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PBL Application to STEAM Education Incorporating Sustainability and Gender Equality Axes: STEAM-ACTIVE Project Implementation in University and High School

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Abstract

Nowadays, students in the scientific-technological field are required to achieve an inter-disciplines competence with attention also to environmental, economic and social awareness issues enabling future technicians to the required challenge-driven approach. Therefore, also a nexus between sciences and humanities is strongly encouraged since the integration of different disciplines produces a holistic approach that enables to better understand real-world problems.
In consideration of what above the STEAM-ACTIVE project (KA2-Erasmus+) proposes an innovative problem-based learning (PBL) methodology, for Teaching Learning Sequences (TLS) design, which implements an active learning approach and incorporates two main transversal axes to be considered throughout the entire process: sustainability and gender equality.
The developed methodology has been deeply formalized in a Protocol, developed for Teachers in the scientific-technological Higher Education. Also an e-learning-based training course for teachers has been realized to support their training. The Protocol, which includes a preliminary theoretical description of STEAM approaches and active methodologies' implementation, guides the teachers in the TLS design process passing through relevant steps as i) definition of the problem to be solved; ii) identification of learning objectives that students should achieve; iii) assessment of learning demands; iv) guiding questions; v) design of activities; vi) assessment of the achievement of each learning objective. In addition, the Protocol gives guidelines on techniques to adapt the TLS to different education contexts.
The e-learning course has been reviewed by external university teachers. Moreover, a collection of 24 STEAM-based TLS has been designed by applying the Protocol and internally reviewed. Part of the designed TLS have been already tested being the project entered the piloting phase.
Globally, the STEAM-Active project enhances students' ability to integrate different disciplines in solving a technical problem taking into account though all the solving process also the social impacts their decisions have. Moreover, it contrasts gender gap in the STEM field increasing women's participation. For this also its application to the high school is preliminary assessed.

Keywords: *STEAM, STEM education, PBL, active learning, gender equality, circular economy*

1. Introduction

The current historical period is characterized by a deep transition in several ambits with a transformative impact in terms of implemented technologies. This is the case of the Clean Energy Transition and the Digital Transition targeted, at the European level, by the Next Generation EU program [1] . As example, the green deal calls for a reorientation of energy systems architecture, a greater attention for rapidly growing and evaluating applications, considering sustainability, environmental and social aspects. The new direction requires responding to existing and future demands, creating and empowering a new generation of citizens with holistic competencies (embracing technical, but also environmental, economic, and social aspects of energy and digital technologies/systems), and promoting knowledge-sharing within a quadruple/quintuple-helix innovation framework. This implies university-industry-government-public-environment interactions within a knowledge economy; therefore, the creation of a nexus between sciences and humanities is required.

With reference to this framework, the CETP – SRIA [2] states that a challenge-driven interdisciplinary and multi-level approach is needed to guarantee the required increase in rate advancement of technological development. Moreover, socio-economic and environmental perspectives have to be integrated in the technological development process, i.e. choices among multiple options have to be guided also in consideration of their impact in terms of social acceptability of the new technology, as well as its cost and environmental impact.
For what above it is clear as students, in the scientific-technologic field, being the future technicians and researchers, need to be trained to address breakthrough research and innovation in support of the targets of the current policies through an interdisciplinary approach achieving multiple competences, including not technical ones.
This aspect has to be considered together with the fact that the STEM sector constitutes one of the main shortcomings on the European territory in relation to the professional skills necessary to face the market of the future as described above [3].
A further issue to be addressed in the STEM field is represented by gender gap. To this regard, even if dedicated actions to be implemented in Higher Education are crucial, such issue needs to be addressed earlier. With reference to the High School, data published by OCSE PISA in 2018 [4] highlights as males achieve in math scores 5 points higher than females. In 2022 such gap increases up to further 4 points [5], with a maximum gap of 9 points in the technical schools.
This difference is higher in Italy for example: 16 and 20 points in 2018 and 2022, respectively with a higher gap in the medium-high score range
The need to develop and strengthen STEM disciplines is evident on several fronts. With reference to the Italian case, it should be noted that:
- Alma Laurea data [6] show that STEM faculties have a greater impact on employment;
- The Ministerial Guidelines for STEM disciplines 2023 [7] target the introduction of activity aimed at the development of mathematical-scientific and technological skills in all curricula of all types and levels;
- The Ministry has provided substantial funding, linked in particular to the PNRR which is included within the Next Generation EU Programme, to be used in the field of training, methodology and for the creation of new environments more advantageous for learning.
The STEAM-Active project [4] (KA2-Erasmus+) contributes to mitigate the lack of STEM skills and it is perfectly aligned with the programmatic choice for an Education model promoting holistic competencies. It aims to provide teachers a methodology to design Teaching-Learning Sequences (TLS) based on STEAM in the context of learning paths in Higher Education, but with a relevant potential impact also on High School. The method follows a Problem/Project Based Learning (PBL) approach and it is based on active learning, thus implying the direct students' involvement through appropriate activities. Moreover, the method integrates gender equality and circular economy as transversal axes in the planning and programming of activities. These completely reflect the targets of the current policies aiming to increase women engagement in technological and scientific fields and to the sustainability of the future European society.
The Protocol, supported by a training course provided in e-learning mode (see Section 2), therefore provides an innovative teaching model which acquires considerable importance in today's training of future technicians and scientists.
The e-learning course is available for teachers interested in applying the STEAM-Active methodology.
The effectiveness of the e-learning course was assessed by means of an external peer revision process. The outcomes of this process are summarised in Section 3.
Subsequently, 24 TLSs were designed by the project partners by applying the Protocol (see Section 4) and then reviewed by means of an internal revision process (outcomes are detailed in Section 5). Finally, the project entered in the piloting phase by implementing the designed TLSs in University engineering courses. Some preliminary outcomes of this ongoing activity are presented in Section 6 together with the description of possible implementation pathways of the STEAM-Active methodology in the High School.

2. e-learning course

2.1 The STEAM-Active Protocol

The STEAM-Active Protocol constitutes a complete guideline for teachers to design TLSs in the scientific-technological field to train students taking into account circularity, sustainability, and inclusion topics (gender issue). Protocol development was based on a wide literature analysis whom outcomes are available on the project website (https://steam-active.pixel-online.org/methodologies.php) as well as the Protocol itself [8]. For what concerns the theoretical background of the Protocol, all details can be found in a previous work of the authors [9].
Aiming to the Protocol development STEAM education is considered as a teaching method integrating content, skills, and beliefs from at least two disciplines that form the acronym and that focuses on real-world contexts. Concerning the level of integration of these disciplines, projects/problems are framed as Interdisciplinary, Transdisciplinary, or Metadisciplinary, all of them developed according to a project-oriented curriculum structure, i.e. PBL methodology [10].
The Protocol, which includes a preliminary theoretical description of STEAM approaches and active methodologies' implementation, guides the teachers in the TLS design process passing through

relevant steps as i) definition of the problem to be solved; ii) identification of learning objectives that students should achieve (technical but also related to circular economy and gender issues); iii) assessment of learning demands in reference to the gap between students' initial knowledge and knowledge related to the achievement of the learning objectives; iv) guiding problems (i.e. learning pathway, each segment focused on achieving at least one learning objective implying a specific learning demand); v) design of activities (inquiry and experiment activities, design and making activities), at least one for each learning objective, identifying the recommended didactic technique for their development and the evaluation modality; vi) assessment of the achievement of each learning objective at the beginning, during the TLS and/or at the end.
The sustainability and gender equality axes are taken into account through specific strategies to be selected to include in the TLS, for each axis among a series of options indicated in the Protocol. Specifically at least two of the strategies proposed in each part have to be chosen by teachers, to have a sufficient implementation of the transversal axes for students training to circular economy principles and for gender gap reduction in scientific-technological contexts.
Additionally, the Protocol gives guidelines on techniques to adapt the TLS to different education contexts.

2.2 The e-learning course

To support teachers in the Protocol implementation, an e-learning course was developed. Each of the three modules is composed of three sections. Each of the sections in the three modules has a similar structure containing a general definition for the section, on-line resources, YouTube videos and Tasks and Activities. At the end of each of the sections, it is possible to add comments and/or ratings about the course. The description of the modules is as follows:

1) Module 1 - Basis of STEAM addressing *i)* the evolution of the STEAM acronym making teachers awareness of features that identify a STEAM as used in the STEAM-Active project; *ii)* features differentiating STEAM projects from the ones which cannot be called STEAM projects (teachers are awareness as a STEAM project must be characterized by integrated content of several disciplines, real-world context, and an active learning approach); *iii)* different levels of STEAM integration (after studying this section, you will be able to choose the appropriate level of STEAM integration in the implemented teaching scheme).
2) Module 2 - STEAM Active approach. It first indicates main ingredients to be taken into account when defining projects based on the STEAM (e.g., creativity, creative-thinking, synthetic-thinking, critical thinking, imagination, cultural sensitivity). Then it provides an overview on learning techniques to be considered (e.g., Project Based Learning, Think-Pair-Share/Write-Pair-Share, Brainstorming, Role play, etc). Finally, characteristics (e.g., to be motivators, knowledge managers, guides, methodical, mediator, etc.) that are considered necessary for teachers in order to design, develop and implement a project based on the STEAM concept are presented and discussed.
3) Module 3 - Basis for designing a STEAM Active project
   This module includes three sections. The first one details the steps to be followed to design a TLS according to the STEAM-Active methodology. Therefore, the different parts of the TLS design protocol are explained step by step, with a particular focus on those not already discussed in Module 1 and Module 2 (e.g., learning difficulties, guiding questions, etc). Examples of each step are given achieving, at the end of the section, to the finalisation of the design of a STEAM training learning sequence.
   The second section is aimed at those teachers interested in using a TLS already designed, supporting them to understand how to manage it, in order to identify the needed modifications e.g., in relation to used subjects, implemented level of integration, background knowledge of students, students and teachers experience in PBL and STEAM projects.
   The final section deals with the adaptability of a TLS, as a crucial factor to allow TLS application in different contexts. Specifically, the e-learning course presents different techniques that can be applied according to different needs of TLS adaptation as the time available, the level of independence of the students when developing projects, the students' knowledge and the specific context of implementation.

3. Review of the e-learning course

The evaluation of the e-learning course was carried out in the 5 countries participating in the STEAM-Active project. It was carried out in two different dimensions. On the one hand, the course was available on the project website [8] and was offered to anyone who might be interested once

registered in the project web site. On the other hand, an internal evaluation was performed by 5 professionals (different from the e-learning course developers) from the institutions involved in the project (a total of 30 participants), answering six specific questions about the e-learning course.
A total of 149 people interested in STEAM education participated in the external evaluation. Although most of these professionals belonged to the institutions partner of the consortium, also staff from other institutions was involved. Participants were asked to register on the website (name and e-mail); once registered they had the opportunity to leave comments on each of the three modules of the e-learning course described in section 2.
The course has received a total of 326 comments about the three modules. Almost half of the comments were focused on the first module entitled "Basis of STEAM", around 30% were about the module "Steam Approach" and the rest, around 20%, were about the module "Bases for designing a STEAM-Active project". The comments in general have a positive character and the most repeated word in the comments is "interesting"; other recurrent words are "useful" and "helpful". Let's look at some examples.

- Great article in order to know basically what STEAM is. Really interesting and useful! (Spanish learner)
- Very useful and informative (Lithuanian learner)
- Very successful online course, which transfers a scientific approach into the everyday world. It also explains very well why stem is relevant. (German learner)
- I like how the teachers advocate for the use of practice because it stimulates the students to get involve and to puzzle over and come up with solutions or ideas (Greek learner)
- The document is well structured and is a good guideline for planning PBL-projects (Greek learner)
- Video reflects how the learning paradigm has changed. I liked it (Lithuanian learner)
- Key chapter to understand STEAM integration levels (Spanish learner)
- Experienced experts talk about their techniques with hints on how to use them. That’s really helpful when you think of using them in own lessons (German learner)
- The protocol for STEAM educational projects is really well-made, providing a systematic and user-friendly approach for teachers. (Italian learner)
- The potential modifications, such as deleting or adding objectives, changing questions, is crucial for successful implementation in varied classroom contexts. (Italian learner)
- The inclusion of studies demonstrating the positive effects of STEAM on students' creative-thinking is invaluable. (Italian learner)

In addition to this piloting of the online course, 5 professionals from each of the project partners (a total of 30) answered a specific questionnaire for the evaluation of the e-learning course. This questionnaire consists of 6 questions, 2 per module, aiming to obtain assessments relative to key points of the e-learning course. The first two questions aim to explore to what extent the definition of STEAM methodology is understood and what is the difference between STEAM and STEM. The next two questions target to explore the connection between the intended disciplines and their relevance to engineering education. In addition, the questionnaire asks about the guidance offered by the course to incorporate multidisciplinary approaches. The questions related to module 3 focus on the strategies offered by the course to adapt the TLSs both in general and in relation to each of the points proposed.
With regard to this section, answers provided by the external evaluators were, in general, more elaborated. As in the previous evaluation, the tenor of the responses was positive.

4. TLS design

During the project 24 TLSs (4 TLSs per partner) were developed by the Universities partners of the project by applying the STEAM approach. As indicated in the next Section 5, designed TLSs were subjected to an internal review process. Subsequently, TLSs have to be revised by the designers according to reviewers comments and suggestions. At now, the review process was almost completed, but 3 TLSs need to be assessed, while other 2 TLSs (already revised) need to be update on the project portal. Therefore, in the following data are provided relative to the 19 TLSs currently available in the STEAM-Active project web site.
First of all, about 60% of the TLSs were developed to be implemented in Bachelor degree study programmes (Fig. 1a), even if the developed teachers guidelines indicate how to adapt the TLSs to different contexts. It is remarked as it is relevant since the Bachelor degree programme is intermediate

with respect to High Schools and Master degree programmes. Moreover, the graph of Fig. 1b provides the number of TLSs per number of ECTS (considering that each ECTS corresponds to 8 hours).

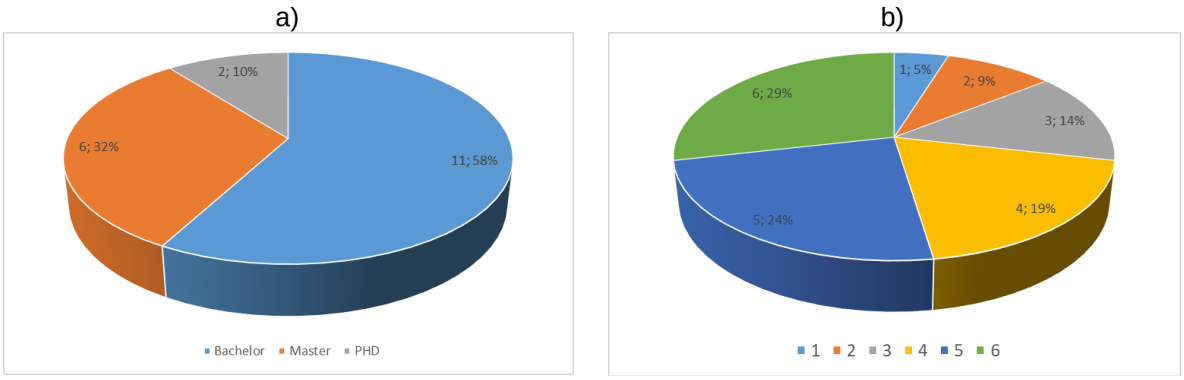

Fig. 1. a) Number of TLSs per study programme; b) Number of TLSs per number of ECTS

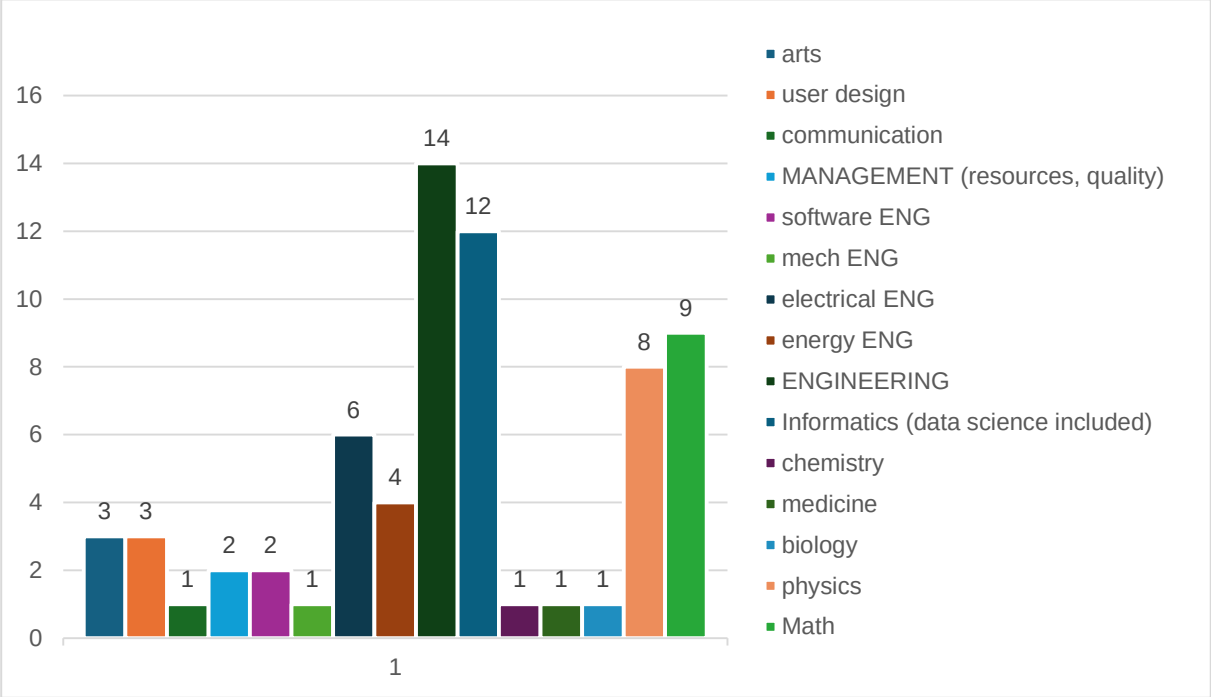

Fig. 2. Number of TLSs involving each subject

Furthermore, for what concerns the number of involved disciplines and the level of integration, developed TLSs are characterized to prove they answer the requirements of the STEAM approach.
The number of subjects involved in each TLS varies from 2 (the minimum required value) up to 5 with a mean value of 3. Fig. 2 depicts the number of TLSs in which a subject is involved. For engineering subject once a specific engineering field is involved (e.g., electrical engineering, mechanical engineering, etc) also the general engineering field is considered. Finally, Fig. 3 shows the implemented level of disciplines integration, reporting the number of TLSs for each integration type among Interdisciplinary, Transdisciplinary, and Metadisciplinary problems/projects.

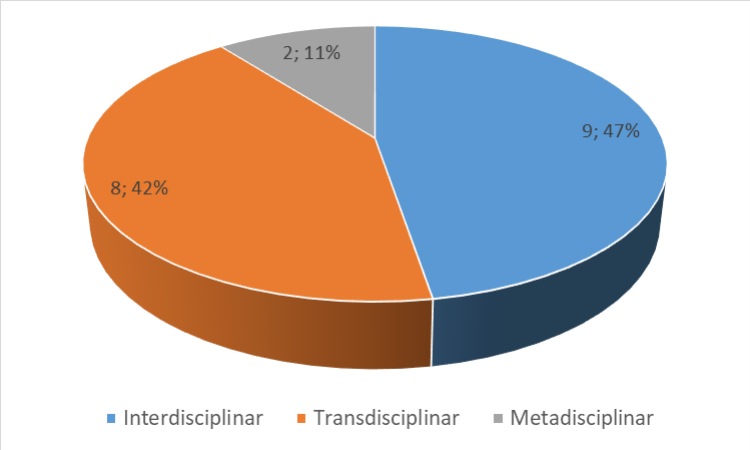

Fig. 3. Number of TLSs per disciplines integration type

5. TLS internal review

The 24 designed TLSs were internally evaluated (21 out of 24) by at least for one (or two) of the project partners. The evaluation was carried out in relation to the Protocol and following Protocol's steps, but in addition some other interesting aspects to be taken into account were incorporated. The evaluation was done following a template. In the evaluation template, data related to the fulfilment of each of the Protocol's requirements were collected. For those cases in which the requirement was not met, the evaluator had to indicate his or her suggested revisions and recommendations for making these changes. Once the authors had received the evaluation, they redesigned the aspects to be improved. In this way, the quality and coherence of the design was ensured.

According to the structure of the evaluation table, as the preliminary review step, general information about the TLS was collected, such as the title of the TLS and the name of the university that designed the proposal following the Protocol. Next, the reviewer was asked about the fulfilment of each of the Protocol's blocks. In the first section general data of the TLS such as the level (Bachelor, Degree or Master) for which it was designed, the name of the programme, the course(s), and the subjects that were integrated in the proposal had to be indicated, as well as whether or not it mentions the level of STEAM integration (Interdisciplinary, Multidisciplinary or Transdisciplinary) proposed for the implementation of the proposal.

The second section asked reviewers to assess the data included in relation to the context for which the TLS is designed. The proposal should include the estimated number of students that will participate in the implementation, the general topic addressed by the TLS, the number of ECTSs that will be used in its development, the resources that will be needed, as well as the previous knowledge that will be required from the students. Finally, the proposal should also include the Project Based Learning (PBL) expertise of both teachers and students.

In the third block, each TLS was assessed with respect to the transversal axes inclusion as required by the Protocol, that is at least two activities related to gender issues and two activities related to circular economy included in the design.

According to the fourth section, reviewers assessed whether the TLS design included the guiding questions, the learning objectives, the learning demands related to learning difficulties and the learning pathway.

In the fifth block of the evaluation template, reviewers checked whether the design was coherent. To this end, it was checked whether the Learning Pathway was correctly related to the guiding questions, the learning objectives, the learning demands, the methodological needs and the activities described in the sixth block. In the seventh block, it was verified whether the assessment proposed in the TLS is appropriate, while in the eighth block it was evaluated whether the transversal axes (gender issues and circular economy) were included in an appropriate way.

Evaluations were generally positive and TLSs didn't need a deep reassessment. The redesign needs consisted on minor revisions focusing on adding aspects that the authors overlooked and were required by the evaluators for a better understanding of the design of the TLS.

6. TLS piloting phase

The overall process for TLSs design up to their piloting implementation is shown in Fig. 4. TLSs highlighted in yellow have to be assessed, while the orange ones are already revised and need to be uploaded in the project web site. The other 19 are already assessed, revised and uploaded in the project web site. In the last column of Fig. 4 the implementation scheme of the first phase of the piloting is shown. The piloting consists in the TLSs test in engineering courses by project partners, specifically University of the Basque Country (Spain), Baden-Wuerttemberg Cooperative State University (Germany), University of Peloponnese (Greece), University of Perugia (Italy), Kaunas University of Technology (Lithuania), and Machine Tool Institute (Spain). Currently 10 TLSs were already tested.

			Assessing partner						
Developer	Title	Semester	DHBW	IMH	KTU	UPV	UoP	UniPG	Tested by
DHBW	1 - Energy Slot Selection for Production	1				X			DHBW
	2 - Object Recognition for Quality & Safety			X	X				
	preparation of daily dosage in a medication organizer	1		X					DHBW
	4 - Tracking and Tracing of Medication				X				
IMH	1 - Competitive Machining Process	1				X		X	IMH
	2 - Diesel Motor Efficiency	1						X	
	3 - Design of a Piping Installation					X			
	4 - Industrialization of a new line of business						X		
KTU	1 - Planning the Placement of Recycling Containers	1					X		UOP, KTU
	2 - Intelligent Traffic Management	1		X			X		KTU
	3 - Automatic Water Level Management using Dam		X						
	4 - Delivery Route Planner						X		
UPV	1 - Looking for suitable materials for a laser printer	1		X			X		
	2 - Electrical Efficiency of buildings	2	X					X	DHBW, UniPG
	3 - Constuction and demolition waste				X				
	4 - How can offshore structures be protected from corrosion							X	
UoP	1 - Save water		X						
	2 - Power is not endless!					X			
	3 - Cycling tour and Tourism	1			X				UOP, KTU
	4 - Enjoy Sailing in Greek islands	1			X				KTU
UniPG	1 - The role of energy storage in the clean energy transition	1	X						DHBW, UniPG
	2 - Battery systems in electric transportation	1		X					UniPG
	3 - Powerline design					X			
	4 - Photovoltaic system		X						
			5	5	5	5	5	4	

Fig. 4. TLSs piloting matching

At the end of the project each partner has to test the four TLSs internally designed plus a fifth one designed by another partner. Professors implementing the TLSs have to report a course diary and to answer a questionnaire. Preliminary feedbacks of the piloting are positive.
Also the implementation of the STEAM-Active methodology in High School teaching has a potential relevant impact. In order to support activities in the STEM area, recently the Liceo Statale A. Pieralli, a High School in Perugia (Italy), activated a Human Science course with STEM enhancement for the first two years (28 hours per week instead of 27): at least one hour at week is carried out in the laboratory aiming to enhance mathematical and digital skills by applying them to scientific, humanistic, social, and economic real problems.
The aim is to enhance digital and mathematical competences, together with computational, communication and collaborative skills and creativity. Specifically, the High School offers educational and design activities with innovative approaches. This is to encourage the development of a STEM thinking, not only in the educational and cognitive field, but as a tool for approaching, understanding and solving a complex reality increasingly oriented to digital innovation.
All activities have a laboratory character and put the student at the centre of the learning process. Very interesting are the feedbacks collected at the end of the courses activated in the 2022-2023 year. Most students say that STEM activities allow them to:

- prefer laboratory activities over classroom activities;
- understand how mathematics contents are applied to the real world;
- know how to read and process real data, graphs, etc. to solve complex situations;
- improve their digital skills (96% of students answers), specifically in using new software and electronic documents/tools;
- improve the study method for participation in university competitions or tests;

- discover and approach the scientific world to orient themselves towards STEM studies or work environments.

6. Conclusion

The STEAM-Active project was started with the aim of achieving 3 results. The first one related to the Protocol was already concluded and this paper discussed the second and third objectives of the project. The second is related to the e-learning course. As discussed in sections 2 and 3, three modules were designed and evaluated both externally and internally. It was explained how the evaluation was developed and evidence of this positive evaluation was shown. In relation to the third objective of the STEAM-Active project related to the design of the TLSs, section 4 provides details concerning the 24 TLSs produced by applying the Protocol.
In addition, section 5 describes how the process of TLSs internal evaluation was developed in detail. In this way, the coherence and understanding of the proposals made were ensured. Although the TLSs implementation and evaluation are not concluded, evaluation outcomes relative to both the e-learning course and the TLSs design are positive and indicate that the STEAM-Active project is successfully meeting its objectives.

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