DIRECTORATE GENERAL FOR
INNOVATION AND EDUCATIONAL
TECHNOLOGIES

EDU SIM STEAM

STEAM Strategies for Best Practices

2023

EDUSIMSTEAM | Erasmus+ KA3 Forward Looking Cooperation Project

With the support of the Erasmus+ Programme of the European Union

Document Control Page

Title	:	STEAM Strategies for Best Practices
Version	:	Report
Publishing Coordinator	:	D2.4
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Year of Delivery	:	2023
Dissemination level	:	Public
Organisation	:	Ministry of National Education / Directorate General of Innovation and Educational Technologies
Licence		Creative Commons

Introduction

This document will provide practical points for STEAM teaching strategies for teachers. It will also clarify principles for successful STEAM education and guide teachers in their classroom practices and implementations. Furthermore, this document will discuss robotics education, and define robotics education in terms of STEAM literacy in the scope of the EDUSIMSTEAM project. Finally, the document will highlight the importance of STEAM scenarios, explain comprehensive design principles of the scenarios in WP-4 Innovative Online Platform, and reveal a sample scenario from WP-3 Learning Scenarios for Schools in tune with the comprehensive design principles of the scenarios.

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Teaching Practices in STEAM Education

Teachers who hold knowledge and pedagogies associated with different STEAM disciplines help students apply STEAM practices. Students gradually build an understanding of core STEAM ideas and practices throughout their education. According to the Scientix Observatory Report (Nistor, Gras-Velazquez, Billon & Mihai, 2018), teachers use the following pedagogical approaches and teaching strategies most commonly in educational settings to organise their STEM teaching.

Table 1. Pedagogical Approaches in STEM Education

No	Pedagogical Approach	Definition
1	Traditional direct instruction	Lessons are focused on the delivery of content by the teacher and the acquisition of content knowledge by the students.
2	Teaching with experiments	Experiments are used in the classroom to explain the subject matter.
3	Project/Problem-based approach	Students are engaged in learning through the investigation of real-world challenges and problems.
4	Inquiry-Based Science Education	Students design and conduct their own scientific investigations.
5	Collaborative learning	Students are involved in joint intellectual efforts with their peers or with their teachers and peers.
6	Peer teaching	Students are provided with opportunities to teach other students.
7	Flipped classroom	Students gain the first exposure to new material outside of class, and then use classroom time to discuss, challenge and apply ideas or knowledge.
8	Personalised learning	Teaching and learning are tailored to meet students' individual interests and aspirations as well as their learning needs.
9	Integrated learning	Learning brings together content and skills from more than one subject area.
10	Differentiated instruction	Classroom activities are designed to address a range of learning styles, abilities and readiness.
11	Summative assessment	Student learning is evaluated at the end of an instructional unit and compared against a benchmark or standard.

12	Formative assessment, including self-assessment	Student learning is constantly monitored and ongoing feedback is provided; students are provided with opportunities to reflect on their own learning.

All pedagogical approaches help teachers to improve the overall quality of STEAM teaching practices in their classroom.

Principles for Successful STEAM Education

STEAM education initiates critical thinkers, enhances science literacy, and facilitates innovators. Teachers have a crucial role to build up this innovation and science literacy but mostly they need help on how to operate STEAM education in their classrooms. According to the Best Practice Guide in The National STEM School Education Resources Toolkit (The Australian Government Department of Education, 2019), there are eight principles for teachers to apply in STEM education. Not every principle will be appropriate in every situation, but each will provide strong guidance.

1. Use inquiry-based learning:

The approach fosters investigation and problem-solving. Thanks to this approach, students learn key STEM and life skills through inquiry-based learning: social interaction, exploration, argumentation, comfort with failure. For example, teachers build active learning into teaching practices through problem-based scenarios to encourage students to think critically.

2. Solve real-world problems:

Students tackle real-world STEM problems from businesses and the community. Real-world problems demonstrate the relevance of STEM; it can enhance student motivation and interest. To illustrate, a teacher asks his/her local council or a local business for a challenging problem they're working on. Then, the teacher takes it to his/her students and sees what they come up with.

3. Teach integrated STEM learning:

Integrated STEM learning combines the subject matter of two or more STEM subjects into a joint learning experience. It supports cross-disciplinary STEM skills; can enhance student interest. For instance, teachers can teach Science using an Engineering process (design-based learning) which is a series of steps that you repeat to develop or improve a product, process or system.

4. Equip and empower teachers:

Equipping and empowering teachers means providing them with the right resources (e.g. high-quality professional learning opportunities, up-to-date technology) and skills to teach best practice STEM education. Thus, teachers have the greatest influence on in-school achievement and engagement in STEM. In addition, it will be a good strategy to connect a STEM teacher with a STEM mentor from a local business.

5. Create partnerships between schools, businesses and community:

Schools, businesses and other organisations create STEM education initiatives to improve student outcomes. This situation helps students to be exposed to the workplace, inspires enthusiasm about STEM and enhances and complements the curriculum. By way of illustration, teachers should choose partners to work with on a STEM problem, and to reach out to schools, businesses, museums, local councils and government.

6. Use technology as an enabler:

Selective use of technology to support high-quality teaching and learning accelerates student learning, increases confidence and ability in using technology. Teachers can get students to program a technology instead of showing them what something does.

7. Differentiate for different levels:

Learning is tailored to the needs and abilities of individual students, and teachers support all students' needs regardless of starting point. As a suggestion, teachers can assess student capability formally and informally so lessons can be tailored.

8. Link education to 21st century learning:

Teachers build in the development of 21st century skills such as critical thinking, creativity, communication and collaboration in STEM education because 21st century skills are highly valuable for students' future careers. The skills encourage teamwork and healthy debate. Teachers can let students 'play' with the subject matter.

EDUSIMSTEAM project supports teachers, learners and all stakeholders to apply the eight principles in STEM education. WP3 Scenarios Development is related to Principle 1 - Use inquiry-based learning, Principle 2 - Solve real-world problems, Principle 3 - Teach integrated STEM learning, and Principle 8 - Link education to 21st century learning. Scenarios based on cross-disciplinary STEM skills aim to develop learners' 21st century skills, and help learners to solve real-world problems and use inquiry-based learning. In the scope of WP2-Pilot Teacher Training Platform, we create STEAM Framework for Teacher Training and we manage pilot teacher training related to Principle 4 - Equip and empower teachers. In addition, Pilot Teacher Training Platform supports Principle 6 - Use technology as an enabler. Furthermore, the project is based on Principle 5 - Create partnerships between schools, businesses and communities. All stakeholders will also be reached in the process of WP7 Project Evaluation and Dissemination. WP4 Innovative Online Platform (IOP) developed in the scope of the project is associated with Principle 6 - Use technology as an enabler and Principle 7 - Differentiate for different levels. The platform supports learners to practise technology in accordance with their needs and levels. The project researches teachers' perceived most important 21st century skills for STEAM education in tune with Principle 8 - Link education to 21st century learning in WP-1 Need analysis report document.

Robotics Education

EDUSIMSTEAM project brings robotics education as a part of STEAM education into the forefront within the scope of WP-4 Innovative Online Platform and WP-2 Pilot Teacher Training Platform. Robotic based tasks on the platform will interest students and teachers who will create their robots and help them move and fly based on nature physics rules. In addition, robotic literacy and algorithmic thinking activities and all relevant e-contents will be included in this platform for the students and the teachers who have completed the required training will be able to help students gain the robotic literacy and algorithmic thinking skills. This platform will be complimentary to teacher training modules, so any teacher completing teacher training can use this IOP in classes with students. Moreover, the use of robots in the platform can increase student motivation and encourage persistence when students encounter challenging and complex learning scenarios.

"Robotics can be a gateway to learning applied mathematical concepts, the scientific method of inquiry, and problem solving" (Bers, 2010, p. 2). The content areas of the robotics are as follows: (1) concept (knowledge) domain; (2) practice (skills) domain; and (3) attitude (disposition) domain (Jung & Won, 2018). In concept (knowledge) domain, a large portion of the content is directed toward robotics-intensified knowledge and skills like knowledge of robots (e.g., physical parts of robots, functions of parts of robots) and understanding of systems of robots as components of robotics education (Mioduser, 2012; Mioduser, Levy, 2010). The knowledge domain is closely related to robotics practices (such as designing, constructing, operating, and applying robots and robotic systems) (Ross, Fardo, Masterson, Towers, 2011). A consideration of the practice domain, problem-solving process, engineering design process, and scientific inquiry skills characterise robotics education as a part of STEAM. The attitude domain of robotics has been defined as a cluster of general good things. For example, collaboration as an interpersonal attitude is the most common component that almost every STEAM discipline stressed (Zeidler, 2016; DeJarnette, 2012). However, the attitude domain of robotics education needs to be developed more specifically in connection with robotics-specific knowledge and practice.

Defining Robotics Education in Terms of STEAM Literacy

Robotics education is promoted as an important piece of STEAM education because it introduces students to complex mathematical and scientific thinking. Robotics is regarded as two perspectives in educational context which are illustrated in the figure 1: The first one is that robotics is a technological environment to teach other subjects, and the second one is that robotics is a tool to teach itself (Jung & Won, 2018). Both perspectives should be discussed under STEAM education. The first view, robotics education as a part of STEAM education, is based on the interdisciplinary nature of robotics, and robotics shares common teaching contents and objectives with STEAM education. The second view, robotics education as a subject, focuses on many common knowledge and skills with STEAM education such as subject-oriented knowledge (e.g., knowledge of physics) and cognitive skills (e.g., analysing, classification, and prediction) but also has distinct teaching contents and features. In fact, it is not easy to differentiate between the two perspectives. In the EDUSIMSTEAM project, we focus on the first perspective: robotics education as a part of STEAM education.

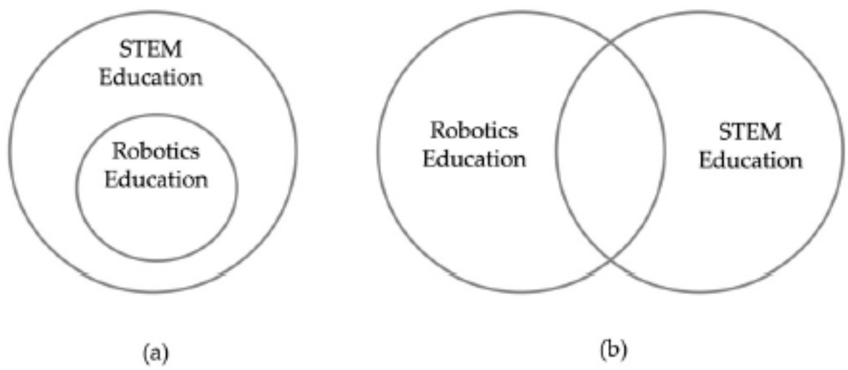

Figure 1. (a) Robotics education as a part of STEAM education; and (b) robotics education as a subject.

A Model of STEAM Scenarios Development

Learning scenarios help the students to make sense of all the work they will do in order to develop their robotic literacy and algorithmic thinking skills in a certain context. Rather than being limited to acquiring a few terms and information on robotic coding, the studies enable students to associate robotic coding with real-life skills through scenarios and use 21st century skills such as problem-solving and creative thinking, etc.

Robotics tasks as a part of STEAM education in the scenarios are presented in a functional environment— that is, an environment that combines problem-solving scenarios and explorations that make authentic use of STEAM skills (Pea, 1987). In a functional environment, students are challenged to identify and solve complex problems by testing and retesting their programming of the robot. While the robot serves as a concrete external embodied representation of students' thinking (Han, 2013), students must also engage in abstraction as they think through and program the physical movement of the robot. Such activities are important for STEAM education because they help students develop the confidence and persistence needed to deal with ambiguous problems and collaborate and engage in rigorous academic discussions with peers (Barr et al. 2011).

Pedagogical Model for STEAM Scenarios in WP-4 Innovative Online Platform (IOP)

In a functional environment, content from multiple STEAM areas (e.g., math and science) is contextualized and applied through the robot to solve an authentic problem and engage students in computational thinking. It is the integrative nature of the approach that has the potential to improve robotics education. STEAM scenarios are developed in three phases* which begin with a thorough analysis and exploration of the literature (Phase 1). Next, STEAM scenarios are designed and operationalized (Phase 2). Finally, the scenarios are tested in the IOP and evaluative data will be collected, analysed, and reflected upon (Phase 3). A description of each phase is provided below.

**The three phases are adapted from the study "Developing an Integrative STEM Curriculum for Robotics Education Through Educational Design Research" (Kopcha, Mcgregor, Shin, Qian, Choi, Hill, Mativo, Choi, 2017).*

Phase 1: Analysis and Exploration

A review of the literature on STEAM education and computational thinking yielded a specific set of three comprehensive design principles to guide our education process: (a) create a functional environment, (b) embed opportunities for learning scenarios, and (c) integrate multiple STEAM standards into the innovative online platform.

Functional environments typically involve an authentic problem in which learners contextualise learning around a complex, open-ended problem. Such problems create an opportunity for learners to engage in productive failure. Productive failure is the knowledge that forms when a learner attempts a problem, fails, and has to construct a new potential solution based on the failed results (Tawfik et al. 2015).

Robotic scenarios engage the learners in the use of robotic technologies for the development of one or more learning objectives, skills or competencies in formal or informal contexts. Scenario creation for robot-based learning refers to the practice of teaching in which students use online robots to build knowledge for the robots themselves or with the help of science attainments.

An integrative STEAM standard would therefore make connections between the STEAM subjects; it would teach students to apply their integrative knowledge to solve a real-world problem in an authentic situation using hands-on, technological tools, equipment, and procedures in innovative ways (Wang et al. 2011).

Phase 2: Design and Construction

Scenarios comprise of a series of eight steps. Table 2 contains the complete objectives by step. Several objectives aligned with multiple STEAM disciplines and spanned multiple lessons, including applying mathematical concepts (i.e., decimals, coordinate algebra) to the robotics practices, engaging in the engineering design cycle (i.e., identify constraints, generate potential solutions, test and revise solution based on results), and drawing on science knowledge to understand the problem and solution.

Table 2. Design of the scenarios

Steps	**Objectives**
Descriptive information	• Describe scenario theme, grade level and duration
Real-life scenario setting	• Identify problem goal, constraints, and possible solutions
Task	• Follow the steps of the given task • Perform the steps in the engineering design process • Define technical information (if needed) • Identify the mechanical components of the robotics • Practice robotics for the given task
Prerequisite skills & STEAM Learning Outcomes	• Enhance prerequisite skills • Explore the STEAM outcomes of the task
Activity Process	• Promote innovative practices in robotics education as a part of STEAM education • Engage in the engineering design process (e.g., plan, test, evaluate, and revise) • Develop and run an algorithm • Practise their robotics to follow basic commands

	• Use/Apply mathematics (decimals, measurement, and coordinate algebra) to optimise programming and planning • Act out the basic programming commands • Determine their best problem solution
Assessment	• Provide an opportunity for reflection • Explain and justify their approach to solving the problem • Share their results with peers • Engage in discussions around programming challenges
Career Connections	• Lead into future career paths
Materials & Related Resources	• Determine materials, online tools and related resources

The eight steps were organised such that descriptive information of the scenario was presented (step 1). Learners were first introduced to an authentic STEAM context for solving a rich, open-ended problem (step 2). Later, tasks were introduced (step 3). After that, skills and outcomes were clarified (step 4). The lessons then led students through the robotics practices, exploring potential solutions to the problem, and finally using mathematics to generate and present a final solution to the problem (steps 5). Next, an assessment procedure was carried out. The scenario stressed career connection (step 7). Finally, materials and related resources were clarified (step 8).

Phase 3: Evaluation and Reflection

Learners and teachers reflect their experiences related to the scenarios and the online platform in the evaluation process.

A Sample STEAM Scenario from WP-3 Learning Scenarios for Schools

A scenario is developed in three phases - Phase 1: Analysis and Exploration, Phase 2: Design and Construction, and Phase 3: Evaluation and Reflection - which are described below:

Phase 1: Analysis and Exploration

It is carried out a review of the literature on STEAM education and computational thinking yielded a specific set of three comprehensive design principles to guide our education process:

(a) create a functional environment – There will be functional environments on the IOP like Street Lighting in a Smart City, Waste Collection in a Smart City, Mission to Mars, etc. which present complex and open-ended problems for the learners.

(b) embed opportunities for learning scenarios - There will be several scenarios based on the functional environments to use robotic technologies and build knowledge for the robots. For example, there are 6 scenarios based on the functional environment - Street Lighting in a Smart city.

(c) integrate multiple STEAM standards into the innovative online platform – All scenarios and functional environments will be integrated on the IOP by applying their STEAM integrative knowledge to solve a real-world problem in an authentic situation.

Phase 2: Design and Construction

"Scenario 1: Detecting Inefficient Street Lighting" is comprised of a series of six steps:

Step 1- Descriptive information:

Description	:	Design a device that will determine the areas having inefficient lighting.
Theme	:	Street Lighting in a Smart City
Grade Level	:	Middle Schools / Junior High Schools (Ages 10 to 14)
Duration	:	2 class hours

Step 2- Real-life scenario setting:

Considering factors affecting the design and use of a thriving street lighting system in the city, DRDI thinks that the first step of SCMP related to new lighting project should include the decisions of the areas that have inefficient (too much or little) lighting in the given street and determine the factors that can affect the amount of lighting on the streets. This process will help determine the problems in street lighting and develop sustainable and effective solutions for your city's digital transformation.

Suppose you will be a team member at the DRDI office and responsible for turning your city into a smart city with a new lighting project. Your team will have several tasks towards smart street lighting in the city by developing an adaptable lighting plan and implementing your lighting solution on the robotics simulation program.

Step 3- Task

In this activity, the task of each team is to:

a. Observe the lighting on the streets given in the simulation environment.
b. Determine the improper lighting spots by using light sensors.
c. Report light levels by numerical values. You can compare the light levels on your streets with the acceptable light levels (given information in the technical part).

d. Prepare a report and present it to the other teams of DRDI.

Technical Information

Did you ever walk on a poorly lighted street, too dark or too bright? It is important to adjust light levels appropriately to walk safely on the street for people and minimise light pollution for the environment. There are many factors that specialists pay attention to when designing light poles, such as pole height, the shape of the lamp, etc. From a physics aspect, there are several terms that we need to know to understand lighting:

Luminous flux: refers to the rate of light emitted from a light source per unit of time. It is measured in lumen (lm) and represented by φ.

Luminous intensity: Light sources emit light in different directions with different amounts. Luminous intensity refers to luminous flux but in a specific direction. It is measured in candela (cd) and represented by I.

Illuminance: It refers to the amount of light that reaches a surface. This term indicates if a surface is lighted appropriately to walk, ride, drive, etc. It is measured in lux (lx) and represented by E.

As you can see, to design or investigate a light pole, if it is appropriate or not in terms of light level, we need to consider illuminance. For medium-density streets, including pedestrians and cyclists, illuminance should be at least 7.5lx. This value can increase according to the density of street usage. For example, 50lx can be appropriate for roads with heavy traffic conditions.

Step 4- Prerequisite skills & STEAM Learning Outcomes

Prerequisite Skills

- Investigate the proper and appropriate outdoor lighting conditions
- Understand that light travels through straight paths in all directions

STEAM Learning Outcomes

Science

- Use luminous flux, luminance, and illuminance in explaining lighting.
- Determine light pollution.

Technology

- Use a light sensor
- Use led or buzzer module
- Use branching module
- Create flowcharts in the simulation environment
- Run an algorithm

Engineering

- Make designs for street lighting poles and fixtures

Arts

- Gain awareness on light pollution
- Gain awareness on energy consumption
- Gain environmental awareness

Mathematics

- Use ratios and proportions

Step 5- Activity Process

Teachers are recommended to follow the following steps:

- Encourage students to carefully read the task statement and brainstorm about lighting conditions around their neighbourhood. Ask students:
- Have you ever thought about lighting conditions on the streets? Do you come across streets that have poor or excessive lighting conditions?
- Do these poor or excessive lighting conditions cause problems? What kind of problems can they create for both pedestrians and drivers?
- What are the factors that may affect light levels?
- Guide students to set up a sensor that can be used to measure light levels in various places on the map.
- Ask students to use and determine inefficient lighting areas on the map.
- Ask students to determine the factors that affect light level when they move the sensor around a light pole.

Step 6- Assessment

The following question can be considered for formative assessment purposes:

- What are the definitions of luminous flux, luminance, and illuminance?
- What are the units of these terms?
- What are the definitions of these units?
- What is the term used for light level?

The following are expected from students:

- Develop a sensor that can measure the illuminance of several points on the map in the simulation environment.
- Write and share a report on the lighting issues on the map using technical terminology appropriately.

Step 7- Career Connections

City and Regional Planning, Electric and Electronic Engineering, Earth and Space Science, Environmental Engineering

Step 8- Materials & Related Resources

Materials

The Simulation environment including a street map and light sensors

Related Resources

Project for Public Spaces. (2008). Lighting Use & Design. https://www.pps.org/article/streetlights.

Römhild, T. (2017). (rep.). Dynamic Light Handbook about Interpretation of En 13201. European Union. Retrieved from https://www.interreg-central.eu/Content.Node/Dynamic-Light/04-DL-Handbook-about-interpretation-of-EN-13201.pdf

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