PROTOCOL FOR TEACHERS

Protocol for teachers illustrating the methodological framework of STEAM-based approach with active teaching strategies

Project Result 1

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Project Result 1 - Protocol

Part 1. Introduction. Definition and characteristics of STEAM

1.1 History of STEAM education

In the early 1990s, the US National Science Foundation (NSF) adopted the acronym 'SMET' to group together the science, mathematics, engineering and technology disciplines as university departments, job categories and industries (Lyons, 2020). The order of the disciplines in the SMET acronym was intended to show the value of the disciplines, with science and mathematics being the most important. The order was later changed to STEM to improve the sonority and to highlight the centrality of engineering (Simarro, 2019). Likewise, when we talk about STEM as a simple term, we are referring to the field in which scientists, engineers and mathematicians work, but if we want to refer to education, we should use STEM education (Sanders, 2009).

Many historical events gave rise to the STEM movement and STEM education, but the most notable are the Second World War and the launch of Sputnik 1. The technological development during the Second World War was immeasurable, for which people from science, engineering and mathematics worked side by side. Towards the end of this first era, the NSF was formed (1950) in order to recognize and preserve all the contributions and research carried out (White, 2014). On the other hand, the launch of Sputnik 1 in 1957 by the Soviet Union marked a turning point in the attitude of the United States towards the aforementioned disciplines, as they saw their role as a world power endangered (Simarro, 2019). Sputnik 1 became a matter of national defense and in 1958, Congress passed the "Space Act" which formed the National Aeronautics and Space Administration (NASA). NASA's mission was to "expand and improve" America's space presence and to use science and engineering in the most effective ways to complete that mission. Along the same lines, a series of educational changes were implemented with the intention of improving outcomes in science and technology fields that would later lead to STEM education (White, 2014).

At the European level, these educational changes were mainly driven by the curriculum development provided by the Nuffield Foundation projects in 1960. Thus, the link between science, technology and society was gaining importance at the educational level with projects such as Science-Technology-Society (STS or STS), Science in Society or SISCON defining the principles of what would later become known as STEM education (Ratcliffe, 2001).

Although STEM was formed in the early 1990s, the expansion of the STEM education movement began in 2009 due to the needs outlined by the National Governor's Association which defined the need for a STEM identity in the citizenry as a means to maintain US economic competitiveness (Perales & Aguilera, 2020). Consequently, the integrative vision proposed by STEM education occupied the space taken by other previous movements that followed the same line. Among them, the most notable is the Science, Technology and Society (STS) movement (Lyons, 2020).

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As Perales and Aguilera (2020) explain, the relationship between STS and STEM and their use in education is the subject of debate in which different authors discuss the origin, characteristics and applications of each. According to MacKinnon et al. (2017) the STEM education movement has evolved from the integrated STS curriculum initiative of the 1990s and the need for technological literacy that integrates the engineering point of view. Thus, the main difference that stands out between STS and STEM is the role of society in each. In the first case, S for society refers to culture, environment, gender and innovation, making explicit the integration between science, technology and society. In contrast, when we talk about STEM, the importance of the integration of disciplines is emphasised and the link with society disappears in the acronym (Lorenzo, 2020; Perales and Aguilera, 2020). Even so, the fact that the link with society is not explicitly made does not mean that STEM education does not promote it, since the integration of disciplines is always done from the approach of real problems or situations (Lorenzo, 2020).

To challenge this idea and highlight the presence of other disciplines in STEM education, the name has been changed to STEAM, thus integrating the arts and humanities. One of the main arguments for this is that creativity has been established as one of the essential skills for the 21st century (Liao, 2016). Be that as it may, some justify STEAM education on the need to provide a more balanced STEM education, improving the integration of STEM disciplines and fostering creativity and innovation among students. Furthermore, some argue that STEAM education is justified not only by the need to motivate and attract students who often feel alienated from STEM education but also to combine convergent thinking (characteristic of STEM disciplines) and divergent thinking (common in the arts and humanities) in solving real-world problem while creating personal meaning to each student (Land, 2013; Maeda, 2013; Simarro, 2019).

1.2 What is STEAM education? Discussing the definitions

The STEAM education movement began in the 1990s and both its purpose and definition have changed over time (Martín-Páez et al., 2019). As Bybee (2013) explains, there is still no consensus on the definition and as a result it has often become an ambiguous movement subject to personal interpretations. Thus, following the words by Gerlach (2012) "everybody who thinks they know what it means, knows what it means within their field, and everybody else is defining it to fit their own needs".

The definitions of the STEAM movement that appear in the literature have as a common feature the proposal to integrate STEAM disciplines, but depending on the authors, this integration is interpreted differently.

Kelley and Knowles (2016), Moore et al. (2014) and Sanders (2009) define STEAM education as the integration of two or more disciplines in a real-world context. Furthermore, Moore et al. (2014) specify that this integration can occur in a class, a specific topic or even an entire subject. Toma et al. (2020) and Couso and Simarro (2020), on the other hand, define STEAM education as the integration of the four disciplines through real-world problem-based learning. Similarly, Merril (2009) understands STEAM education as a meta-discipline with an integrated approach where content is undivided, providing for dynamic and fluid instruction.

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Some studies propose an approach that integrates, to a greater or lesser degree, conceptual and procedural content from Science, Technology, Engineering and Mathematics. Thus, Shaughnessy (2013) defines it as problem solving based on concepts and procedures from Science and Mathematics, incorporating the strategies applied in Engineering and the use of Technology. Sanders and Wells (2006) also mention the importance of technological or engineering design in the practices of science and/or mathematics education with the practical concepts of technology and engineering education. However, other studies such as Martín-Páez et al. (2019) and Baran et al. (2016) do not explicitly indicate engineering design when defining STEAM education.

However, apart from the definition, there is also no consensus when it comes to the acronym. There are papers talking about STEM, STEAM or I-STEM and, although they can look the same, there are slight differences between them. McComas and Burgin (2020) claim that teaching any of the individual elements should be referred to as "STEM" education, but when there is full or partial educational integration of any of the parts, this is best referred to as "I-STEM." In fact, this affirmation can be applied to the acronym selected by Sanders and Wells (2006), Sanders (2009) and Kelley and Knowles (2016) in their interpretations.

Besides, the purpose of adding the A to the acronym has already been explained in the historical development, highlighting the need to integrate different disciplines in the projects in order to attract more students. However, despite the intentions to add new letters to the acronym such as medicine (STEAM-M) or reading (STREAM), the usefulness of the word and the ease of use must be considered (McComas & Burgin, 2020).

Therefore, on the one hand, all the definitions analyzed had the integration of the disciplines in common. As a result, there is no need to add "I" at the beginning of the acronym, since the word itself asks for integration in every educational interpretation. On the other hand, to remember the option of combining new disciplines, we think that the acronym with the A can be useful.

For this reasons and taking into account all the definitions in the literature, STEAM education is a teaching method that integrates content, skills and beliefs from at least two disciplines that form the acronym and that focuses on real world contexts.

1.3 Integration types

The literature on STEAM teaching shows that the integration of disciplines plays a key role. Integration in STEAM is defined as contextualized work on a complex problem or phenomenon that requires the knowledge and skills of different disciplines to understand and solve it (National Research Council, 2014). Likewise, Boix Mansilla et al. (2000) define interdisciplinary knowledge as the capacity to integrate knowledge and the modes of thought of two or more disciplines to produce a cognitive development. This integration can take place at different levels, but as with definitions of STEAM education, the different types of integration vary depending on the studies consulted in the literature. Due to this lack of consensus, for this project we are defining three main integration levels based on the interpretations of different review and synthesis works on the subject made by Drake and Burns (2004), Gresnigt et al., (2014), Martin-Páez et al. (2019) and Simarro (2019).

Firstly, we have a **pre-STEAM level** in which there is no integration of content and skills as understood in a STEAM education. Here we can differentiate different levels that range from treating the disciplines separately in which each one works on its own content and objectives (fragmented level) (Gresnigt et al. 2014), to defining some common points between the disciplines. A characteristic feature of this level is that the connections are made by the teacher and there is no room for students to draw their own conclusions from the possible connections (connected level) (Gresnigt et al. 2014). Finally, in this pre-STEAM section is the nested/fused level where the content of one subject in the curriculum can be used to enrich the teaching of another subject (e.g. language acquisition through reading in the subject of history). Consequently, in the nested level, there is a dominant subject and the rest are used to enrich it (Gresnigt et al. 2014).

Next, the **first level of STEAM integration** has as its main feature the definition of a common theme between the integrating disciplines. Two sub-levels can be distinguished depending on the intensification of the integration: multidisciplinary and interdisciplinary (Drake & Burns, 2004; Simarro, 2019). In the first, the topic is common, but the disciplines are dealt with individually, i.e. each one works on it from its own point of view and sets its specific learning goals. In contrast, in the second option, in addition to having a common theme, there are also common learning goals and the overlap of STEAM content areas is taken into account. So, both options have a theme in common but in the interdisciplinary integration level there are cross-curricular concepts used to create connections between them and achieve general learning objectives. In this integration level, as PBL active learning methodologies could be used to achieve the learning objectives.

Lastly, the **second level of STEAM integration** is based on creating projects or solving problems that require the use of content and skills from different disciplines. In other words, the context in which the learning takes place gains special importance, which can be a project or the resolution of a problem, and for this not only the common contents that appear in the curriculum are taken into account, but also the interdisciplinary, disciplinary and transversal competences are important. Here we can also define sub-levels of integration: if the disciplines are maintained, we speak of transdisciplinary integration (Drake & Burns, 2004; Gresnigt et al. 2014; Simarro, 2019), and if, on the other hand, the disciplines disappear, it is called metadisciplinary integration (Martín-Paéz et al. 2019; Simarro, 2019).

To exemplify the above, we can take the sun as a project axis. In the case of multidisciplinary integration, in physics you can analyse the sun as a star, the spectrum of light, etc. In biology, on the other hand, you can expand on the phenomenon of photosynthesis. Thus, starting from the same subject, each discipline works from its own perspective without creating links with the others. If we move towards interdisciplinary integration, common objectives would emerge, such as analysing which part of the light spectrum helps photosynthesis and why. In this way we unite the contents of different disciplines from the same central theme.

In the case of the second level of integration a problem is posed that requires the integration of contents and skills from different disciplines. For example, to answer the question of whether or not plants can grow in any light type, it is necessary to know the biological relationship of plants with light and its components. That makes it possible to combine both disciplines in the search for a common answer. If the disciplines or subjects are kept together to solve the problem, we would be talking about transdisciplinary integration, but if the project is developed in a single subject or as a workshop, by working together with different disciplines without differentiating, it would be metadisciplinary integration.

In addition, implementing STEAM education with higher integration levels can cause the improvement of students' 21st century skills, their attitudes, and teachers' enthusiasm and commitment. Nonetheless, higher integration levels also ask for higher teacher commitment and support, professional development, and sustained facilities such as time, funding, and schedule (Gresnigt et al., 2014).

1.3.1 The importance of the context

As well as the integration level, the choice of the topic or theme it is also important since involving students in socio-scientific problems that require critical thinking can lead towards a better comprehension of the scientific practice and how it relates to social problems. Teaching through socio-scientific problems seeks contextualized learning in which importance is given to the social and cultural context in which science is developed and, to achieve this, students must know scientific procedures, norms and ways of acting (Sadler, 2009). In this theoretical framework of teaching, students learn by engaging in problem discussion and using evidence-based argumentation to reach conclusions. This way, students have to combine discipline's concepts and procedures to make decisions (Bell et al., 2000). These educational proposals are characterized by working on current social problems, controversial and interesting for the students while also related to science, which open up the option to be debated (Hancock et al., 2019). In the same way, these problems have several solutions and cannot be resolved just with simple, memorized scientific content. Furthermore, they can be analyzed from the scientific point of view, and from the economic, social, political or ethical perspective (Sadler, 2009).

In this respect, various studies have demonstrated that teaching based on socio-scientific problems has a positive impact on learning science content (Lewis & Leach, 2006; Klosterman & Sadler, 2010; Herman, 2015), on understanding the nature of science (Zeidler et al., 2002; Sadler et al., 2004: Khishfe & Lederman, 2006; Eastwood et al., 2012) and on students' capacity to argue and analyze (Zohar & Nemet, 2002; Sadler et al., 2007; Zeidler et al., 2013; Romine et al., 2017). In summary, teaching-learning based on socio-scientific problems has been demonstrated to be an effective way of contextualizing scientific knowledge within a complex social context (Hancock et al., 2019).

1.3.2 Which integration levels are we using on STEAM-ACTIVE project?

The definition selected in section 2 remarks on the need for real-world contexts or socio-scientific issues to develop the STEAM projects, since they allow students to contextualize learning in a meaningful way. But, at the same time, real-world problems usually do not involve a single discipline, so integration is needed to fully understand and solve them. Therefore, there need to be connections between the different disciplines in the project by defining common learning goals that allow students to integrate content and skills of different subjects into the solution.

If we analyze the different integration levels defined above, those characteristics appear from the interdisciplinary level onwards. So, neither the pre-STEAM level nor the first level multidisciplinary approach meets the identified needs of STEAM education. In contrast, while the interdisciplinary level approach calls for a common context with shared learning objectives across disciplines, transdisciplinary and metadisciplinary forms the second level of STEAM integration go further and focus on project- or problem-based learning. Thus, these are the three integration levels in which the Teaching-Learning Sequences designed for STEAM-ACTIVE should be developed:

1. **Interdisciplinary (First level of STEAM integration):** there is a common theme that involves more than one discipline and there are shared learning goals. The disciplines are separated.

2. **Transdisciplinary (Second level of STEAM integration):** It focuses on a project or a problem to be solved in which more than one discipline is involved. The disciplines are separated but all the disciplines work together to solve that issue.

3. **Metadisciplinary (Second level of STEAM integration):** It focuses on a project or a problem to be solved in which more than one discipline is involved. The disciplines are worked on together (at the same time), without differentiating the subjects.

It is also important to mention that the decision on the level of integration depends on each situation and does not mean that one is better than the other.

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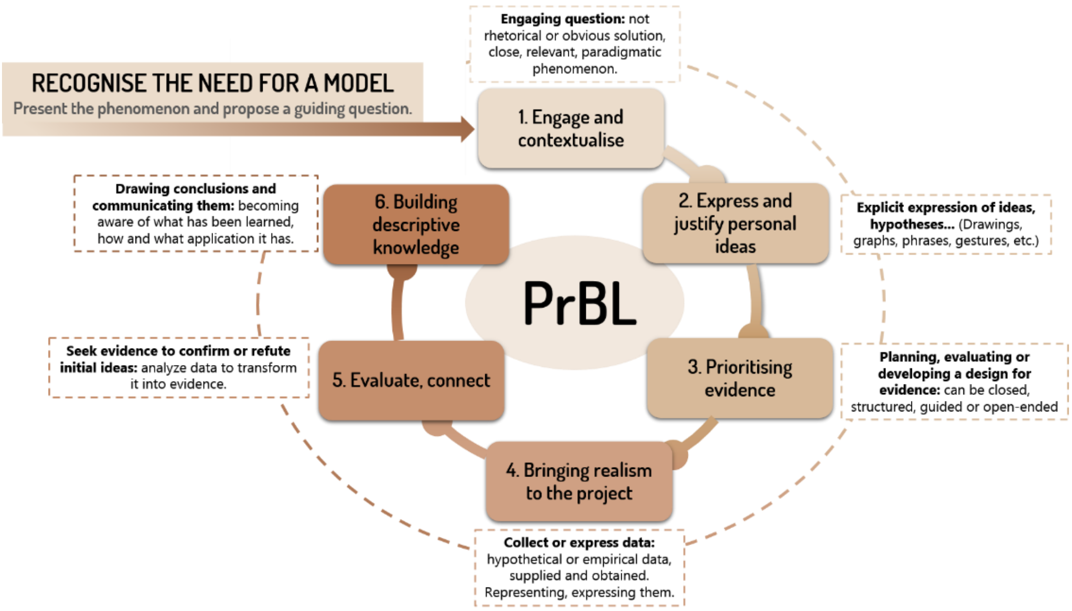
Part 2. STEAM for Engineering. Designing, implementing and evaluating Teaching Learning Sequences.

For the designing of the TLS there are different theoretical perspectives that should be taken into account, such as, Problem/Project based learning approach, links and differences between the disciplines of STEAM and the STEAM approach for engineering focused contexts.

2.1 Project/Problem Based Learning

Project/Problem-Based Learning approach involves moving beyond the traditional framework of each discipline and adopting a project-oriented curriculum structure to re-integrate and re-organize related STEM subject knowledge according to the chosen theme (Fan et al., 2021). It has six main steps: (1) first, you have to create a context related to the phenomena or model you want to analyze during the project. That context or issue should be interesting and familiar for the students, but it should not have a single and obvious solution. (2) After the presentation, students should be allowed to express their initial ideas and hypotheses about the project just presented by using graphs, drawings, and written argumentation... Thus, on this basis, the process of knowledge acquisition begins. (3) During the process, evidence has to be prioritized by planning, evaluating, or developing a design that can be closed, structured, guided, or open-ended. The decision depends on the experience and skills students have in PBL. (4) In order to bring realism to the project, it is advisable to analyze real or hypothetical data that allow the results to be represented, evaluated, and connected. (5) In this way, students can confirm or refute their initial ideas using the data analyzed and (6) solve the project according to their learning. Those conclusions have to be communicated while students become aware of what they have learned, how, and what application it had (Guisasola et al., 2008).



2.2 Links and differences between STEAM disciplines.

STEAM is not a discipline in itself, but takes the characteristics of the disciplines that form it into itself (Quinn et al., 2020). Therefore, it is essential to differentiate each one while working on a STEAM project. Without a distinction, there is a possibility that students will not understand what is unique about the content, history, philosophy, processes and implications of each academic field, and that they will confuse the boundaries and processes of one discipline with those of another (Simarro, 2019; McComas & Burgin, 2020).

Although in the acronym of STEAM engineering and technology appear as two independent disciplines, the "T" was added both because of its tangential relationship to the other elements and because it permitted the formation of an engaging acronym. Furthermore, the relationship between engineering and technology creates a domain that is essentially "two sides of the same coin" (McComar & Burgin, 2020). Likewise, the research developed about mathematics in STEAM is scarce so the analysis of specific characteristics of this section will mainly be centered on science and engineering. Thus, although each discipline has its own characteristics, there are also main processes they share:

1. **Aim:** science, starting from the already accepted theories about a phenomenon, makes new proposals for explanations or models; in other words, it seeks to create new knowledge about nature and its social interactions. In engineering, on the other hand, the main objective is the production of a design (material or computational construction) that helps to solve a socially relevant problem (NRC, 2014; Couso & Simarro, 2020; Ortiz-Revilla et al., 2020).

2. **Definition of the issue:** The ability to create well-formulated and precise questions for each situation is indispensable in any discipline, but the type of question changes according to the situation. If the aim of science is to generate knowledge about natural phenomena, the questions will be what, why and how things happen. These questions may be driven by mere curiosity, inspired by an existing model or theory, or be the result of a problem. In contrast, in engineering you start with a problem or social need that has to be addressed, so the questions are something like "What can be done to solve this problem? What tools exist or can I develop to do so? What conditions and constraints do I need to take into account? What are the criteria that define a successful solution?" (NRC, 2014; McComas & Burgin, 2020; Reynante et al., 2020). In the case of mathematics, the main questions done could be "How can we prove or solve?" (McComas & Burgin, 2020; Reynante, 2020).

3. **Designing and developing an investigation:** When developing an investigation, in science what needs to be measured and which variables need to be controlled must be identified. The results are used to test existing theories or to develop new explanations. On the other hand, in engineering, research is used to obtain essential data and specify design criteria or parameters for testing your designs. Variables need to be identified, how they are to be measured and results obtained in order to analyse the effectiveness, efficiency and durability of designs (NRC, 2014). Therefore, the aim of the evidence is supporting a conclusion about a solution (in engineering) and an explanation (in

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science) or explore the truth or a proposed conjecture (in mathematics) (Reynante et al., 2020).

4. **Modeling:** Models are explicit representations of the phenomenon they represent. Thus, in both engineering and science, they allow a better visualization and understanding of the phenomenon and facilitate the development of solutions to the problems posed. These models can be diagrams, physical replicas, mathematical representations, analogies and simulations, but it should always be borne in mind that certain approximations are made that limit their resemblance to reality and that it is advisable to identify the limitations of each model (NRC, 2014; Develaki, 2020). The use or purpose of these models varies depending on the discipline.

   In science, models are the main form of knowledge creation, i.e. the final product, as they are used to represent the object of study. In this case, models are idealized representation that mediate the application for the theories to complex real world systems, since the real ones are too complex for direct application (Develaki, 2020; Ortiz-Revilla et al., 2020; Reynante et al., 2020). In mathematics A model is a set of objects with precisely defined features and operations, which fulfills the axioms of the theory. Models provide an interpretation of formalized axiomatic systems/theories and their interpretation through the substitution of meaningful elements for its formal terms leads to true and valid statements (Develaki, 2020).

   The essential difference between models in sciences and in mathematics is that in pure mathematics models are basically abstract entities used to instantiate or interpret formal systems, whose development is not committed to any relations with the real world. However, in the empirical sciences models are simplifies representations of aspects of the real world intended to explain and predict phenomena and their relation to the real world (Develaki, 2020)

   In engineering, modeling involves all the different kinds of models: material/scale models (physical prototypes), theoretical-mathematical models, and computer simulation models. In this case modelling is a strategy for understanding, predicting and optimizing the behavior of devices or the properties of materials (Ortiz-Revilla et al., 2020). The difference between the natural and the engineering sciences is the purpose for which the models are constructed, which in the first case is the acquisition of knowledge or explanation of the phenomena modeled and in the second is intervention in the phenomena. It is also important how the final choice of the model is made in each discipline (Develaki, 2020).

5. **Validation:** The validation criteria are the ones that ensure the quality and value of the study. For science, validity relies on accuracy, objectivity, universality and theoretical consistency. Thus, theory is accepted when it has been shown to be superior to other explanations in the breadth of the phenomena it explains and in its explanatory coherence and parsimony. On the contrary, in engineering each proposed design is the result of a process of balancing competing criteria of desired functions, technological feasibility, cost, safety, aesthetics and compliance with legal requirements (NRC, 2014; Couso & Simarro, 2020).

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6. **Argumentation and conclusions:** In all the disciplines the argumentation is needed to defend one solution or another. However, in science, this is done by comparing it with prior knowledge, and in engineering by comparing it with the constraints and conditions defined by the initial question (NRC, 2014; Couso & Simarro, 2020; Simarro, 2019).

2.3 STEAM for engineering focused contexts

Engineering is of particular importance in some of the interpretations of STEAM, such as those of Shaughnessy (2013), Sanders and Wells (2006) and McComas and Burgin (2020), where the need to involve engineering design strategies in the STEAM approach is highlighted. Although in our definition in section two we do not mention this feature when talking about the general STEAM approach, the STEAM-ACTIVE project focuses on undergraduate engineering students. Therefore, the presence of this discipline is essential.

Engineering design requires and interdisciplinary approach that incorporates knowledge from science, mathematics and technology. Thus, by developing an engineering design based project the rest of the disciplines can be analyzed too (Roehrig et al, 2021). Fan et al. (2021) defined six steps for Engineering Focused Curriculum in which we can also integrate the Epistemic Practices of Engineering identified by Cunningham and Kelly (2017):

1. **Defining the problem:** Engineering is developed in social contexts and to define the problem students have to take into account the context itself and the parameters set by clients and conditions. To do so, they have to understand the needs and make trade-offs between criteria and constraints. It is sometimes necessary to assist students in developing viable solutions to reduce the size of the solution-space.

2. **Developing solution:** Students have to develop processes to solve the problem by envisioning various solutions.

3. **Analyzing data:** Applying mathematics and science knowledge students will get data that will help them making evidence-based decisions. The following practices should be performed:
    a. Define and specify problems
    b. Analyze the decisions of the design
    c. Predict the performance
    d. Determine the feasibility
    e. Evaluate alternatives by assessing implications of each solution
    f. Investigate failures

4. **Modeling a solution:** A model is a product that can take any graphical, physical or mathematical representation. Modeling is a way to analyze the performance of different materials and their properties. It is interesting the application of system-thinking where students understand part–whole relationships, and how choices for parts of a system have consequences for the overall functioning of the whole system. This process can enhance students' understanding of conceptual knowledge and performance in engineering design.

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5. **Testing, modifying and optimizing solutions:** Analysis of the different solutions considering the constraints of the initial problem. The optimization phase of the engineering design helps students innovating processes, methods and designs while they learn from failure.

6. **Working in teams:** Communicating skills are essential to develop a project, since students have to work in teams. So, they need to see themselves as engineers and communicate effectively to achieve a successful process.

2.4. TLS design steps

Considering all the theoretical perspectives explained above, here we present the detailed explanation of the STEAM-ACTIVE TLS structure protocol document composed of 8 tables (see Annex).

1. **General data definition (Table 1):** Selection of the degree, level, subjects and the type of integration chosen (interdisciplinary, transdisciplinary or metadisciplinar).

2. **Contexts definition (Table 2):** Number of students, topic, duration of the project, resources needed for the activities and prior knowledge. The latter is referred to the knowledge the students should already had to solve the project.

3. **TLS structure details:**
   - 3.1. ***Main guiding question (Table 4):*** which problem or project have to be solved? Remember that the project should have specific parameters and constraints to align with the characteristics of the engineering design process and that must have relationship with a real world context or issue.
   - 3.2. ***Learning objectives (Table 4):*** Regarding the curriculum, the definition of learning objective students should achieve is needed. Some of these learning objectives are going to be related with concepts and skills on engineering curricula but learning objectives related to circular economy and gender issues must be included. These learning objectives should be inferred from the description of the main problem or project.
   - 3.3. ***Learning demands (Table 4):*** Once the learning objectives are defined, as TLS designers, we should though about what is the gap between students' initial knowledge and the knowledge we expect they will achieve related to a certain learning objective (Leach and Scott, 2000). This gap should be measured in a qualitative way as low, medium or large taking into account following parameters: How often appears learning difficulties, The analysis of learning difficulties related to a learning objective, or the commonality of a certain concept like how often appears a leaning difficulty, how persistent is or how is related to other learning goals.
   - 3.4. ***Learning pathway (Table 4):*** Which questions guide the students learning process? In fact, STEAM problems are problems that can be usually decomposed in a set of intersecting sub-problems, which can all be framed as scientific problems, mathematical problems, or engineering problems.
   - 3.5. ***Align the concepts of the previous phases (Table 5):*** the sub-questions created should be focused on achieving at least one learning objective that has an specific learning

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demand. Knowing that the methodological approach can be also defined. High learning demand objectives are saying that this learning objective is difficult for students to achieve, so, active, complex and high cognitive level activities are needed to help students to overcome these difficulties. Low learning demand objectives could be addressed proposing lower cognitive level activities.

4. **Activities (Table 6):** To help teachers that will implement the sequence, the activity has to be explained in detail: the statement for the students, the activity answers and the methodological explanation for the teacher. The activities should be focused on developing the steps defined on section 5 about the engineering design process. However, to avoid the "trial-error" mechanisms in engineering, students have to make knowledge-based decisions. To do so, Fan et al. (2021) propose the creation of a cycle of inquiry and making activities, which means organizing effective activities in relation to important Math and Science knowledge together with engineering competencies. There are two types of activities that facilitate the transition from abstract to tangible knowledge:
    - 4.1. ***Inquiry and experiment activities:*** Exploration and validation of scientific principles and their application as well as mathematical analysis
        - 4.1.1. GOAL: help comprehend conceptual knowledge related to curriculum theme. This will enhance observational and analytical skills and, as a consequence, students will perceive the prospective efficacy of applying scientific principles to engineering practices.
        - 4.1.2. Examples:
            - 4.1.2.1. Pinpointing the problem (observation)
            - 4.1.2.2. Data recording and analysis
            - 4.1.2.3. Assesment
            - 4.1.2.4. Communication with objective data
        - 4.1.3. Skills
            - 4.1.3.1. Defining a problem
            - 4.1.3.2. Analyzing
            - 4.1.3.3. Optimization
    - 4.2. ***Design and making activities***
        - 4.2.1. GOAL: Help understanding how to apply practical skills by concretizing abstract scientific principles and concepts
        - 4.2.2. This will reinforce
            - 4.2.2.1. Knowledge of materials
            - 4.2.2.2. use of tools and equipment
            - 4.2.2.3. Model building
            - 4.2.2.4. Problem rectifying
        - 4.2.3. Skills
            - 4.2.3.1. Developing solutions
            - 4.2.3.2. Modeling
            - 4.2.3.3. Testing and modification

5. **Evaluation (Table 7):** Each learning objective should be evaluated and this can be done in three different times of the project: at the beginning, during the TLS and at the end. It should be explained also in which activity and how it is done and if it is summative or formative.

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Formative evaluation should inform to students how they could improve in their work. It must be based on actions for improvement to finally, get good marks in the summative evaluation. Any evaluation tool (exam, task, inform, oral presentation, prototype,…) could be evaluated as both, but it is recommended that at the beginning and during the TLS, the formative evaluation prevalence.

Part 3. STEAM for Gender Equality and Environmental Awareness of Engineers

This project has two main transversal axis that must be considered throughout the entire process: Sustainability and gender equality. On the one hand, fast technological developments and the rapid uptake of digital technologies are changing the structure of traditional industries in the EU, pushing towards the so-called Advanced Manufacturing (or Industry 4.0). The impact of this transformation derives from the need for a highly qualified workforce able to evolve and be resilient to constant changes and be a driver to innovation. According to the Communication from the European Commission "A New Skills Agenda for Europe", 40 % of European employers have difficulty finding people with the skills they need to grow and innovate, seeing that, European Commission is promoting new skills for jobs such as interdisciplinary and social related learning and skills to support a fair transition to a green and digital economy. But this issue is not just a social problem, it is, in fact trans-disciplinary so, it must connect STEAM disciplines with all of the components of sustainability science. Therefore, all STEAM interventions designed will take into account environmental impact, sustainability and circular economy, increasing students' awareness of these issues and also bringing their learning closer to more real contexts. This has to be done during all the process, this is, the problem definition by authors has to take into account some environmental impact conditions as well as the students solutions both in designing and evaluating their designs for the optimization.

To do so, in our design protocol we are proposing some strategies that can be useful to tackle that issue in the Teaching-Learning sequences:

1. Efficient use of resources (water, energy)
2. Efficient use of raw materials (metals, oil-plastic, biomaterials, biopolymers…)
3. Waste reduction
4. Waste hierarchy
5. Environmental impacts (Atmosphere, water, soil, noise)
6. Life cycle of products, services and constructions

On the order hand, regarding gender equity, the concern about the difference between male and female STEM students and workers percentage is well known. Furthermore, there are some reasons why female engineers do not feel comfortable in their studies or jobs: first, it has been analyzed by different studies that female students have less professional role confidence than male, and, at the same time, students with greater confidence in their expertise and career-fit are more likely to persist in engineering. This confidence problem is due to the lack of variety of competencies worked on in class, by emphasizing only stereotypically male competencies, the lack of social-related problems as well as the lack of female role models in workplaces. And second, other studies analyzed the reasons why women leave engineering jobs and the main reason was the sexist environment they have at their workplaces (fewer opportunities for development, less likely to report support, and more likely to report undermining behaviors). As a result, the representation of female engineers remains lower than it should be nowadays. Consequently, it is compulsory to design and implement projects and activities in order to improve female STEM confidence to promote vocations with a focus on engineering in the future.

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Considering all those, in our design protocol we are proposing the following strategies with the aim of helping to reduce the gender gap in engineering contexts:

1. Same number of female/male students
2. Changing leadership roles (Changing between different roles during the project)
3. Selection of topic with a gender perspective
4. Having the participation of female STEAM professionals (Role-Models)
5. Use of female protagonists or characters in the presentation of the issues to be addressed (e.g. testing the safety of a car taking the female body into account, if the context requires that there are certain customers who aren't all male...).
6. Intervention protocol to order when each person participates and ask them if they consider that this protocol is necessary and why (assess power relations within the groups).
7. Ask students to indicate the number of women and men cited in the bibliography of an academic paper and present the resulting numbers.
8. Critical analysis of the representation of women, through questions such as: Why don't we know of any female authors? How are women represented? What do the dominant theories make invisible?
9. Making women and their contributions to the disciplines visible.
10. When presenting authors, the first name (and not only the surname) is used and their photograph is shown.
11. Introduce gender categories into the analysis in the evaluation of the project's final product.

3.1 Integration of the transversal axis to the TLS

For each TLS design the authors have to choose at least two of the strategies proposed in each part (Table 3), so we all can ensure that the transversal axis are being represented in the projects. Likewise, when finishing the design, in Table 8 of the design protocol authors need to specify which strategy, how and where they have implemented it. This cyclical methodology allows us to realize at the time of design whether and how the transversal axes of the project have been integrated. Furthermore, by explaining this explicitly in a separate table, it will also help other teachers to get ideas on how to implement these strategies in their own projects.

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ANNEX

STEAM-ACTIVE TLS STRUCTURE

1. General data	
Country	*Choose from all countries in the world*
University Name	
Study Programme	☐ Bachelor ☐ Master ☐ PHD
Name of the programme	*e.g. Informatics, Engineering*
Study Year	*e.g. 1, 2 , 3*
Subjects involved	e.g. *Math, Physics*
Integration Type	☐ Interdisciplinar ☐ Transdisciplinar ☐ Metadisciplinar

2. Context	
Number of students	
Project Topic	
ECTS	
Resources	
Prior knowledge *Is there anything mandatory for students to know to solve this project?*	
Expertise on PBL of teachers and students	

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3. Axes to consider *The objective of this part is to give some examples of possible strategies to incorporate the two transversal axes into the TLS. Select and use at least two from each part.*	
Gender equality	☐ Same number of female/male students ☐ Changing leadership roles (Changing between different roles during the project) ☐ Selection of topic with a gender perspective ☐ Having the participation of female STEAM professionals (Role-Models) ☐ Female protagonist ☐ Intervention protocol to order when each person participates and ask them if they consider that this protocol is necessary and why (assess power relations within the groups). ☐ Ask students to analyze the gender of the authors cited in the bibliography of an academic paper and present the resulting numbers. ☐ Critical analysis of the representation of women, through questions such as: why don't we know of any female authors? how are women represented? what do the dominant theories make invisible? ☐ Making women and their contributions to the disciplines visible. ☐ When presenting authors, the first name (and not only the surname) is used and their photograph is shown. ☐ Introduce gender categories into the analysis in the evaluation of the project's final product. ☐ Other Please specify: ………………………………………………..
Circular economy	☐ Efficient use of resources (water, energy) ☐ Efficient use of raw materials (metals, oil-plastic, biomaterials-biopolymers...) ☐ Waste reduction ☐ Waste Hierarchy ☐ Environmental impacts (atmosphere, water, soil, noise) ☐ Life cycle of products, services, constructions ☐ Other Please specify: ………………………………………………..

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4. TLS structure details	
Main guiding question *Which problem or project have to be solved?*	
Learning objectives *This can be also related with evaluation criteria*	
Learning demands *Analysis of students' prior ideas, and conceptual and reasoning difficulties. This information can be obtained from previous literature together with teachers' experiences.*	
Learning pathway *Which questions guide the students learning process? There can be more than one as well as main questions followed by sub-questions*	

→The objective of this table is to facilitate the design and justification of the sequence's activities.

5. Relationship between different stages of the TLS				
Learning Pathway	**Objective**	**Learning Demand**	**Methodological needs**	**Activities**
Guiding question	*Specific learning objective related to the question*	*Which students' difficulty can appear?* *e.g.*	*Which type of activity or methodology is needed to solve the guiding question?*	** This column can be filled in at the end of the design, once the sequence of activities has been completed*
1.		*☐ Low ☐ Medium ☐High*		
2.				
3.				
4.				
5.				
...				

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6. Activities

Guiding question			
Activity number:	**Time:**	**Subject related:**	**Main content:**
Activity Type	*e.g. group work, presentation, discussion, laboratory work or similar*		
Statement for students			
Main aspects. Answer should include			
Explanation for the teacher			
Evaluation (If any)			

Guiding question			
Activity number:	**Time:**	**Subject related:**	**Main content:**
Activity Type	*e.g. group work, presentation, discussion, laboratory work or similar*		
Statement for students			
Main aspects. Answer should include			
Explanation for the teacher			
Evaluation (If any)			

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For the sequence evaluation, we will use students' feedback and teachers' diary. Every learning objective defined in table 4 and 5 should be evaluated:

7. Evaluation				
Learning objective	**When?**	**How? (Which tool or activity is used?)**	**Character**	**Final mark percentage**
1.	☐ At the beginning ☐ During the TLS ☐ At the end		☐ Summative ☐ Formative	
2.	☐ At the beginning ☐ During the TLS ☐ At the end		☐ Summative ☐ Formative	
3.	☐ At the beginning ☐ During the TLS ☐ At the end		☐ Summative ☐ Formative	
4.	☐ At the beginning ☐ During the TLS ☐ At the end		☐ Summative ☐ Formative	
5.	☐ At the beginning ☐ During the TLS ☐ At the end		☐ Summative ☐ Formative	

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8. Application of transversal axes *Explain where and how have you have applied the strategies chosen at the beginning.*	
Gender equality	*Strategy:* *Where:* *How:*
	Strategy: *Where:* *How:*
Circular economy	*Strategy:* *Where:* *How:*
	Strategy: *Where:* *How:*