, the European average in mathematics is 527 points and in science it is 522 points.

In the 8th year of compulsory schooling, the results drop as the European average in mathematics is 511 points and in science it is 515 points.
France is the worst performer in the TIMSS reports since, in both mathematics and science, its level is below the international average (EU and OECD) and the TIMSS mid-point.

If we look at France's results in science and mathematics, the scores are not only below the EU average but also below the TIMSS mid-point (located at 500), with a score in mathematics of 485 and in science of 488.

In 4th grade, students receive far fewer hours of teaching per year in science than in mathematics: on average, students receive 156 hours in mathematics compared to 67 hours in science. In France, the gap is even more pronounced, with 182 hours of instruction per year in mathematics compared to 47 hours in science.
France, in addition to being the worst performer in these reports, is among the countries with the smallest gap between the lowest and highest performing students. Only 2% of students are taken to the advanced level compared to 11% at the international level. Moreover, France is one of the countries where there is a significant gap between boys and girls.

c. Knowledge assessment and analysis between boys and girls in the results in STEM in general

In mathematics, in 4th grade, boys have a slight advantage over girls. In Europe, girls have an average score of 532 and boys have an average score of 541. The gender gap is present in 17 European countries. The gap between girls and boys ranges from 7 points for Denmark and Sweden to 19 points for Cyprus. In Portugal too, boys score 17 points higher, in Belgium, they score 11 points higher and in Poland they score 8 points higher than the girls.
In science, on the other hand, the results are more balanced between the sexes with a score of 521 for girls and 522 for boys. France follows the same trend with boys scoring 2 points higher than girls

Over the last 20 years, the trends of TIMSS show that the differences between boys and girls tend to fade away in mathematics and in science, especially in science as girls started performing well. In 1995, in most of the countries, boys performed better than girls in mathematics and science. The situation changed drastically in 20 years: in 2015, boys had better results in only 3 of the 15 countries. Whether in 4th or in 8th grade, there is no significative difference between boys and girls.

In studies, it is shown that boys and girls choose different fields of study in higher educational levels. For example, in North Macedonia, girls tend to choose mainly social sciences, medicine, foreign languages or others that are not related to STEM and boys are more likely to choose engineering, production, construction.

A survey carried out in North Macedonia asked 15-year-old male and female students about the work they thought they would be doing by the age of 30. The study showed that among the students who thought that they would work in the field of health in the future, 9.4% were boys and 26.8% were girls, which is a considerable difference of 17.3%. The percentage of girls who think they will be working as ICT professionals by the age of 30 is one of the highest among the countries participating in PISA. There is a gap of 7.2% in favour of boys in ICT professionals and a gap of 1% in favour of boys for those who expect to become science-related technicians and associate professionals.

These positive statistics and the fact that North Macedonia is experiencing one of the most important growths among PISA-participating countries can be explained by the fact that this country values the well-being of students. Indeed, the average level of life satisfaction of students is one of the highest among the PISA-participating countries. They have confidence in themselves and their abilities.

Festo Didactic. (2021, 19 february). *Pupils finish a bionic fish in motion* [Photo]. https://opleht.ee/2021/02/toomaailm-vajab-integreeritud-stem-haridusega-spetsialiste/

1.2 Why students underperform in STEM?

a. Lack of motivation in STEM

Motivation is a very important factor in student achievement. Half of the countries in Europe have put in place a strategy to increase student motivation. Indeed, the student's state of mind is determining: being positive towards STEM goes with better results in STEM. Motivated students are more likely to make the decision to study and work in STEM.

But, before going any further in the reflection, it is important to define the concept of motivation. According to Rolland Viau, a pedagogical researcher, teacher and writer, "motivation in school context is a dynamic state that has its origins in a student's perceptions of themselves and their environment and encourages them to choose, engage in and persevere in an activity in its accomplishment in order to attain a goal".

Rolland Viau also takes up in 2003 a theory developed by Edward Deci and Richard Ryan in Motivation in school context, their theory of self-determination. It postulates that individuals, in order to motivate themselves, need to feel autonomous, to have control over their actions. This need would go hand in hand with the need for competence and the need for social belonging.

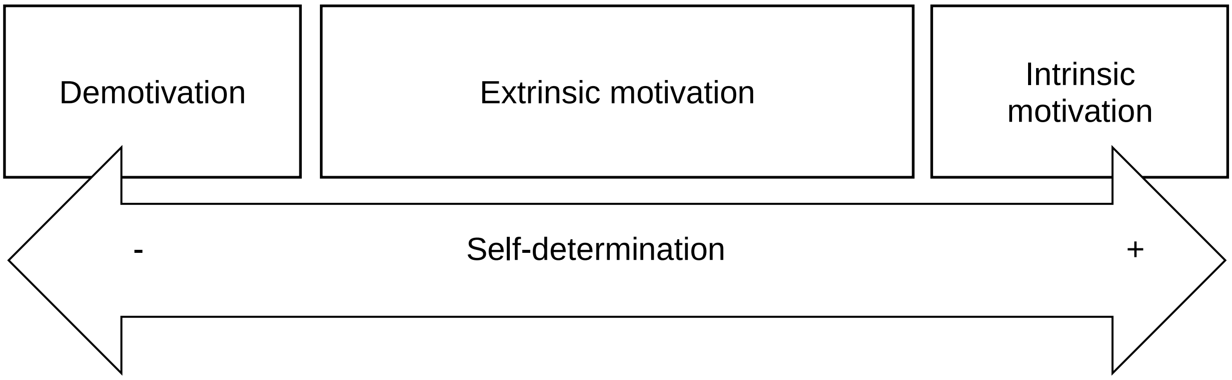


Figure 2: Aude André. (2015a). *The motivational continuum according to DECI* [Illustration]. https://dumas.ccsd.cnrs.fr/dumas-01280787/document

Lack of motivation is referred to as “demotivation”. Impairment, as opposed to motivation, is a sense of hopelessness or anxiety about obstacles. It can express itself in the form of a lack of enthusiasm and energy and can prevent learning. Demotivation can lead to poor grades, absenteeism and dropping out of school. According to a study conducted by Eurostat, in Europe, 9.9% of 18–24-year-olds leaving school at secondary school without going further. In the EU, in 2020, early leavers went from 2.2% in Croatia to 16.7% in Malta.

Motivation can be divided into two types: extrinsic motivation and instrumental motivation. The so-called “extrinsic” motivation is generated by a cause external to the student. They are the consequences of his work: good grades, approval from his parents, obtaining a reward, etc. This is the most common motivation among students. Intrinsic motivation comes from the pleasure of doing the task itself. Researchers and teachers have the opinion that anxiety in mathematics is an important obstacle to achievement in STEM. This opinion is powerful because if it is correct, succeeding in STEM is not only a matter of cognitive ability but a matter of emotions. Negative emotions towards mathematics can lead to avoidance of mathematics and underperformance.

b. Our education system lacks practical application of theorical knowledge

The current education system is mainly based on theoretical knowledge rather than practical knowledge.

Students do not play an active enough role in acquiring knowledge. To appropriate the knowledge students learned at school, it is important that they apply through practice.

Practical work should include laboratory experiments, study trips, projects, assignments, etc.

Lack of experience can be detrimental when finding a first job. In fact, companies offering jobs often ask for profiles with experience and in job interviews, people with little or no experience are often turned down

The acquisition of theoretical knowledge is of less value if students cannot apply it through practical measures.

One must be aware of what one's knowledge can bring to this world. The lack of experience among young employees requires companies to take time to train them, therefore they are reluctant to employ young graduates. Therefore, it is better to prepare and look for ways to apply your knowledge through practice.

Whether it is science, art, business or professional studies, education must fulfil its main purpose of helping students to think for themselves. And to do this, practical experience helps to make knowledge their own.

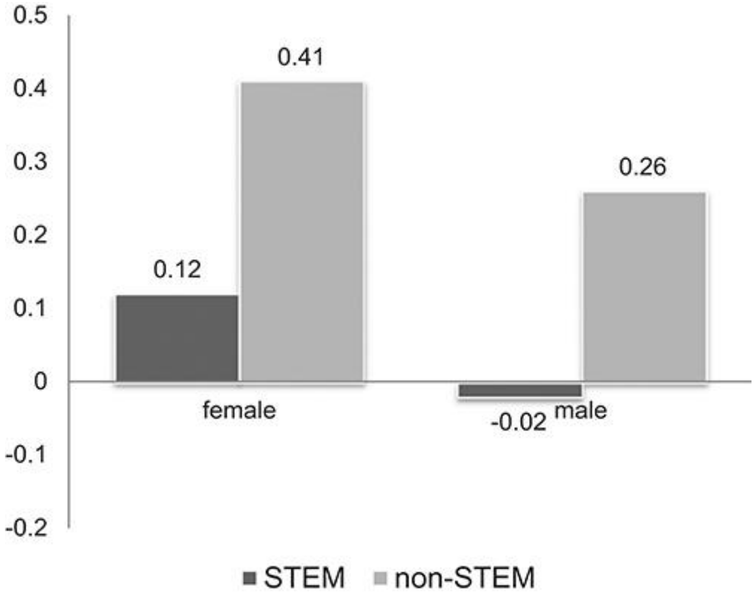
c. The gender gap in STEM fields

Numerous studies show that mathematics and science are perceived as male domains and scientists as predominantly male. Indeed, mathematics is seen as the most masculine domain and chemistry is the STEM domain the most attributed to women. According to the Global Gender Gap Report of the World Economic Forum, the numbers reflect these stereotypes. In STEM, the field of informatics has the lowest proportion of women: they are only 10.4%. On the other hand, the fields of chemistry and life-sciences have the biggest proportion of women: they represent 43.7% of them.

According to UNESCO data, only 35% of all female students in higher education study science, technology, engineering or mathematics, and only 28% of researchers worldwide are women. Globally, information and communication technologies attract very few female students (3% of all students), as do natural sciences, mathematics and statistics (5%), and engineering, manufacturing and construction (8%).
On average, men are under-represented in the fields of education, health and welfare. Women are under-represented in STEM fields.

This imbalance in the gender balance can be explained by stereotypes that are ingrained in children's minds at a very early age, as according to DAST studies, students from kindergarten to high school perceive scientists as male. In a study which consisted of asking students from kindergarten to fifth grade to draw a scientist, only 28 images of a female scientist out of 4.807 were found, and all 28 were drawn by girls.

The study shows that girls are more likely to restrict their occupational choices because they perceive certain occupations as inappropriate for their gender.
In summary, young women who aspire to study a STEM subject see chemistry, math and physics as less strongly masculine compared to young women who aspire to study non-STEM subjects. Among young men, only mathematics is seen as strongly masculine among students who chose a non-STEM study program.



Bernhard Ertl. (2019, 10 july). *Figure 3 : Masculinity index of math and career aspirations* [Graphic].
https://www.frontiersin.org/articles/10.3389/feduc.2019.00060/full

This figure shows that female and male students in a non-STEM major tend to attribute masculinity to maths more than students who chose STEM studies.

d. An example: motivation in mathematics

To illustrate the extent to which motivation is essential in the study of mathematics, we will take the experience of Alexandra Martinet and Ophélie Morel in the context of their thesis for the Master of Teaching.
They decided to set up their project in a 5th grade class.
In a mathematics class, they decided to implement a strategy to increase the motivation of the students, make the teaching more relevant to the students and consequently make the students achieve better results.

They proposed a math activity on the theme of sport, an activity that seemed to be appreciated by most of the class. It was a survey where the students made assumptions: girl or boy? Age? Which sport? Frequency? One or more sports?

Then the pupils, in teams of two, went to investigate and made a diagram to present their results orally.

The result of this activity was that, at first, the choice of the theme of sport interested them. The proof is that they anticipated all the instructions that the students were going to give and wanted to go beyond the time limit to produce a better-quality work.

They worked independently and during the oral presentation, they had enriching exchanges.

In conclusion, when there is a theme that speaks to them, teamwork and an oral exchange between everyone, the students want to work and go further. This develops their critical thinking and their reflection, skills in high demand in the world of work.

1.3 Consequences for society

a. Science for society

Science is necessary for society: it allows for longer life expectancy, good health and access to basic necessities such as water, food, energy...

In everyday life, it is impossible to function without science. It allows us to speed up communication between everyone, but also to entertain us with all the technologies. The advantage is that it is universal: no matter what language you speak, no matter what culture you belong to, science is a universal link.

It must respond to the needs of society and global challenges. Public awareness and engagement with science and citizen participation, including through the popularisation of science, are essential to enable citizens to make informed personal and professional choices. Governments need to make decisions based on sound science to guide health or agricultural policies, for example. The latest scientific knowledge must inform the work of parliaments when legislating on societal issues. National governments need to be aware of the scientific aspects of major global challenges such as climate change, ocean health, biodiversity loss and freshwater security.

To address the challenges of sustainable development, it is important that governments and citizens understand the language of science and become scientifically literate. Furthermore, scientists need to identify the problems facing policy makers and should strive to make their research results relevant and understandable to policy makers and society at large.

Alexander Raths. (2014, 1 april). *Why we need women to advance science* [Photo]. https://www.huffingtonpost.fr/laurie-glimcher/pourquoi-nous-avons-besoin-des-femmes-science_b_5070212.html

b. The world needs more specialists with integrated STEM education

Science, technology, engineering and mathematics are four very important subjects. In today's schools, mathematics, physics and perhaps even various technologies are taught, but as separate subjects. Engineering is usually completely absent. However, these four subjects are interrelated and have a close influence on each other. Without one of them, the development of the others inevitably stops. It is even more important that students understand the interdependence of these four subjects. Understanding this would motivate them to explore their individual areas in greater depth later on.

STEM education should be comprehensive and complex, focusing on real problems and allowing students to find solutions themselves. Students learn best when they are encouraged to seek their own knowledge in the world around them. Today's STEM education should consist of relevant programs focusing on technology and

engineering learning, with scientific and mathematical components. Through a project-based approach, students have to solve or optimise real-life problems.
A crucial issue in implementing an appropriate STEM program is to find teachers who are prepared to teach concepts and skills using an integrated approach. This is especially the case for engineering and technology-related content, which is not usually part of teachers' preparation. In order to successfully integrate STEM into the curriculum, teachers need to be appropriately trained. To apply science, mathematics and technology to engineering issues, traditional methods, learning environments and curricula need to be reassessed. Innovative content and learning facilities must be made available. Innovative content must incorporate a modern, integrative learning methodology focused on real-world problem solving.

c. The world needs inclusive and diverse science

In order to attract more people into STEM fields, it is necessary to make them accessible to as many people as possible.
As we have seen before, STEM fields tend to be allocated to men. It is important to make STEM fields more accessible to women.

Role models are very important in changing the mindsets of young people. Dr. Sharon DeVivo, President of Vaughn College of Aeronautics and Technology in New York says: « Girls need to be offered meaningful opportunities during their secondary education and be given a pathway to higher education that includes internships, mentoring and motivating experiences. Our industry partners must welcome women and encourage their success throughout their careers. »
Pupils with dyslexia, for example, are usually sidelined and not well integrated into education. They tend not to pursue STEM subjects.
Students from disadvantaged socio-cultural backgrounds also find it difficult to perform well in STEM fields. Indeed, in a study in Australia, Aboriginal people were found to perform poorly in all STEM subjects except Earth and Space. According to the researchers, these subjects resonate with their culture. In order to better include Indigenous students, the researchers suggested that Indigenous perspectives be incorporated into the course content.

Microsoft. (2018b, avril 25). *Girls in STEM : the importance of role models* [Photo]. https://news.microsoft.com/europe/features/girls-in-stem-the-importance-of-role models/

Chapter 2: How to engage students in secondary education in STEM learning

Introduction – STEM learning what is this?

The word STEM stands for Science, Technology, Engineering, and Maths. STEM learning approach connects academic concepts with real-world lessons. It is an interdisciplinary approach that removes the traditional barriers between subjects and instead focuses on innovation and the applied process of designing solutions to complex contextual problems using current tools and technologies.

With the STEM learning approach, students gain important skills, which are applicable in everyday life. In addition, if they do not pursue careers in STEM, they will be better prepared for future challenges.

Source: Free stock image

2.1 How to engage students in STEM learning?

a. The way of teaching and facilitating STEM learning.

If we want students to be engaged in STEM as an interdisciplinary area, the definition of STEM education must go beyond improving the individual STEM discipline and looking at STEM more holistically. Integration of STEM activities can be done through the science and mathematics curriculum; however, it can be related to other subjects (Arts for example). This promotes scientific inquiry and the engineering design process. With the STEM approach, students are required to demonstrate their understanding of STEM disciplines in a work-based, contextual environment. Students have to be part of learning activities, that challenge them to innovate and invent. They have to apply the knowledge they already got to an engineering problem and utilize technology to find a solution. All this can be reached by applying the basics of teaching STEM in every class topic.

b. Teacher's readiness to teach STEM.

The important link between implementing STEM activities and students gaining the most knowledge they can from it are ready, motivated and well-equipped teachers. Just those teachers can promote applied and collaborative learning. Using available technology, which has to be integrated into the culture, curriculum, teaching strategies and daily operations of classrooms is essential to enhance learning.

To support students learning, teachers should use problem-based and project-based learning with a set of specific learning outcomes and let the students be curious, investigate, invent and create. It has to require students to demonstrate their understanding in a real-world context for learning and work.

The teacher has to know how to step out from the classical role of the teacher who just passes the academic knowledge to the students, no matter the context. The teacher has to be someone who guides the students, inquire about them and value their opinions and work, to give them the chance to get STEM-related skills and knowledge.

Cooperation between teachers is especially welcomed whether working in the same school or in different institutions if they are working in the same school or they are part of a different institution. Pedagogical models that provide well-rounded education and exchange of practical issues and solutions can be developed.

c. Integration of STEM subjects, also with Art

Students are more engaged in STEM subjects if they can create something by themselves. The Art can be perfect to develop engagement with engineering design. Students are always ready and enthusiastic for creative activities, which can be coupled with academic knowledge and problem-based activity when they are working to solve some practical issue from real life. Problem-solving is the process of identifying a problem, solution, innovation, prototype, evaluating, and redesigning as a way to develop a practical understanding of the designed world.

Art is one of the most valuable thinking tools we have. The important learning input we use is also visual. If the teacher needs to explain something, he/she can draw a picture. It goes also in the other way – if students want to explain something to the teacher, they can sketch or illustrate it.

Applying art designs can make everyday teaching materials attractive and have a valuable impact on students' engagement.

d. Practical hands-on experiences

Teachers should be prepared with different materials, which can help with implementing hands-on STEM activities anytime in the learning process, even without planning. Equipped with grade-appropriate materials, teachers can encompass a hands-on, minds-on, and collaborative approach to learning, which means more engagement for students. Students see the practical and creative hands-on experience as a game because playing is in their nature. This can be used in everyday teaching by creating attractive and practical activities for the most engaging and effective learning process.

Using different innovative technologies can enhance STEM education learning experiences and investigations such as modelling, simulation, and distance learning – using educational apps, quizzes, augmented reality, visiting different places with virtual field trips.

Many teachers are not prepared to teach STEM subjects using active learning activities or through the inclusion of 21st-century skills. They need professional development in teaching STEM and curriculum appropriate to this type of teaching. However, this cannot be achieved in every school setting. Fortunately, online resources provide an ever-growing number of free materials including professional development, curriculum, and success stories, all aimed at helping them engage students in a STEM context.

e. All children need STEM opportunities.

With the STEM approach, all students must be part of its vision. Activities can be adjustable to various groups of students: different ages, diverse cultural and social backgrounds, students with different learning problems and conditions… This makes STEM inclusive for everyone.

All students need STEM opportunities – all of them learn more with a well-designed, project-focused curriculum. When teachers design STEM activities, they should make them in such a way to ensure the opportunity for real involvement and success for all students involved.

Source: Free stock images

2.2 Importance of role model

In a world without football on the television, would children spend hours dribbling a ball in the yard? Probably not. Because we have created role models and superheroes elsewhere, students do not see the real value, the excitement, the fun of science and technology.

It is essential to empower a culture that celebrates science and technology in the same way than the worlds of sport and entertainment. This requires highlighting role models and superheroes—people like astronauts because they bring context and students can connect with them.

Role models for students represent an inspiration, spark interest in learning and exploring STEM disciplines, but also the interest in achieving a future career in the STEM field.

Students must first know what is possible to achieve. Identifying a role model at an early age helps students to find the motivation to search through the possibilities of working in a similar field.

If the presentation of role models is correctly performed, it can contribute to engaging more students, who are usually underperforming in STEM (girls, students with difficult socio-economic backgrounds, students with learning disorders ...). Promoting a diverse range of role models is key to closing the diversity gap that still exists in these areas.

In the study from the Microsoft company girls, engaged in STEM with help of role models, have been studied. Microsoft's study found that the number of girls interested in STEM in Europe nearly doubles when they have a role model to inspire them. However, the gap between the number of girls interested in STEM subjects and the number of young women with actual STEM careers still exist. Because girls lose interest in STEM by the age of 15, results address the need to leverage role models and increase their exposure in this age group, to ensure that classroom passion blossoms into a career.

When searching for role models from the STEM area to present them in the classroom, it is recommended to follow these tips. The Internet has a lot to offer, just take some time and search for some STEM role models, who will fit in your classroom to present them and get students engaged.

Search for:

- Males and females – try to cover both genders equally, although maybe females role models are harder to find.
- Persons who are actively working in the STEM field (engineering, mathematics, programming, computing, medical sciences, environmental sciences, life sciences, physics, chemistry, …)
- Persons who have some inspirational stories to offer. We want to show the students the concept that anyone can become an expert in some field and can do and create important things in his or her life. If you can, choose persons with diverse backgrounds, cultures, genders and show to students what can be achieved despite our nature and circumstances.
- Persons working in different areas of STEM, present the extensiveness of STEM fields and the most possibilities and ideas for STEM future careers.
- Young persons, also their age. This helps to connect the students with the role models and to see, they can start creating their story now.


Source: Free stock images

2.3 New ways of teaching

As was said in the previous chapter, STEM is connected to the specific teaching approach, which is interdisciplinary and gives a real-life context to the problem that students are trying to solve. This teaching approach is not limited just to science-based and technology-based curriculums but can be applied in a variety of classes and for populations of different ages.

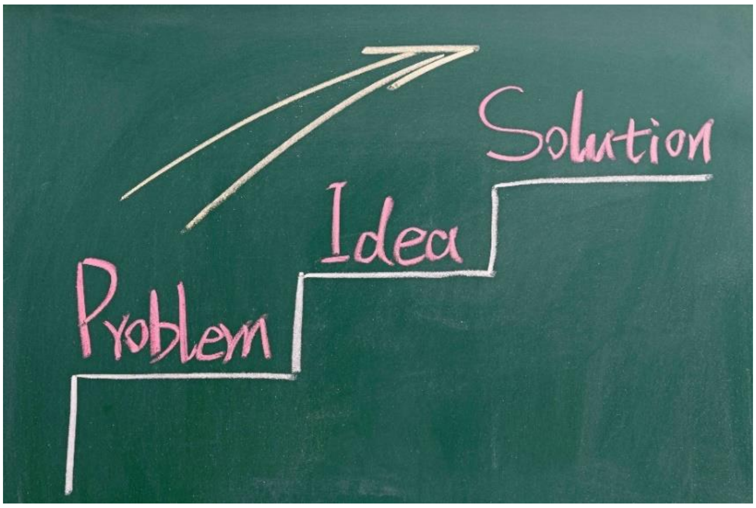
When students are young, they have an undeniable interest and curiosity in the things around them. They are in the perfect stage to embrace the integrated, hands-on learning, with a sparkle in their eye and creative spirit.

STEM learning is tailored for every curious learner who is ready to engage in fun and connected learning. Do not think that students are too young to do some activity and decide not to do it. Sometimes, it is not going as planned, even for the teacher. But with this, you can show to the students that things are not ideal all the time – so also this is a lesson they should learn. Next time they will try to solve the problem with some modifications and perhaps they will succeed.

a. Aims of STEM teaching approach

The STEM teaching approach is attractive to children, but it also provides them with soft skills, which cannot be transmitted through the usual academic approach. Students learn to solve the problems in the wider context and to apply knowledge in other situations. When faced with experiments or design challenges, students begin to figure out their role within a group. With STEM learning approach students get involved in:

- An experience → by doing the activity
- Share → by communicating and observing the results
- The process → by analysing and reflecting the experience
- Generalize → by comparing the experience to a real-world example
- Apply → by using what was learned in a distinct or similar situation



Source: Free stock images

b. Important skills for future development with STEM learning

The world is changing fast and most of the jobs of the future do not even exist yet. Students need to develop important skills and traits for future work, which will put students in a stronger position also when it comes to coping with other challenges, such as competing in a more globalised labour market and against global talent. Skills students develop with STEM learning: problem-solving, critical thinking, teamworking, independent thinking, communication skills, digital literacy and global competencies.
For example, imagine scientists and engineers - they regularly work in multinational teams to research critical global challenges. As online commerce platforms serve international customers, technology interfaces must address differing cultural norms. No matter what industry one is working in, being able to communicate and function in a team with people from different backgrounds is critical.

Try to use these actions in your classroom:

Asking questions, especially open-ended questions, gives a chance to apply what students have learned and build on prior knowledge, allowing them problem-solving and providing an opportunity to express themselves in front of their peers.

Encouraging decision-making enables students to apply their knowledge to different situations, weigh the pros and cons and decide which ideas work best.

Working in groups expands their thinking and worldview by demonstrating that there is no one right way to approach a problem.

Incorporating different points of view and connecting different ideas shows the aim to assess different points of view before an opinion is formed and apply knowledge in the new contexts.

Inspire creativity by searching for new ways to use the information and create something new. Students can construct inventions, write a story or poem, create a game, sing a song – there are no limits.

Brainstorming is an excellent learning tool, especially when paired with visual elements to encourage original thinking and classroom discussions.

Give the students **freedom of learning** – let students lead the activity as much as possible and the teacher can act as an expert guide on the topic.

Source: Free stock images

c. Different STEM teaching approaches

- Problem/case/project/inquiry-based learning

Students need to learn and practice the process as much as the teachers. Often, the misconception is that teachers and students can “jump in” and have a deep, meaningful experience.

● Problem-based learning

Students work in groups, identify what, how, and where to access new information that may lead to the solution of the problem. The role of the instructor is crucial in facilitating and guiding the learning process. Problem-based learning is better for long-term retention of material and developing ‘replicable’ skills, as well as for improving students’ attitudes towards learning and usually follows a strongly systematized approach to solving problems.

● Case-based learning

Students develop skills in analytical thinking and reflective judgment by reading and discussing real-life scenarios. It creates a collaborative learning environment where all views are respected.

● Project-based learning

It tends to be longer and broader than case-based learning, with more student autonomy and responsibility. Based on real-world problems gives students a sense of personal engagement and responsibility.

● Inquiry-based learning

Similar to project-based learning, but the role of the teacher is less active.

- Hands-on experiments

The use of hands-on learning for developing the knowledge and skills needed nowadays is very effective, it involves students being active and engaged. The goal is to build mental models that enable "higher-order" performance such as applied problem solving and information and skill transfer. Lesson plans should essentially focus on "making, producing, practicing, and observing" exercises rather than teacher-directed lectures. A key component is allowing students to share the outcomes of their experiences and self-evaluate their group performance. it is beneficial to ask, "If you could do the activity again, what would you do differently?" or "What improvements would you make?"

- Learning with new digital technologies

Implementing new digital technologies experiential learning can be fun, engaging, and accessible in partially or fully online learning environments.

Digital technologies can be applied in different contexts: by using online multimedia resources to create reports, presentations, research on the topic and asynchronous tools, e-portfolios, multimedia for reporting, playing educational games, using digital learning environments (laboratory, studio, working environments, field trips or visits…).

More effective in learning is active digital screen time, like playing an educational game or learning a new digital skill. It engages a pupil's mind or body that involves more than observation, on the contrary of passive screen time, such as watching a video or listening to an online lecture. Nearly all students say digital learning tools are fun and help them to learn things on their own.

Educators select digital learning tools that support student learning and meet learning standards. This applies the need for integrating digital learning tools and curriculums for better fitting and easier use in school classes.

- Integrated approach

Students do not see a separation between math, art, science or reading - educators teach them how to separate the classes. Nonetheless, if we take a more integrated approach, we can provide a well-rounded educational experience. Skilled teachers can carefully craft connections between subject areas that result in meaningful learning for students. Real-world problems are not limited to a discipline and solutions almost always draw from many fields.

2.4 Examples of activities: connection of theory and practice

Activities used in school lessons have to be easy and uncomplicated to perform in the classroom but always connected with real-life cases, problems and solutions.

The educator should lead the lesson adapted to the learning needs of the students. Educators have to be prepared to guide on the activity, its goals, and the development of learning.

Every learning skill is developed—skiing, cooking, writing, critical thinking, or solving mathematical problems—by practice: trying something, seeing how well or poorly it works, reflecting on how to do it differently, then trying it again and seeing if it works better.

Hands-on STEM activities are often time-consuming, but the STEM learning approach offers more than just learning details about the topic. Practical lessons show to the students that they are capable of getting knowledge themselves and giving them confidence and power to apply it in another context. Students should learn to do things rather than having them be told about what others have done. They should know that without experience you cannot learn. So, if you want to know something – TRY IT.

Before implementation – Role of the educator

- **Students population**: The educator must first identify what type of learners are in the class and how much experience do they have with the material and tasks. Each lesson has to be tailored to meet the needs of the students.
- **Facilitation**: The educator facilitates the process of learning and achieving activities' pre-defined goals. The role of the facilitator is to know where the activity starts and where it is intended to go, but not to define in advance what happens during the ongoing learning process.
- **Environment**: An area has to be designed with the activity. Different areas, where to work in groups, with the computer, other tools, areas to get dirty etc. should be marked. Marking can help also identify and locate the materials to do the activity process quicker.
- **Materials and Resources**: Working with recycled, reused materials sustainably with the environment adds value and engagement to the activity.

Implementation of STEM activity in action

The following text describes the implementation of the learning process in the classroom with example.

Imagine that in the next week, students will be taught in physics class about the forces. The teacher decides to work with students on a design challenge.
First, the teacher should plan how to do the activity and what materials to prepare for it. Preferred materials are already available at the school or home as straws, circular candies, bottle caps, twist ties, index cards, paper clips, paper, cardboard, popsicle sticks…

First, the problem has to be described. Teacher searches for the lesson plan and studies it – students will create the vehicle, which is driven just by the wind. The teacher prepares different materials students can use in the creation of their invention.
When the class starts, the teacher gives some introduction of what they will be doing today. Students are told to work in groups and their assignment will be to build the vehicle, which must move across the floor just by using the force of the wind, from the available materials. Then they form groups. Groups are spread out across the classroom. Let students do the activity on the floor or the table, how they prefer. There is no need for an ordered setting, except if the activity is dangerous in some way (working with chemicals, knives…).

The teacher explains to them, what process they should follow. At first, students look at the materials, what is available, and get an image in mind for the design of the vehicle. Then they start to create a sketch on paper or the whiteboard. Discussion with the members of the group, giving opinions, ideas, effective team-working should help to do the task easier. Then, they start to create the model, fit pieces together and see, if the vehicle is developing as planned. The next step is testing. If your vehicle passes the test, no part has fallen and it is moving as it should, think to do some specific improvements. If your vehicle breaks down, repair it and figure out what the problem is. Readjust, redesign and fit pieces together again. Is it better now? At the end of class time, the students gather to share their ideas with others and get feedback.

The teacher explains that this is the work of designers and engineers. They make changes to their models and try again. Some are successful while others head back to the previous idea and try with other improvements.

Examples of engaging activities that can be implemented in class

Source: Free stock images

1. Laboratory, workshop, or studio work

It gives students hands-on experience in choosing and using common scientific, engineering, or trades equipment appropriately while giving them a better understanding of the advantages and limitations of laboratory experiments. It enables them to see science, engineering, or trade work 'in action', test hypotheses and see how well concepts, theories, and procedures work when tested under laboratory conditions.

2. Develop a Makerspace

If students have the opportunity to visit a makerspace, they will use it in many different ways. Makerspaces within classrooms and schools can offer a hands-on workspace with a 3D printer, a laser engraver, a sewing machine, a recording studio, and other tools for those with an urge to create. Educators can prepare the lessons complemented with tools and materials offered there.

3. Students explore different themes connected with real-life cases

For example, try to explore climate change by performing an experiment that investigates the science behind the greenhouse effect. Or practice engineering by designing buildings or bridges that can withstand the effects of natural disasters.

4. Exploring technology

Technology is constantly evolving. Try to research older communication or recording devices (or even bring them in, if possible) and then compare them with currently available objects to showcase how much things change in a relatively short period.

5. Relate math to real life

You could have your class record gas prices in a few different areas over a certain period and then find the mean, median, and mode of the numbers, one of many relevant activities when you consider all of the everyday items and situations that evolve from STEM.

6. Incorporate online resources

The internet offers an abundance of valuable resources that can make STEM classes fun and interesting for students. From online courses featuring engaging video lessons to game-based apps that make learning an interactive experience, find something that feet in your classroom or present to students to have a look after the school.

Chapter 3: STEM method: a beneficial approach for all

3.1 Inclusion and Students with Specific Learning Disorders

Inclusion is defined as: “the action or state of including or of being included within a group or structure”. It is not a new concept, nor is it complex, yet it has received, in recent years, an increasing amount of attention, especially in the field of education. In this sense, the European Commission promotes inclusive education as such: “Everyone has the right to quality and inclusive education, training and life-long learning in order to maintain and acquire skills that enable them to participate fully in society and manage successfully transitions in the labour market.” (European Commission, 2017). In 2017, inclusive education became part of the European Pillar of social rights, which marked the importance of social, education and cultural dimension of EU policies.

In other terms, inclusion is about making learning and materials flexible, accessible, and understandable to all learners. It is about constantly rethinking the teaching process so that all students feel included in the practice. The idea behind “inclusion design” is to go back to the original design of the process and to build it in the most inclusive and efficient way for all.

Students with Specific Learning Disorders

Specific Learning Disorders are permanent conditions that affect the learning process. They have a **neurobiological cause** that affects the way the brain processes information: how it receives, integrates, retains, and expresses information. It can thus disturb the **cognitive development of a learning ability** but is in no way stemming from a physical impairment such as a visual or hearing impairment, a motor or intellectual disability. Nor is it due to an emotional disturbance, nor a disadvantage of the economic, environmental, or cultural nature.

Each SLD generates their own set of challenges that impact students school life:

- **Dyslexia** causes difficulties in reading and language-based processing skills. This is the most common disorder, and it is not rare to have it overlap with another one (phenomenon of co-occurrence). It can affect reading fluency, decoding, reading comprehension, recall, writing, spelling, and sometimes speech.

- **Dysgraphia** affects a person's handwriting ability and fine motor skills. It will often show as illegible handwriting. It can also lead to difficulties with: remembering specific orthographic combinations, spelling, spatial planning on paper, sequencing sentences into words, composing writing, or thinking and writing at the same time.

- **Dyscalculia** generally translates in difficulties with understanding math symbols, counting, memorizing, and organizing numbers, thus hindering them in calculus or abstract mathematical operations.

- **Dysphasia** typically manifests into difficulties speaking and understanding spoken words. This leads to challenges with oral exercises and presentations. It can translate into difficulty to "sequence sentences into words" when heard.

- **Dyspraxia** will cause issues with coordination, movement, language, and speech. It typically affects fine motor skills and muscle control (including eye control), which leads to problems with movement and coordination, especially hand-eye movements, language, and speech.

Additionally, it is important to note the notion of "Co-occurrence". Co-occurrence implies several disorders in the same pupil which greatly increase difficulties. According to the 2014 publication of the French National Institute of Health and Medical Research (Inserm), 40% of children with one "Dys", a Specific Learning Disorder, also have at least one additional accompanying Dys.

According to the European Dyslexia Association:
• 50 % of persons with dyslexia are dyspraxic as well.
• 40 % of persons with dyspraxia are either dyslexic or have attention disorders.
• 85 % of persons with dysphasia are dyslexic as well.

• 20 % of persons with dyslexia are having differences in attention with or without hyperactivity
• 50 % of hyperactive children are dyslexic etc.

Inclusion is a source of power. Students with learning difficulties are not ‘less intelligent’ or ‘less capable’ than others if they are not suited for classic teaching methods. Allowing them to express themselves, play on their own strength, nurturing their qualities and providing them access to education is beneficial for the entire classroom. How?

- Benefits for the students that need to be included

Being included allows learners with learning difficulties to develop skills that they will need to thrive in their future professional and personal life. They will be better equipped to face the challenges of a society that is not adapted to their needs, and they will be able to navigate through life more comfortably.

- Benefits for the other students

The inclusion of different profiles will broaden their horizon and will help them learn tolerance. This will also help learner focus on something else than ‘success at all cost’ and promote teamwork. Additionally, learners without SLDs will benefit from adaptation as learning is often more interactive, structured, and entertaining.

- Benefits for teachers

Inclusion of all profiles will lower the number of underachieving students and allow for a smoother and more efficient teaching process. By helping all students to follow, the rhythm of the class will be steadier, and the students will be less likely to fall behind. Adapting will also prevent ‘bad surprises’ if new students would come to struggle with specific topics.

- Benefits for society in general

Learners with SLDs might not display the usual “professional strengths” sought-after by recruiters, but they also have the potential to develop complimentary competences that are just as useful and essential. For example, they tend to be hardworking, to visualise things in 3D, to see links between concepts, and they are big picture oriented. Including everyone results in a more diversified pool of neurodiversity with a wider set of skills and competences and will give us a broader array of potential solutions to the problems of tomorrow.

Some basic tips and adaptations:

Structure: starting the lesson with an explicit explanation of the activity, a clear set of guidelines, and subdividing the tasks into small steps if necessary is advised. The use of visual elements to illustrate the concepts and bullet points to clearly structure processes is advised. Make sure to give enough time for each task and that all students understand the task beforehand.

Environment: should be quiet, but with enough multisensory stimuli to allow for in-depth learning. Space should be uncluttered and not overcrowded, to help with the students' spatial orientation and with their focus. It is also advised to avoid the necessity of long eye movement and to give special support to learners with tasks involving space management.

Tasks: multiple types of short exercises will help train the students to process different types of situations, by having them focus on one task at a time. It is better to focus on logic-based exercises rather than memory-based ones.
To reduce the instances of double-task mode, try to reduce the number of tasks requiring the use of fine-motor-skills, such as writing tasks, and to avoid difficult manipulations. This way, students will concentrate on the content of the lessons rather than on executing a supporting task.

Written materials: The formatting of written materials can be a source of challenge, and as such the text should be aligned on the left, in an adapted font for written guidelines such as Arial, Century Gothic or OpenDys with a spacing of **1.5 in between the lines**, in a font size that ranges between **12 and 14**. The use of paragraphs to break down the text into more manageable units with short, clear sentences is also recommended. The use of subtitles, colour (but be consistent with your colour codes) and bullet points can help with that.

3.2 Inclusion and Students from Migrant Backgrounds or Poor Socio-Economic Background

The EU Action Plan on Integration and Inclusion states that "integration and inclusion are key for people coming to Europe, for local communities, and for the long-term well-being of our societies and the stability of our economies." Indeed, population data of 2019 estimates that around 34 million inhabitants were born outside the EU (around 8% of the EU population) and 10% of young people (15-34 years) born in the EU have at least one foreign-born parent[iv]. Second-generation students accounted for 6% and first-generation migrant students for 5%. With 1 out of 10 learners coming from a migrant background, it is paramount that the educational system throughout Europe be as inclusive and integrated as possible. In other words, "A student who is well-integrated into the education system both academically and socially has more chance of reaching their potential." [v]

Consequently, findings have shown that learners from migrant background were found to achieve better academic results when they are well integrated in the school environment and are expected to perform well[vi].

Accordingly, students from migrant background tend to have lower socio-economic status, which in turn affect their performance as well. According to the OECD, migrants' decision to relocate to another country is commonly associated with a desire to improve their living standards. Yet, as a result of displacement, adjustment periods to host countries, and changes in living conditions, immigrants often endure economic hardship and precarious living conditions. This helps explain why, on average across OECD countries, students with an immigrant background tend to be more disadvantaged than non-immigrant students.

Factors enabling or inhibiting learners from success in education can be classified in 4 main categories[vii]:

- Individual characteristics
- Family and community characteristics
- School characteristics
- Education system and national characteristics

Individual characteristics

These set of factors is focused on the individual learners rather than its surroundings. Indeed, personal predispositions to specific situations can lead the learner to be more or less resilient in academic situation. These factors can encompass academic motivation and engagement, but also social skills and socio-demographics such as gender. They can also be based on the length of time the learner has spent in the resident country. For example, it is known that quality of education has a bearing on educational outcomes; hence, first-generation migrants arriving more recently from countries of poorer educational standing have less exposure to the typically higher quality education provided in their new country of residence[viii].

Family and community characteristics

In general, students who risk poverty and social exclusion are more likely to underperform and drop out of school early. They are less likely to continue their education following compulsory schooling. In the EU, 20.9 % of people were living at risk of poverty or social exclusion in 2019.[ix]
Children aged between ten and twelve tend to choose professions that are part of their social class[x]. It is important to take this into account if we want to motivate children from difficult-to-reach target groups, such as families with a low socio-economic status, to become interested in a STEM field. To improve the prospects of children and young people who experience barriers within their environment, it is important to improve pupils' self-confidence and to make it possible to discuss the restrictions they experience, consciously or not, in their environment.[xi]
It therefore does not come as a surprise that overall migrant students underperform and express a lower sense of well-being in school compared to native-born students in most European countries. As reported in the OECD's PISA survey of 2015, the proportion of low-achieving migrant students exceeds that of native-born students in most participating European countries, even when socio - economic status is controlled for (OECD, 2016) [xii].

The family and community characteristics can take the form of various factors such as the low socio-economic status (SES) of the family. The parental education but also the composition and cohesion level of the family. "Higher rates of upward social mobility have been noted among young people whose parents are together, as well as among young people where extended families play a role in everyday lives. This can be explained by the fact that there are more adults who can play a motivating and guiding role within the young people's lives, thus potentially steering them away from negative pathways"[xiii].

Lastly, the language spoken at home can also influence STEM learning outcomes. From understand instructions and guidelines, to parents helping with homework, the language level of the disadvantaged learner will play an important role in his success.

School characteristics

Learners from disadvantages backgrounds tend to attend schools that reinforce the inequalities in educational quality. Their schools suffer from a shortage or inadequacy of educational resources, including teacher preparedness, or where the concentration of disadvantaged students results in a poorer disciplinary climate. [1]

Accordingly, although expenditures for education increased in Europe, the share of science and technical programs graduates declined. The quality of education, measured with PISA scores has not been improved. These factors can also lead to the lack of interest in STEM subject, as, when mathematics and scientific topics are becoming increasingly abstract, that moment is key to keep learners engaged and interested.

Other factors in the school characteristics include the role of the teacher, which can prove paramount in motivating learners, increasing academic outcomes, dealing with academic adversity and values. In addition, a positive learning environment can also promote positive academic outcomes. Indeed, "an experience of academic adversity common to migrant and minority language students involves having to deal with prejudice and discrimination at school (and elsewhere). Such negative experiences can detrimentally impact migrant and minority language students' well-being and resilience".[xiv]

Education system and national factors

Despite having European education goals, approaches to disadvantages and education vary between school system and countries. There tends to be fewer achievement gaps in countries where substantial support for upward mobility (e.g., language support programs) exists, whereas in other countries, migrants have little or no access to public education.

In sum, past PISA results have shown that, beyond its association with socio-economic status, the lower average performance of immigrant students compared with that of non-immigrant students is associated, individually or in concert, with other factors, including language barriers, the concentration of disadvantage in the schools in which many immigrant students are enrolled, stratification policies that result in different opportunities for learning, and much more.[xv]

With so many odds stacked against them, it is easy to assume that learners from disadvantaged backgrounds will remain underachievers. However, studies have shown that disadvantaged learners have a core element that allows them to succeed regardless – their resilience. An “academically resilient” student is defined as student who succeeds academically despite facing education-related adversity, for example, low socio-economic status. To counteract these factors, new and inventive ways of teaching are paramount. As explained in the chapters above, whether it is through pedagogical innovation or role modelling, changing the way we approach STEM subjects is key. Lastly, it is noteworthy to mention that on average across OECD countries, PISA 2015 showed that the proportion of students who expect to work in an occupation that requires further science training beyond compulsory education is slightly larger among immigrant students (27.3%) than among non-immigrant students (24.4%).[xvi]

Conclusion

Research, data, and statistics gathered here have shown 3 main things:

1. There has been no significant increase in mathematics score since 2015,
2. There has been a decreasing interest in STEM careers over the years,
3. We can observe an almost stable yet decreasing trend in sciences scores and interest.

Whether it is due to demotivation, lack of practical knowledge in regular education, inadequate learning adaptation, or the gender and socio-economic gap, the conclusion remains the same; it is time to re-engage learners with STEM careers.

Indeed, STEM is one of the best weapons to answer today's societal needs and global challenges. Science allows for longer life expectancy, good health, and access to necessities such as water, food, energy... It also allows for improved communication, entertainment, medical and scientific advancement. In more urgent time, sustainable development and climate change are all deeply correlated to the scientific fields.

Ensuring that learners are involved, engaged, and interested in the STEM field from a young age is therefore paramount. There are a series of methods explored in this guide that can be applicable in classroom to convey positive outcomes. For instance, changing the way we teach STEM subjects. Indeed, using work based, contextual and practical environment to teaching stem can increase the pupil's engagement. In the same sense, using project-based and problem-based learning with specific learning outcomes allow for the learner to be curious, investigative, and overall implicated in his own learning.

Another method is to integrate STEM with Art (also known as STEAM). Pupils tend to engage more when there is a creativity component, which then changes the way problem-solving is done. Using hands-on, practical experiments can greatly help the learning process. Pupils can then visualize and clearly see the outcomes of their learning. Similarly, using innovative technology is key. It can enhance STEM learning experiences and investigations by using tools such as modelling, simulation, or by using educational apps, quizzes, augmented reality (AR), visiting different places with virtual field trips and more. Additionally, with the help of role-models, both male and female, learners can be inspired and delve deeper into exploring the STEM fields.

Ultimately, there are a wide array of new methods to teaching STEM that can develop specific skills that pupil needs to succeed in society such as: problem-solving, critical thinking, teamworking, independent thinking, communication skills, digital literacy, and global competencies. Consequently, encouraging reliable STEM engagement between students is important not only in preparing students for future careers in STEM, but likewise in strengthening students with 21st-century skills in general.

To this end, the Stembot project has for purpose to engage and increase student’s access to hands-on, practical STEM experiments. Using technology and a chatbot, learners will be able to experiment, watch videos, follow lessons, and discuss with an Artificial Intelligence about scientific topics relevant to their curriculum. This project combines a series of new teaching methods that can increase a learner’s engagement in STEM fields, as well as developing their skills to reduce STEM drop-out rates and increase STEM careers. The benefits of this project do not stop there. With a special focus on learners with specific learning disorders, and learners from disadvantaged background, Stembot will allow to these groups of learners to engage with STEM in the same capacity as their peers and avoid higher dropping out rates. The results will be accessible, free and adapted, which ultimately benefits all types of learners, regardless of their origins, socio-economic status or gender.

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Chapter 3

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