Enhancing STEM skills through Arts and mini-games

IO3 - BEST PRACTICES' REPORT IN COMBINING STEM, ART AND MINI-GAMES

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

Erasmus+ Programme: KA2 - Strategic Partnership - School Education

G.A.STEM, Grant Agreement Number 2018-1-FI01-KA201-047215

Elaborated by	Pixel Associazione
Activity related	IO3/A4 Output on the best practices collected and recommendations.
Deliverable N° and title	IO3 – Outputs and Recommendations on Arts and Mini-Games in STEM Education

Contents

1. What is STEM? What does STEM skills means?

It's widely accepted that the acronym STEM stands for "science, technology, engineering and mathematics."

According to the National Science Teachers Association (NSTA), "a common definition of STEM education […] is an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons as students apply science, technology, engineering, and mathematics in contexts that make connections between school, community, work, and the global enterprise enabling the development of STEM literacy and with it the ability to compete in the new economy"[1].

STEM skills are defined as those skills "expected to be held by people with a tertiary-education level degree in the subjects of science, technology, engineering and maths" (STEM)[2] [3]. These skills include "numeracy and the ability to generate, understand and analyze empirical data including critical analysis; an understanding of scientific and mathematical principles; the ability to apply a systematic and critical assessment of complex problems with an emphasis on solving them and applying the theoretical knowledge of the subject to practical problems; the ability to communicate scientific issues to stakeholders and others; ingenuity, logical reasoning and practical intelligence"[4] [5].

2. Rising STEMs

Despite the economic crisis, employment of physical, mathematical and engineering science professionals and associate professionals is around 12% higher in the European Union (EU) in 2013 than it was in 2000 and this trend looks set to continue. Vocational education and training (VET), including that provided at upper secondary level, is traditionally an important supply line for STEM skills, but there are concerns that the supply of STEM skills may be insufficient and constrain Europe's economic growth[6].

Demand for STEM professionals and associate professionals is expected to grow by around 8% by 2025, much higher than the average 3% growth forecast for all occupations. Employment in STEM-related sectors is also expected to rise by around 6.5% between by 2025, although this masks big differences between different sectors. For example employment in computing and professional services is expected to rise by some 8% and 15% respectively, while the pharmaceuticals sector is expected to see zero employment growth.

Having STEM skills is no longer sufficient on its own. Graduates at all levels, including those from upper-secondary VET, need personal and behavioral attributes as well as STEM-related skills[7]. Creativity, team working, communication and problem solving are needed as scientific knowledge and innovation is increasingly produced by teams that often combine different nationalities as well as different organizations and enterprises. Understanding the application of new technologies in everyday life presents new challenges. In many cases it is not enough that something works well. It should also be well-designed, stylish and desirable for more than just practical features.

---

[1] https://www.nsta.org/
[2] EU Skills Panorama Glossary at http://euskillspanorama.cedefop.europa.eu/Glossary/default.aspx?letter=S
[3] Chaniel Fan and Ritz (2014), *International views of STEM education*
[4] UK Parliament (2012), Science and Technology Committee – *Second Report: Higher education in Science, Technology, Engineering and* Mathematics (STEM) subjects
[5] UKCES (2011), *The supply and demand for high-level STEM skills*, Briefing Paper, December 2011
[6] BusinessEurope (2012) *Plugging the Skills Gap – The clock is ticking (science, technology and maths)*
[7] European Commission (2012) *Assessment of impacts of NMP technologies and changing industrial patterns on skills and human resources*

By 2025 around two-thirds of the anticipated job openings in STEM-related professions will be to replace people working in these areas but who will retire. Currently, around 48% of STEM-related occupations require medium (upper-secondary) level qualifications, many of which are acquired through initial upper-secondary level VET. This figure is forecast to fall a little to around 46% in 2025 but, despite the image of highly-educated scientists in white coats, most STEM-related occupations will still require medium-level qualifications over the next decade or so. Demand forecasts are difficult to make for highly competitive science- and technology-driven industries. STEM-related sectors such as pharmaceuticals, motor vehicles, engineering and other types of manufacturing are particularly exposed to the boom-and-bust of the economic cycle. Such sectors are also more prone to restructuring and outsourcing. That demand for STEM-related skills is likely to be highest in professional services reflects how the work has changed. In engineering, for example, work tends to be linked to projects for which external contract engineers are brought in as appropriate. Long-term employment with a single firm has been replaced by temporary assignments that can quickly end when a project ends or the market shifts. These factors affect short- and long-term demand for STEM workers and the skills they need.

Despite the rise and the demand of STEM skills, it has been observed in recent years that students are drawn away from Science Technology Education and Mechanics (STEM)[8]. This is due to the difficulty of the subject, the non-connection of what they learn to real life and the fact that students do not "learn" STEM. The only thing that they do learn is solving "some equations"[9]. The investigation of students' attitudes towards studying science has been a substantive feature of the work of the science education research community for the past 50 years. The increasing attention to the topic is driven by recognition that all is not well with school science and far too many pupils are alienated by a discipline that has increasing significance in contemporary life, both at a personal and a societal level[10]. As Osborne states in his review article, "while it would be difficult to transform the nature of science offered in most curricula, at least in the short term, a better understanding of the attributes of science classroom activities that enhance 'task value' might make a significant contribution to how the quality of students' experience might be improved".

For this reason, several approaches have been implemented so to facilitate students' approach towards STEM subjects. Amongst them, two revealed to be successful:

1. integrating art in the study of STEM, moving from STEM to STEAM
2. using more practical and challenging methodologies – like game-based learning – to teach STEM

3. From STEM to STEAM

Education policymakers went back to the drawing board and many influential educators started to champion the introduction of the Arts into the STEM movement. They believed that STEM focused on innovation, but missed elements that were crucial for innovation: design thinking and creativity. For this reason, the STEAM neologism was created. STEM represents science, technology, engineering and maths. "STEAM" represents STEM plus the arts – humanities, language arts, dance, drama, music, visual arts, design and new media. The main difference between STEM and STEAM is STEM explicitly focuses on scientific concepts. STEAM investigates the same concepts, but does this through inquiry and problem-based learning methods used in the creative process. This looks like groups of learners working collaboratively to create a

---

[8] Batzogiannis Ilias, Hatzikraniotis Evripidis, *Changing Students' Attitude towards STEM by Educational Robotics & Digital Games Programming*, International Conference New Perspectives in Science Education, 5th edition
[9] McDermott, L. C. (1991), *What we teach and what is learned—Closing the gap. American Journal of Physics*, 59 (4), 301-315
[10] Osborne, Jonathan, Simon, Shirley and Collins, Sue (2003), *Attitudes towards science: a review of the literature and its implications, International Journal of Science Education*, 25:9, 1049

visually appealing product or object that is based in the understanding of a STEM concept, such as the mathematics of the parabola used to create fine art imagery. STEAM is not a new concept: people such as Leonardo Da Vinci have shown us the importance of combining science and art to make discoveries. There was some debate amongst STEM enthusiasts who believed that studying 'Arts' would take away the emphasis on what they were trying to achieve with STEM. However, STEAM supporters explain that STEAM education explored the same subjects, but incorporated creative thinking and design into the STEM teachings.
The 'Art' in STEAM represents visual arts, social studies, history, physical arts, fine arts and music. Art is about using creativity and imagination to increase the development of STEM's essential skills, as well as enhance flexibility, adaptability, productivity, responsibility and innovation: all required skills for a successful career in any field of study. Educators state that STEM may be necessary for technological progress, but without the arts they believe that it is impossible for students to reach their full potential because art subjects give students the freedom to harness the capabilities of STEM subjects. It increases interaction, makes the STEM topics more enjoyable, thought provoking and increases student engagement. Slotting the arts into a child's STEM education have proven benefits such as increased creativity, improved academic performance, increased motor skills, higher decision making skills, better visual learning and an enhanced learning experience.

The benefits of integrating art in STEM education

There are several benefits of integrating art in STEM education:

1. **Increased Creativity**: in our society, technology is advancing and developing at lightning speed. Creative thinking skills are essential for innovation and keeping up with this ever changing industry. It teaches children to think outside the box and allows them the freedom to explore different designs and ideas that no one has thought about before.
2. **Improved Academic Performance**: a report[11] from the Americans for The Arts Foundation showed that students that took four years of arts and music classes while they were in high school scored an average of 92 points higher in STEM subjects than their counterparts who only had one year of art education.
3. **Increased Motor Skills**: educators from Stratford School[12] tell us that children who engage in creative arts and music classes from a young age are more likely to develop better hand-eye coordination, focus and fine motor skills which are essential for jobs that require a steady hand such as robotics.
4. **Higher Decision Making Skills**: allowing creativity and imagination to flow freely can lead to improving a child's problem solving skills as they learn how to interpret information and voice their ideas and opinions in a creative, confident way.
5. **Better Visual Learning**: the STEAM aspect of visual arts combined with scientific projects can help students reflect on their scientific studies through creating drawings or paintings. Not only does it make the project more fun and enjoyable for the student, but it can also encourage more focus, improve observation skills and can support problem solving skills. Manipulative visual arts such as sketching, photography, and origami have been reported to be effective for spatial intelligence, which is a crucial attribute of successful STEM professionals. Drawing activities help students learn quicker and more effectively.
6. **Enhanced Learning Experience**: studying STEM subjects can be intense and daunting for students who are unfamiliar or disconnected from these subjects. Involving the arts into STEAM projects can help students understand science, technology, engineering and mathematics in a different way, increase engagement when they connect the artistic mediums that they enjoy to these projects and allows them to explore these subjects in a non-pressured environment.

[11] Osborne, Jonathan, Simon, Shirley and Collins, Sue (2003), *Attitudes towards science: a review of the literature and its implications, International Journal of Science Education*, 25:9, 1049
[12] https://www.stratfordschools.com/stratford-blog/

4. Best Practices of combining STEM and Art

Art and science share many things in common and it has been suggested that their relationship may best be described as a continuum rather than one in which the negotiation of separate domains is occurring[13]. "Ironically, art and science differ most noticeably in the great trait they have in common: communication. While both art and science depend on successful communication, they differ in the direction in which they are communicating, as follows: Science begins with the physical, observable, the concrete occurrences in the world, and scientists generate abstractions that communicate their understanding of those phenomena. Artists begin with their abstract, often subjective perceptions, beliefs or feelings, and thereafter generate something specific and concrete based on those abstractions. Science creates new paradigms of thought and it is the process of creating an objective understanding of the world"[14]. The arts and sciences have the potential to develop new approaches by being implemented together in cross-disciplinary educational setting[15]. STEAM represents the best educational setting to combine science and art. In fact, imagination and creativity have always been at the cornerstone and joining factor between mathematics and art. These faculties have guided and sustained the science branches during the long millennial development, in which the assimilation from the students' side has always resulted in a certain degree of separation and difficulties. In view of the above, authors claim, that imagination and creativity are potentially capable to recreate the harmony of the integral (holistic) vision[16].

Since the art is a unifying element among different languages, it encourages the development of both cognitive and emotional dimensions and becomes an important element for the harmonious development and growing up of human being[17][18]. The current separation between science and humanities in school education has deep roots and stems from ancient concepts that led to the birth of the school system[19]. The results of this training are reflected in the overcrowding of the humanities departments in university and lack of professionals in science subjects[20]. In order to avoid the overcrowding of humanities departments and the lack of professionals in science subjects, the STEAM approach can be successful.

Arts, music, painting, dance, theatre, etc., help students connect better scientific subjects and reality by rediscovering their usefulness and their application in everyday life. Consequently, an innovative learning approach based on this new combination between logic and creativity is necessary, by giving up the past logic and critical distinction. Logic and creativity become essential elements in the learning path in both formal and informal education[21]. In particular, on the base of the theory of the Didactics Hexagon proposed by Guy Brousseau constituted of four elements (knowledge, learner/student, teacher and milieu), the art can be considered as the "context" or, referring the Author schema, the "milieu" to be used to reach knowledge. This allows students to reinforce their STEM knowledge through the arts to develop systems thinking based on applicable knowledge, imagination, creativity and problem solving skills. The artistic activity becomes a sort of prosthesis of the mind, a form of reasoning by which to promote interaction with the external world[22] which, as the mathematician J.D. Barrow claims, is well represented by the mathematical language that explains its nature and operation. Certain

---

[13] The ArtScience Interfaculty "Royal Academy of Art and Royal Conservatory in the Hague" See online access: http://www.interfaculty.nl/interfaculty/. 2015
[14] Rorie, A. Lecture Art&Science. See open access: (https://www.almostscientific.com/2010/03/23/lecture-on-the-relationship-between-art-andscience/, 2010
[15] Giedre Straksiene, Aleksandra Batuchina, Oded Ben Horin, *Science and Art: A Phenomenological Approach to Developing a Dialogue in the Educational Context,* International Conference The Future of Education, Edition 7
[16] Giedre Straksiene, Aleksandra Batuchina, Oded Ben Horin, *Science and Art: A Phenomenological Approach to Developing a Dialogue in the Educational Context,* International Conference The Future of Education, Edition 7
[17] Dallari M., *L'esperienza pedagogica dell'arte*, La Nuova Italia, Firenze, 1998
[18] Montessori M., *Come educare il potenziale umano,* Garzanti, Milano 1992.
[19] Berlin, *Il divorzio tra le scienze e le discipline umanistiche*, AA.VV., G.B. Vico, Roma, 1975
[20] OECD, *PISA 2012 Results in Focus: What 15-year-olds know and what they can do with what they know*, OECD, 2014. Retrieved March 13, 2017, from https://www.oecd.org/pisa/keyfindings/pisa-2012-results-overview.pdf
[21] Hofstadter D. "Gödel, Escher, Bach", Adelphi, Milano, 1979.
[22] Penrose R., *La strada che porta alla realtà*, Rizzoli, Milano 2011.

structures and certain real-world objects can be represented by a mathematical abstraction, and conversely, the mathematical world contains abstract notions that may be reflected as "examples" in the real world. Thus, the human accomplishments reflected in the art become attempts to break free from a binding concreteness. The art itself heads for the opportunity to represent dreams, ideas, and fantasies as math does[23].

There are two best practices' methods in combining STEM and art. The first method aims to introduce the art-works through a specific pedagogical approach, inspired to the three phases (concrete, pictorial and abstract) of the Singapore's method for mathematics study. The second method is recognizing mathematics in art-works[24].

Within the first method, the supposed teaching and learning method is based on the three phases (Concrete, Pictorial and Abstract), as defined in Singapore's method[25] applied to mathematics study that can guide students to the discovery of the challenging connections between math and reality. The concrete phase is the first step of the pathway focused on the object manipulation, passing through the visual representation of the topic studied. Through the second phase, which is the pictorial one, students will reach the abstract representation, third phase. Students learn mathematical subjects by discovering that different relationships exist among things or math concepts and by developing, accordingly, problem solving skills yet avoiding just memorizing the solution procedure. They are supported by the worksheets providing instructions to lead the student from the concrete phase to the pictorial, and up to the abstract one (didactical situation). The use of the modeling program, like Geogebra, in the concrete phase, has allowed students to explore and understand mathematical concepts through the help of visualization and virtual object manipulation (Fig. 1). Therefore, students learn and familiarize themselves with the specific objects' construction, e.g. a dodecahedron[26]. This helped students to reinforce their visualization skills, modeling the real world problems and making connections between the real world and mathematics.

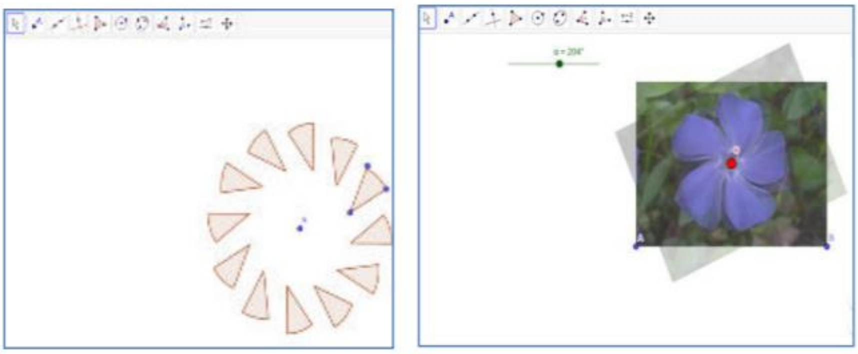


Fig.1: Visual Modelling Programming – Examples of symmetry study – Geogebra

The aim of the second method identified is to reinforce student knowledge in mathematics through the use of specific art-works which support the development of systems thinking based on applicable knowledge, imagination, creativity and problem-solving skills. A practical approach would be involving students to recognize mathematics in the art-works, working in groups and individually. For example, they can be asked to find the art works containing dodecahedron shape, such as in "The Portrait of Luca Pacioli" of Jacopo de' Barbari (around 1500 A.D.) as shown in the Fig. 2.

[23] Eisner E. W., *The arts and the creation of mind*, Yale University Press, 2004
[24] Michela Tramonti, Arts and STEM for Social Inclusion, International Conference The Future of Education, Edition 9
[25] Ministry of Education Singapore, *The Singapore Model Method for Learning Mathematics*, Marshall Cavendish Education, pp. 1-13, 2009
[26] G. Brousseau, *Theory of didactical Situations in Mathematics*, New York, Kluwer Academic Publishers, 2001.

Fig. 2: Dodecahedron contained in “The Portrait of Luca Pacioli” of Jacopo de' Barbari.

5. Game-based learning

Games have been used as a learning tool for centuries. Chess was used to teach strategic thinking as far back as the Middle Ages, and the game of Kreigsspiel was invented in 1812 specifically to teach Prussian officers strategy. Beyond military strategy, the genesis of Kindergarten in the mid-1800s was Friedrich Fröbel’s ideas of learning through play. The core concept behind game-based learning is teaching through repetition, failure and the accomplishment of goals. Video games are built on this principle. The player starts off slow and gains in skill until they’re able to skillfully navigate the most difficult levels. Games that are planned and designed well will offer enough difficulty to keep it challenging while still being easy enough for the player to win. Game-based learning takes this same concept and applies it to teaching a curriculum. Students work toward a goal, choosing actions and experiencing the consequences of those actions. They actively learn and practice the right way to do things. The result is active learning instead of passive learning. Game-based learning describes an approach to teaching, where students explore relevant aspect of games in a learning context designed by teachers. Teachers and students collaborate in order to add depth and perspective to the experience of playing the game[27].

Karl William Kapp[28], Professor of Economics at the City University of New York and later at the University of Basel, provides a thorough analysis of game dynamics implementation in the educational process:

- game-based learning facilitates learning by laying its foundations upon the game: the process is more easily followed while the concepts are assimilated;
- the game creates a virtual environment that recreates realistic situations. In this way, users (students) learn to function in a safe context, but with rules, interactivity and feedback;
- students accept rules more easily in a playful environment: following certain rules, students can advance and succeed in the game;
- it is an efficient training tool because it incorporates gaming elements: challenges, fantasy, motivation, easy achievement metrics (levels, ranking, score), as well as satisfaction by the achievement of goals.

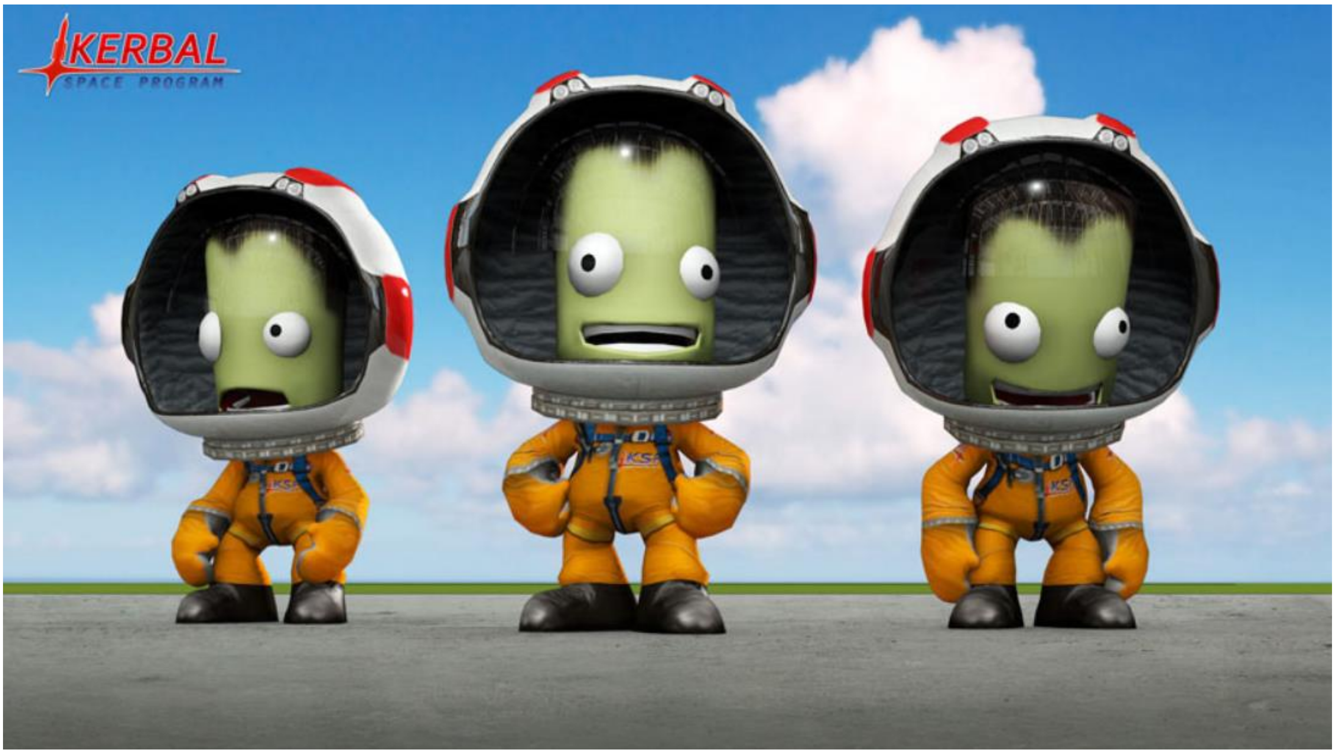
[27] Anna-Maria Markova, Teodora Gechkova, *Let’s Play - The Gamification Method in Education,* International Conference The Future of Education, Edition 9

[28] Kapp,Karl, *The Gamification of Learning and Instruction. Game-based methods and strategies for training and education*, Kapp, Pfeiffer; 1 edition 2012

Karl William Kapp distinguishes between two types of motivation: intrinsic and extrinsic. The first occurs after a certain activity is performed; the second, extrinsic, is the behavior specifically aimed to getting a reward. The best game-based learning is the one that has both types of motivation.

6. Best Practices of combining STEM and game-based learning

One of the best examples of combining STEM and mini-games is represented by Kerbal Space Program[29].



Kerbal Space Program is somewhat like a NASA simulator except for the fact that it is set in a fictional star system on the planet Kerbin. Players purchase various rocket parts, put them together, and then see if they can get their ship into orbit, to one of Kerbin's two moons, or even to another planet. The star system closely resembles our own, but the planet is populated with cute green characters reminiscent of the minions in the movie Despicable Me.

The game has three modes: Career, Science, and Sandbox. In Career mode, players manage and expand their own space center, researching new technologies and going on missions. The Sandbox mode is open-ended; students can learn to fly without restrictions. Science mode lies somewhere between the other two modes in terms of freedom. Some other activities include managing a budget, going on expeditions outside the ship, docking spacecraft, and discovering new worlds. What emerges from all these features is a series of unique, self-designed experiences that highlight the trials and tribulations of space flight.

In Kerbal Space Program, students set goals, build rockets, evaluate mission results, change designs, and try again. It offers a solid simulation of astrodynamics and physics, and students who take the time to observe flight readouts and toy with the ship's trajectory will learn fundamentals of rocket science and realistic, modern-day space flight.

[29] Simona Romaniello, *The Use of Storytelling, Coding and Gamification for Teaching STEM. Two Case Studies*, International Conference New Perspectives in Science Education, 10th edition

Since it's tough, students will also need to help each other or watch player-created video tutorials and read forums for tips. In short order, students will be able to say, “Well, actually, it is rocket science,” just before explaining that it's most efficient to adjust a ship’s trajectory at the apoapsis or periapsis of its elliptical orbit. Students learn that small differences like this mean greater fuel efficiency and the difference between reaching mission goals or crashing and burning.

Given Kerbal Space Program's accurate modeling of rocket construction and the underlying calculus, Newtonian physics, and trial-and-error processes that ground rocket science, it could easily integrate into math, physics, or engineering classrooms. For instance, teachers could supplement a physics lesson on forces and angular momentum with homework in Kerbal Space Program, asking students to achieve orbit and record the stats of their rockets for comparison.