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Building STEM Inquiry-Based Teaching Proposal Through Collaborations Between Schools and Research Centres: Students' and Teachers' Perceptions

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Abstract: This study presents an inquiry-based teaching approach using a rich methodology involving STEM (science-technology-engineering and mathematics) projects, developed using a cooperative way to work between schools and research centres. We describe the teaching pattern scenario with students, teachers, and scientists. We also illustrate the learning process, conducted through two inquiry-based problems in Biochemistry, the mutagenesis process and the transgenesis effects caused by inoculation of bacteria. The teaching sequence, as well as the scientific knowledge and students' competencies involved, are shown. We then analyse the students' and teachers' perceptions in this scenario regarding the development of students' STEM learning through their inquiry skills promoted and concerning predictors to vocational careers involved (students' identities as potential scientists, scientific attitudes, social implications towards science or students´ agency). Finally, we add some conclusions and contributions to teaching STEM education, related to factors of the design teaching scenario that bring connections with the interests and motivations of students, such as the relevance of the projects to evoke understanding of processes or causal relationships of content or the teacher's professionalisation supported by a proper allocation between scientists and teachers.

Keywords: *Genetic problems, inquiry-based learning, STEM education, students-teachers-scientists collaboration.*

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Introduction

New socio-cultural environments require innovations in science education that allow students to acquire an adequate understanding of science, technology, engineering, and mathematics (STEM), which is applicable in real everyday situations to contribute to their personal development and active integration into society as scientifically and technologically literate citizens (European Commission, 2014). Similarly, the current demand in scientific-technological studies needs to advance to an interdisciplinary treatment of the subjects. This requires studying science content knowledge to solve daily life problems to develop science education standards. Thus, with the advent of the Framework for K-12 Science Education (National Research Council [NRC], 2012), suggesting that the instruction of science education make a radical change focusing on scientific inquiry to learning about science and integrating dimensions associated with disciplinary core ideas, crosscutting concepts, and science and engineering practices that reflect how scientists and engineers engage "in a systematic practice of design", we will cover every aspect of science education (curriculum, instruction, and assessment (Morrell et al., 2020).

Along the same lines, the PISA assessment (Organization for Economic Co-operation and Development [OECD], 2017) considers the notion of the "context" in which these activities occur. This idea is based on analyses of real-life situations or problems to facilitate their use as a starting point for the development of scientific ideas that must address students' competencies as well as their knowledge and attitudes (Bybee, 2013).

However, knowledge transfer is one of the main problems to be addressed by science education. Thus, inquiry was popularised over 50 years ago and continues to be a cornerstone of science education at all grade levels across the globe. In contrast, STEM education is a more recent construct, coming into vogue in the late 1990s (Blackley & Howell, 2015). Focusing on science inquiry and STEM education in school curricula responds to vocational and economic pressures and

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global competition. Bybee (2013) stressed the need for STEM education to increase the diversity of people choosing a STEM career and to prepare a "STEM-literate citizenry" (p. 1).

The growth of science and technology and its impact on our everyday lives again focus on science and STEM education. Alternative energy sources, genetically modified organisms, the body's immune defences, vaccinations or concerns with climate change are just a few of today's pressures.

The definitions for both inquiry and STEM are varied. For the purposes of this paper, science inquiry will involve identifying and posing questions and working to answer them. It is concerned with doing science and thinking scientifically, evaluating claims, investigating ideas, solving problems, reasoning, drawing valid conclusions and developing evidence-based arguments. It can easily be summarised as the 'work of a scientist' (Hackling, 2005). STEM, while easy to define, is harder to find in practice. For research purposes, in this paper, STEM education will refer to instruction that integrates at least two of the four STEM components.

Hence, the orientation guided by the ideas of dialogical and problematising education, both from the perspective of the teachers who teach science as well as the scientists who research Science, requires a constructive identification and problematisation of the epistemological understanding about experimentation (Philip & Taber, 2016) among science trainers (teachers and scientists) in their formative support to the construction of students' knowledge.

According to these premises, here we present a case study describing the design and implementation of an inquiry-based teaching proposal (TP) using a cooperative framework that includes the strengthening of students, teachers, and scientists, through two different STEM projects on genetic problems designed to promote a more holistic view in the students of the key processes and their relationships to each other on a cellular level (Gericke & Smith, 2014), from the PISA framework (OECD, 2017).

Literature Review

Real Problems in STEM Education

Several studies have proved the difficulties of carrying out real-world problems due to their inherent complexity and multidisciplinary. Such problems claim for a proper approach in which STEM projects embrace the content and skills of all the subjects involved, reflecting in this way an understanding of the synergies between them (Moore et al., 2014).

Although similar to the Science/Technology/Society movement of the late 1970s, which focused solely on the reciprocal nature of the impact of science on society and vice versa, STEM education focuses less on the social aspect and more on the interaction of the four disciplines.

Both K-12 STEM Education and the definition of best practices for integrated STEM Education agree on the variety of tasks and responsibilities that a STEM teacher needs to accomplish (Morrison, 2006), most of them related to the design and implementation of the curriculum and the introduction of innovation in the classroom practices (Morrell et al., 2020), which allows to connect them to the real world. Thus, an extra effort to design solutions to complex contextual problems is required (Kennedy & Odell, 2014).

Therefore, the STEM implementation in school is certainly challenging, as it regards the epistemological variations among science, technology, mathematics, and engineering, which produces several barriers (organisation in an extracurricular schedule, design teaching, and evaluation) that certainly difficult the implementation of active teaching methodologies (e.g., inquiry-based science education approaches (IBSE) (Akuma & Callaghan, 2019; Gunawan & Shieh, 2020).

Inquiry-based Teaching as a Plausible Solution to Approach Student Learning and STEM Relationships

Within the recommendations derived from the K-12 Science Education (NRC, 2012), scientific and engineering practices include planning and carrying out investigations, using models, analysing and interpreting data, and providing a solid base for inquiry instruction. In this way, inquiry helps students to develop a conceptual framework to understand facts and ideas, organising their knowledge to facilitate retrieval and application. Thus, despite the extra work, IBSE leads to positive results such as developing students' content and scientific competence and their training as future citizens.

More than 100 studies have revealed the positive effect of inquiry-based teaching on student cognitive and attitudinal outcomes (Marshall & Alston, 2014), with a major emphasis on knowledge, reasoning, and argumentation, and in student attitudes towards science (Chen et al., 2014), who extend their dedication to a regular interest in science. These main achievements, together with the multiple benefits for all learners (Marshall & Alston, 2014), provide us with a valuable and promising tool to approach STEM relationships into everyday school life, including problem-based, inquiry-based approaches, and design-based pedagogies or the assessment of multiple STEM learning outcomes (Gatan et al., 2021), among others in a series of defining characteristics associated with the design and implementation of STEM units (Toma & Greca, 2018).

Promoting a Cooperative Framework to Create Interdisciplinary Learning and Promoting Predictors of Vocational Careers

The education systems of most developed countries do not have the educational structure or the curricular organization necessary to implement a true interdisciplinary or integrated pedagogical approach, which emerges synergistically from the STEM areas (Gardner & Tillotson, 2019). Despite the difficulties regarding the preparation and implementation of the STEM curriculum collaboratively, by joining professional forces, teachers can generate robust learning communities that result in a remarkable improvement in students' performance (Bybee, 2013). Developing a team-teaching pattern (McLaughlin et al., 2016) is essential to achieving the STEM curriculum goals, working collaboratively (in opposition to the single-teaching alternative), and becoming more productive (El Nagdi et al., 2018).

A plausible approach to harvest interactions between STEM subjects would be to foster cross-curricular links (rather than a total integration), adding instructional strategies involving pedagogical perspectives, for which a student-centred learning environment is essential (El Nagdi et al., 2018). Methodological approaches and technological tools should also be considered to improve the scientific thought as a primary goal to understand the world around us and to be able to make decisions and–promote predictors to vocational careers (Lupión-Cobos et al., 2019). In general, despite the differences between the STEM models, we can find as a common aspect the learning centred on the student to promote their motivation that involves the mobilisation of their scientific capacities (OECD, 2017). For it, a collaboration way by a team-teaching pattern through a cooperative scenario student-teacher-scientist ("Project in the Introduction to Innovation and Investigation in Secondary Education in Andalusia," PIIISA) (Lupión-Cobos & Pérez-Cáceres, 2017; Pérez-Cáceres, 2013) can offer essential aids from the exchange of learning that can be established. In this collaborative scenario, the participation of scientists allows students to engage in school projects connected with lines of work of the research centres themselves, bringing it closer to real contexts and to the approach of STEM treatments, promoters of more interdisciplinary learning (Gatan et al., 2021; Gunawan & Shieh, 2020). We consider this a plausible strategy to bring students closer to the scientific world and how it develops, socializing their research. Also, for teachers who can integrate the inquiry approach in science class and approach, from science education, inquiry as a learning objective. Both axes will contribute to the European strategic objective of promoting scientific vocations as a key bet to build a solid knowledge society (European Commission, 2014; Lupión-Cobos et al., 2019; NRC, 2012).

Aims of the Study

We have used a cooperative framework by the PIIISA collaborative scenario that includes the strengthening of students, teachers, and scientists to approach student learning through an inquiry teaching proposal (TP) on genetic problems by STEM projects. Therefore, we propose to analyse the perceptions of students and teachers in relation to the following research questions:

1. What are the contributions of the TP to the development of students' inquiry skills?
2. How does the interaction between schools and research centres promote predictors concerning students' vocational careers?

Building the STEM Inquiry-Based Teaching Proposal

Below we describe the general structure of both the cooperative learning framework and the structure of the inquiry-based teaching proposal (TP) developed through the study, particularly exemplified in real STEM inquiry-based projects involving relevant contexts such as genetics in Health Education.

The Cooperative Learning Framework

We provide the cooperative dynamics (the teaching collaboration) and the programme's timing of the scientists and teachers (stages of the programme), carried out the teaching experience through the PIIISA programme (Lupión-Cobos & Pérez-Cáceres, 2017; Pérez-Cáceres, 2013), which promotes collaboration between secondary schools and Spanish research institutions (Spanish Research Council [CSIC]) and some universities. This scenario helps to encourage a more realistic inquiry and STEM process by a cooperative working framework between scientists (SCTS), teachers (TCHR), and students (SDNT), where teaching, learning, and scientific inquiry are closely intertwined (McLaughlin et al., 2016. From a multifunctional approach, the aim is to develop adequate science education for students and contribute to promoting their scientific vocation and interest in science.

The Teaching Collaboration

Scientist and teachers (S&T) worked together in a teaching collaborative way. The teachers from the schools contacted the scientists requesting their participation in the programme, elaborating online spaces with a continued follow-up and sharing work to study the design and planning of practices. Thus, they studied the crosscutting concepts and core ideas, the relation to the nature of science and the conduct of scientific research methodology (NRC, 2012; European Commission, 2014; OECD, 2017) as well as possible limitations in teaching skills, or the challenges of the new roles of the teachers and the new roles of the students, to solve the management of technical problems, among other factors (El Nagdi et al., 2018; Gardner & Tillotson, 2019). Table 1 shows the tasks of scientists and teachers and the exchange implemented along the programme.

Table 1. Scientists and Teachers Exchanges Along the Programme

TERM LESSON	SCIENTISTS	TEACHERS
1	**Scientists and teachers exchange**	
	Research project design. *Invitation to students to participate.*	*Dissemination of the project among students.* *Project information to families.*
	Presentation of research and concretion of tasks. *Observation of personal skills and definition of tasks/working sub-teams, etc.*	*Allocation of students to work groups.* *Tutoring and supervision of teaching proposal.* *Guardianship and visits organization.* *Management of communication and development between students and researchers.* *Decission making in temporality.*
2	**Scientists and teachers exchange**	
	Recapitulation of previous results and planning and realization of the next question/experiment to be solved. *Advice on experimentation.* *Active participation in the blog.*	*Photographic record.* *Training advice on tasks.* *Elaboration of supporting documents for:* *Compilation of results.* *Explanation of valuations.* *Drawing conclusions.* *Establishment of implications.* *Active participation in the blog.*
	Distribution of complementary "out-of-school" work sessions for organization of task (both scientists and teachers)	
3	**Scientists and teachers exchange / individualized and collective students' advice through virtual spaces with support for:**	
	Review of reports prepared by the defined working groups. *Individual and collective formative feedback.* *Advice for exhibitions.* *Emotional management.* *Participation in congress.*	
4	**Scientists and teachers exchange / individualized and collective students' advice through virtual spaces with support for:**	
	Conduction of shared reflection spaces. *Dissemination of the generated material (educational centres, science weeks, specific scientific journals, etc.).* *Internal evaluation.*	

Phases of the Programme

The TP is structured as complementary curricula along the academic year, with four phases in its lessons plan (4 hours each one): PRIOR, 3 SESSIONS, CONFERENCE and LAST. Figure 1 shows the flowchart and timeline of the cooperative working framework through the PIIISA programme for all the participants: scientists (SCTS), teachers (TCHR) and students (SDNT).

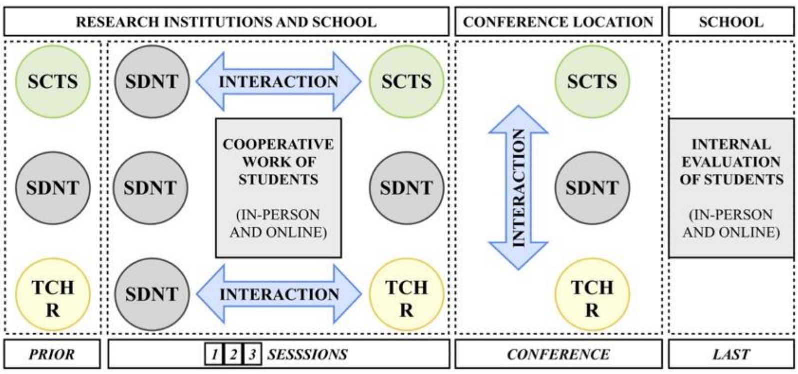

Figure 1. Flowchart of the Cooperative Working Framework Through the PIIISA Programme.

Prior: Students attend a preliminary session at schools and three hours of practical sessions throughout the school year at research institutions. Scientists and teachers presented the project, introducing students´ inquiry training. It is required special guidance from the scientists, especially for presenting the hypotheses and the variables to be observed. Working online and in person, students organised the acquired information.

Sessions: Consequently, scientists and teachers directly monitored the students at this stage, helping them work scientifically. The teacher must coordinate these students. The tutoring begins accompanying them to the facilities where the research is carried out.

The students work collaboratively with their group members in an autonomous way (usually online), with the tutor's monitoring. They also complement their tasks through specific cooperative sessions at their schools and use online follow-up sessions to prepare the presentation of results. Therefore, it is essential to provide students with a well-supported online platform (Google Drive). Both students and teachers could share documents and monitor projects, working collaboratively.

The inter-sessional period makes it necessary to highlight the objectives of the projects; this done consistently throughout the course and complementing their tasks with contact sessions in their schools (cooperative work of students) as well as in online follow-up sessions, using virtual tools to provide shared documents to facilitate more dynamic monitoring of projects.

Conference: In the third part, once the experimental part is done, students focus on preparing the documents that make the "Initiation to Research and Innovation" effective, a poster, and an oral presentation that will be disseminated through a final one-day conference. These assignments are subjected to peer interaction, with all the students who have accomplished the experience and the scientists and teachers that have monitored it. To help in this purpose, online guidelines and tools are provided, giving all the scientists and teachers access to supervise and support the projects' development and to prepare the students' presentations and communicate in an audience.

Last: After the conference, a final lesson is set up to evaluate the whole programme, where the students register their opinions about participation and results.

Methodology

The Study Design: The Inquiry-Based Teaching Proposal (TP) Designed Through the STEM Projects

Specifically, we will focus on two biological problems related to mutagenesis and transgenesis processes and defined in the following research projects:

- Project 1: "Mutagenesis in *Saccharomyces cerevisiae* and *Schizosaccharomyces pombe* yeasts following exposure to certain mutagenic agents (magnetic fields and UV rays)." The preliminary hypothesis was to determine whether ultraviolet light and magnetic fields generated by an electromagnet have mutagenic effects on certain living microorganisms. To test this hypothesis, the so-called "survival rate of cultures" was measured in two different types of yeast (*S. Cerevisiae* and *S. Pombe*) using different doses of the two mutagenic agents. In this project, students investigated one independent continuous variable, the so-called "survival rate of cultures," measured in two different yeast types, proportionally to the exposure time to both UV radiation or magnetic fields.
- Project 2: "Inoculation of *Pseudomonas syringae* in bean plants." In project 2, an analogous study was proposed in which symptoms of an infection caused by the inoculation of bacteria in bean plants were analysed. The independent discrete variable investigated in this project was the strain of bacteria used. The analysis of symptoms induced by three pathovars (PPH, PTO, and RW60) of the *Pseudomona Syringae* bacteria in bean plants was the purpose. The results obtained had a qualitative nature and were collected by direct observation of detected symptoms.

The use of skills and main concepts of the knowledge involved that will be introduced during instruction are shown in tables 2 and 3.

Table 2. Use of Skills

Project 1	**Project 2**
Set the hypothesis	
The number of yeast colonies is inversely proportional to exposure time to radiation.	Each type of bacteria attacks beans differently.
Determine questions that could be answered through research	
The wavelength of the UV radiation and the number of colonies that survive radiation.	Pathogenic bacteria cause bean plants to react, producing necrosis.
Draw a conclusion based on scientific data	
UV rays have the capacity for destroying living organisms.	Higher or lower levels of necrosis are observed according to the type of bacteria.
Give reasons for or against a conclusion	
The number of colonies decreases with UV rays, but the electromagnetic field doesn't affect the growth of these yeasts.	There are bacteria that produce necrosis whilst others are defeated by the bean plant.
Communicate conclusions to an audience	
Presentation in the secondary school (in class and the auditorium) and at the PIISA conference. Publication in the secondary school's newspaper.	

Table 3. Scientific Knowledge

Project 1	**Project 2**
• *Key ideas of molecular genetics.* • *Concept of mutation.* • *Nature of UV radiation and magnetic fields.* • *Reproductive process in yeast.* • *Mutagenesis in yeast due to magnetic fields and UV waves.* • *Study of culturing and counting techniques for yeast colonies.*	• *Cytological study of bacteria. Concept of pathovars.* • *Elements of microbiology: mechanisms of infection by pathogens.* • *Preparation techniques for growth mediums.* • *Fluorescent microscopy: basic notions.* • *Symptomatology of organisms infected by bacteria.*

The Sequence of the Lesson Plan

To establish the sequence of the lesson plan in the instructional inquiry-based teaching proposal (TP), we studied the design of the projects regarding capacities, abilities, and attitudes by tracking the progression of students' knowledge, implemented in the completion of the research undertaken, which was sometimes challenged due to the lack of students' interest in science. Thus, the teaching-learning process was planned to be led by scientists and teachers in four main integrative stages using interleaving during instruction that improves student long-term retention of concepts and generates a better understanding of the relationships among the processes (Ylostalo, 2020). The first and second stages, outlining the problem and solving the problem, specify the previous students´ ideas and the construction of the new ones. By the third stage, Communicating the results, the students apply the knowledge required. Finally, at the last stage, students reflect on the experience.

Its tasks were aimed to contribute to the students' development of scientific competencies (design and evaluation, D; explaining phenomena scientifically, E, and using scientific evidence, U) according to the PISA model (OECD, 2017), considering that these competencies are not independent of others.

Figure 2 shows the relationships in the stages with the tasks and competencies of students involved in the projects and the STEM disciplines involved (in this paper, we also consider the contribution of arts discipline in relation to the connections and the social repercussions established with science, technology, engineering and mathematics).

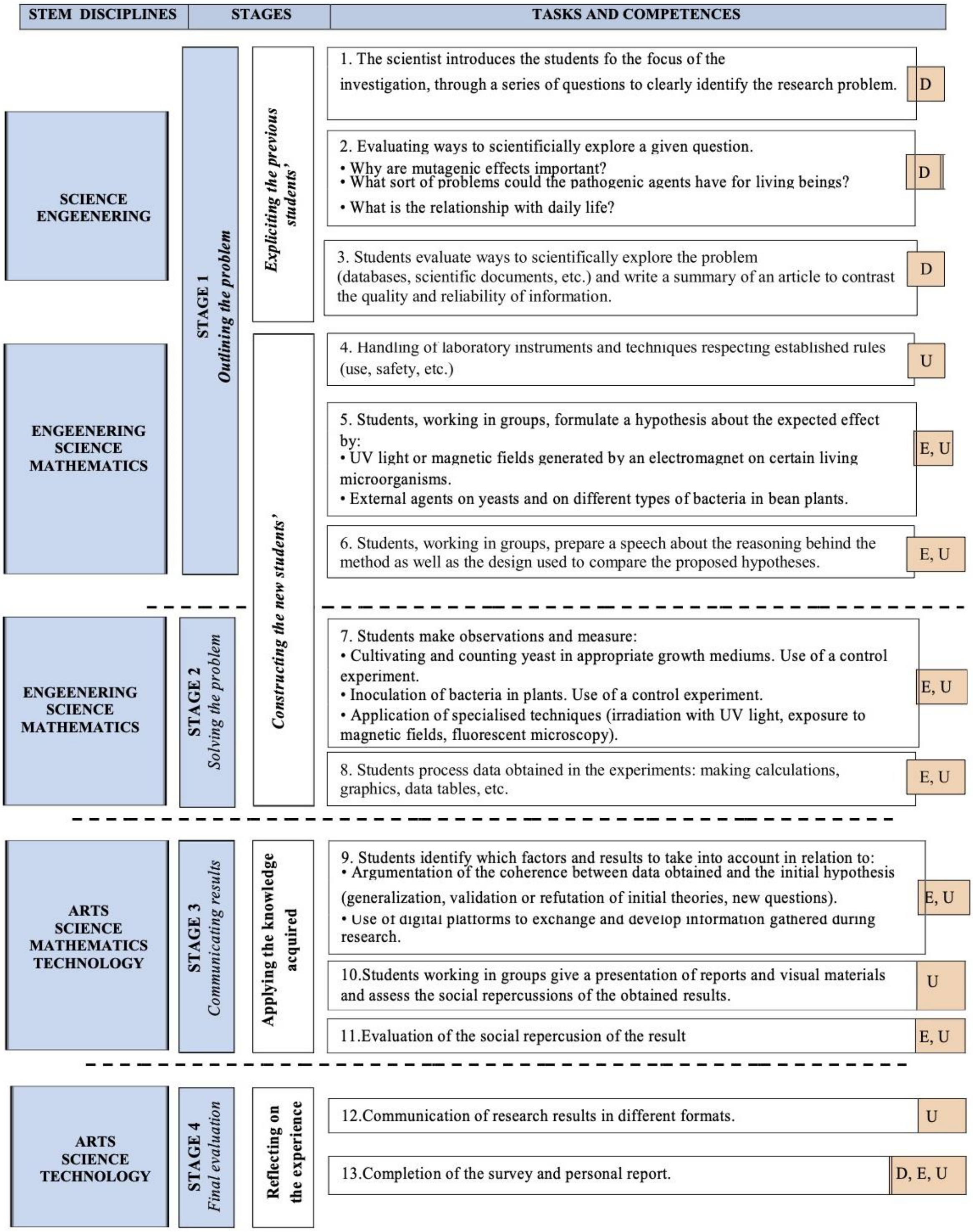

Figure 2. Activities and Competencies Involved Within the Stages of the Projects.

Stage 1. Identifying the problem. In the context of the projects, students present the goal of the study and the related factors. They are prompted to identify the problem (why are mutagenic effects important? what sort of problems could the pathogenic agents have for living beings? what is the relationship with daily life?) and establish connections between their academic knowledge and the proposed situation while reporting their knowledge on the topic (the effects mutagenic or pathogenic agents can produce on living beings) and reorganise their ideas. Thus, developing their scientific competence in design and evaluation (competence D) to recognise the wavelength of the UV radiation and the number of colonies that survive radiation (project 1) or how the pathogenic bacteria cause beans to react, producing necrosis (project 2). Also, in this stage, the students may explain phenomena scientifically (E), and using scientific evidence (U) in their tasks working with scientific instruments or formulating some hypotheses with several suggestions like the presence of different types of radiation affect yeast differently (project 1) or the way as different bacteria react in different ways (project 2).

Perhaps these predictions were limited due to both the reasoning behind the method and the design used to compare the proposed hypotheses by a shortage of specific materials, instruments, and techniques in a secondary school science classroom (specific cultures, UV chambers, electromagnets, autoclaves, and incubation chambers, among others). Nevertheless, scientists and teachers could share the assessments (expectations, motivations, unknown variables) and consider them in the project's future.

Stage 2. Solving the problem. This stage puts in play skills and abilities related to the procedures associated with the design of the experiments in a way to respond to the question exposed (growth of bacteria in plaques, study, and morphology of colonies). It also requires students to identify variables and assess the implications of such changes (presence or absence of a particular gene or explainable mutations) supported by information from relevant sources in a gradual process of appropriation of learning. Thus, the students use scientific evidence (U) and explaining phenomena scientifically (E) when they are analysing their data as the values on the graphs of the number of colonies compared to exposure time to radiation (project 1) or answering given on the danger of magnetic fields and UV rays (project 2).

Stage 3. Communicating the results. The students draw conclusions based on scientific data, for example, when they establish relations with UV ray's capacity for destroying living organisms and giving reasons for or against that conclusion, using the negative effect of the growth of the number of colonies decreases with UV rays or the electromagnetic field (project 1).

Figure 3 shows the strategies and tasks proposed in the TP to support the students' learning about the processes required to answer the hypothesis and show the final congress results involving competencies in relation to data analysis and conclusions, also evaluating social repercussion of results (E, U). In addition to the third face-to-face session, didactic strategies are used online, through collaborative work between students, teachers, and scientists (forums, virtual tools), as well as complementary documents and extra material to develop students' oral and written presentations (posters, slideshows, and oral communications).

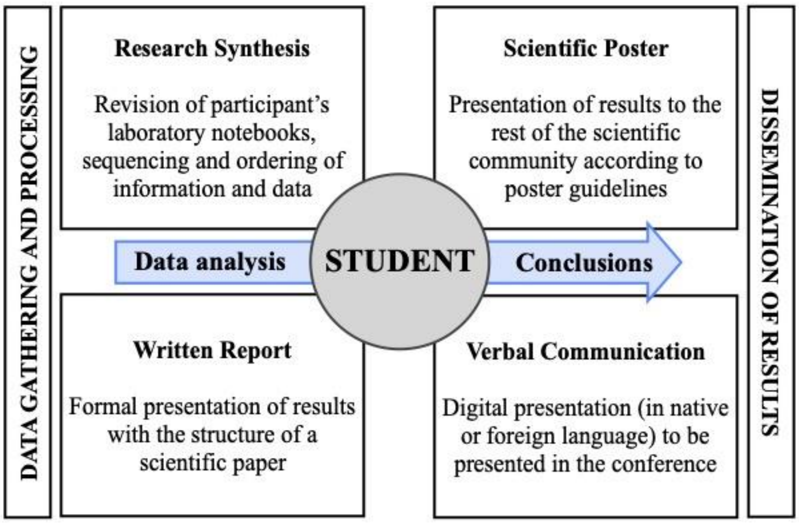

Figure 3. Learning Strategies Involved in Tasks of "Communicating Results"

The knowledge acquired for the students is shown by the results and conclusions established in the research report and the oral presentation to communicate in the PIIISA Congress. They had the autonomy to choose the language (Spanish or English) in the projects' posters (Figure 4).

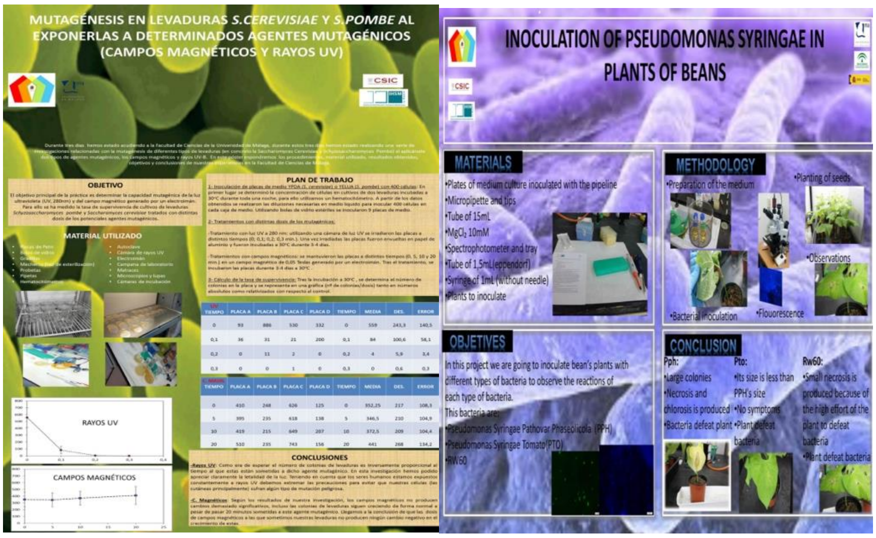

Figure 4. Final Report Presented as a Poster in Projects 1 and 2.

Stage 4. Evaluating the experience. This stage involves the students' evaluation of the learning process with several tools: a student survey (carried out after the end of the conference) to express their opinions about some statements (Appendix A) and their evaluation of the projects. These considerations hold great value according to the PISA criteria assessment model (OECD, 2017) to contribute to the development of their scientific competencies (D, E, U).

The Study Participants

The students who participated voluntarily in the TP were either in their last year of compulsory secondary education (ages: 15 and 16; 10th grade) or at the first year of post-compulsory education (ages: 16 and 17; 1st year of 'A' levels), and the instruction was complementary to their Spanish curricula studies. They were selected based on their high marks obtained in science subjects (biology, physics, chemistry, and mathematics); previous participation in other scientific research programs ("PROFUNDIZA, http://profundiza.org" or Science Summer School) was also considered. All of them participated voluntarily, with a distribution of 8 students working in project 1 (4 females and 4 males) and 10 students in project 2 (5 females and 3 males).

Twenty in-service secondary school teachers participated from a range of six urban state school centres in Andalusia. Thirteen of them belong to the area of Biology and Geology, five to Physics and Chemistry, and two to Technology. 25% had a teaching experience for fewer than ten years, 55% between 10 and 30 years and the remaining 20% had taught for more than 30 years.

Data Collection and Analysis

The evaluation of the designed and implemented TP by the PIIISA scenario and the perceptions of students and teachers relied on several instruments. We recognise the complexity associated with the consideration of perceptions (Mansour, 2015). In this paper, we will assume their meaning in a broad sense that includes attitudes, beliefs, views, and conceptions to achieve a positive impact from the teaching intervention.

Using a Likert-type questionnaire (1, strongly disagree; 2, disagree; 3, agree; 4, strongly agree and 5, completely agree) adapted from the literature to age of the participant students (Fraser, 1981) and validated internationally (Toma & Greca, 2018; Welch, 2010), the researchers carried out the documentary analysis (Atkinson, 1992), assessing the written and visual productions of the students where key terms associated with the research objectives related to predictive aspects present in the questionnaire were identified (Fraser, 1981). The adapted questions were related to aspects such as social implications of science, attitudes of students towards implications of science, scientific research, adoption of scientific attitudes, enjoyment of science classroom, interest in science in leisure time or in studying careers scientific and vision of the life of scientists. Also, an extra question was introduced regarding the teachers' assessment of their experience with students during the project. Since the adapted questionnaire was not used for grading the students and it was completely anonymous and confidential, we agree with Fraser (1981) that fake responses are minimized, guaranteeing the reliability of the data collected this way.

During the research, other instruments were employed. Personal reflections of the participant students were collected through individual portfolio of the work carried out, final reflections on the blog of the PIIISA website and prepared posters. As for the teachers, semi-structured interviews were used, gathered at the end of the TP (Appendix B).

To perform the analysis of the data collected, we have used a mixed-method (Creswell & Plano Clark, 2017) that combines the quantitative analysis of the responses of the questionnaires and the qualitative analysis of their reflections, following a case-study approach (Varsavsky et al., 2014) of each profile collaborator. We followed Yin's guideline (Yin, 2003) to ensure the study's reliability and minimize possible errors and biases when performing qualitative analysis. Thus, all data were codified accordingly, and the researchers met regularly to discuss emergent themes and interpretations.

From the researchers' landscape, this methodology enables identifying individual points of view to obtain an overall group in the stakeholders' views of the collaborative framework in the inquiry process. To do so, researchers first quantitatively analysed the results from the student questionnaire (considering positive responses including "agree," "strongly agree," and "completely agree") and compared them to the qualitative results, with the intention of better illustrating and supporting the opinions expressed by teachers and students. The qualitative responses were categorised inductively to be consistent with the analysis's goals and related to the quantitative results. Researchers established the final value by consensus when a coincidence of 85% on the positive and negative qualitative answers was not achieved.

Results

Students' Inquiry Skills

Figure 5 shows the results of the students' questionnaire about the contribution of the TP to the development of their inquiry skills. *I1* (methods in professional scientific research), *I2* (comparison learning hands/minds-on than with theory) and *I3* (to perform successful investigations).

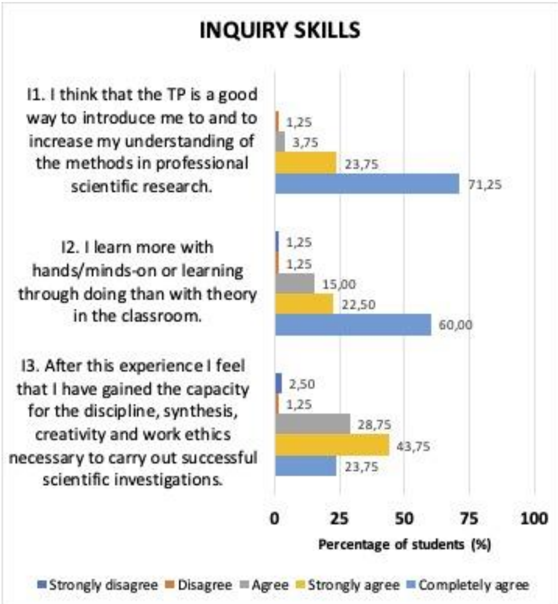

Figure 5. Students' Perceptions About the Contribution of the TP to the Development of Inquiry Skills I1, I2 and I3.

Most of the students (98.75%) were in complete and strong agreement with the methods used in professional, scientific research (*I1*). The students used expressions such as "throughout our research, we have been able to verify and to carry out some of the steps of the scientific method like the development of a question, hypothesising and experimenting, always with our researcher's guidance" (boy, aged 15 years old).

They also considered having learned more with hands/minds-on or learning through doing (97.50%) in comparison to learning through theory (*I2*), thus awakening their interest in "acting" in the world, participating in scholarly scientific practices that model it and allow intentional intervention in phenomena (observing, experimenting, arguing, etc.) and making socio-scientific decisions in an appropriate way.

Finally, 96.25% of the students claimed to have gained the capacities needed to perform successful investigations (*I3*), showing the student's motivation, an active protagonist of the process, who can tackle authentic learning activities based on problems.

Regarding the students' inquiry skills, the surveyed teachers (*T*) almost unanimously agreed that scientific activities induce a positive response in the students (*Question1*). Thus, 45% supported their response in their perception of the influence that the applied methodology could have exerted on the students when confronting them with problem-solving that allows them to give value to theoretical knowledge, questions and share ideas, and be aware of the difficulties associated with research and personal satisfaction: "Your mind thinks more scientifically. They are already asking and looking for answers to different problems" (*T15*); "I think they are more aware of what the research work entails and the discovery of their ideas" (*T5*); "I think they can develop certain scientific competencies related to an increase in rigour in their analysis of reality" (*T20*).

Predictors of Vocational Careers

The students' and teachers´ perceptions of the PIIISA framework brought growing benefits with the students' learning. The joint participation of the programme process arises student-teacher-scientist collaborations allowing interrelationships of diverse routes. Thus, teaching, learning and research have been closely intertwined to get students to participate in authentic epistemic practices and establish connections between the academic context in which it is taught and the real context in which we live (Erdogan et al., 2016). Also, the interactions and communications with others by cooperative working groups promoted greater students' engagement in relation with predictors of vocational STEM careers (Lupión-Cobos et al., 2019) as the following ones:

- *Students' Identities as Potential Scientists*; the students' perceptions about the contribution of the collaborative working environment (Figure 6), showing a positive motivation to work with scientists (*I4)*, to realise this learning process (*I5*) and to dedicate their professional future (*I6*).

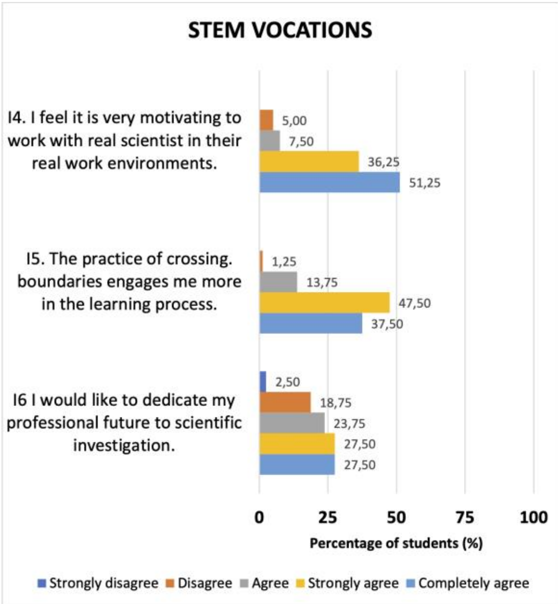

Figure 6. Students' Perceptions About the Contribution of the TP to the Vocational STEM Careers (I4, I5 and I6).

This reflects good values concerning the experimental setting of this framework since 95.00% of the students considered that working with real scientists in their real work environment is beneficial (*I4*). This was also reflected in comments such as: "I love going to the lab. I had always wanted to visit a real science lab. We have an entire building for us! "(girl aged 15 years old); "What we saw is something that would never have happened in a school, which makes it really interesting but difficult at the same time" (boy, aged 15 years old).

They also felt strongly and completely engaged (98.75%) during the learning process, thanks to the practice of crossing boundaries (*I5*). This factor promoted bridges supporting teaching capacities and overcoming the widely identified difficulties teachers face in this educational stage to address instruction in real inquiry processes (Morrell et al., 2020), selecting strategies and dynamics to enable them.

However, the percentage of students considering dedicating their professional future to the scientific investigation was considerably lower (78.75%) (*I6*). Some comments regarding these perceptions are: "This project will help me to decide my future profession" (girl, aged 15 years old); "The time I had there was really interesting and encouraged me to do research in the future" (boy, aged 16 years old); "This experience was exciting because it offers us choices that we did not know" (boy, aged 16 years old); "Doing something that I like, in a place like this, learning about it… it sounds too good! Maybe in the near future, I will be the one doing research every day" (girl, aged 15 years old).

Teachers also considered several predictors of vocational factors related to student connections to this students' behaviour.

- About *scientific attitudes* (*Question2*), 90% of teachers agreed that these projects could make students adopt this type of attitude, either because they allow them to contact scientific disciplines little known or unknown to them or because they awaken a particular interest in science. Thus, the perceptions of this faculty are: 60% of them considered that their students already possessed these attitudes but that the realisation of the experience had reinforced them: "They already showed interest and it is reinforced" (*T4*); "Yes, and they also discover science disciplines unknown to them, such as geology or engineering" (*T14*). 20% of the teachers pointed to the development of certain aspects of scientific competence, especially those related to the attitude towards science (interest in scientific problems, which manifests itself by being more participatory in class) and scientific activity (increases their curiosity and desire to learn): "They become more rational students who ask and wonder, the why of the things" (*T3*); "It is a project that increases their curiosity and desire to learn" (*T12*). Another 20% of the teachers contemplated the possible influence in the personal field by making the students rethink their attitude to their work or their future work: "I think that knowing and practising the way of working of scientists would make them more rigorous and self-demanding and would help them in their maturation" (*T18*); "You have to work this aspect a lot more in the classroom. With participation in the project, it is insufficient" (*T2*).

- The *social implications towards the science* (*Question3*) were also considered. The majority of the teachers (90%) justified that the students participating in the projects acquire a more significant relevance in this feature by means of expressions like: "This type of initiatives make the students aware of research advances in society" (*T16*); "It is the only way in which scientific vocations could be increased" (*T3*).

Specifically, regarding the interest in *studying scientific careers* (*Question4*), it is not surprising that 95% of the surveyed teachers indicate that these students showed interest in studying scientific careers: "I think at least it will help them to know if they really are attracted to continue studying science" (*T11*); "Evidently, not all, but the vast majority" (*T17*).

- *Students´ agency promoted.* The PIIISA cooperative working scenario makes the case that inquiry projects provide students with a greater sense of academic agency. The findings of the students' perceptions (Figure 7) situate authentic scientific inquiry as an individual and collective characteristic of learners (*I7*) and the learning community afford students opportunities to gain expertise (*I8* and *I9*).

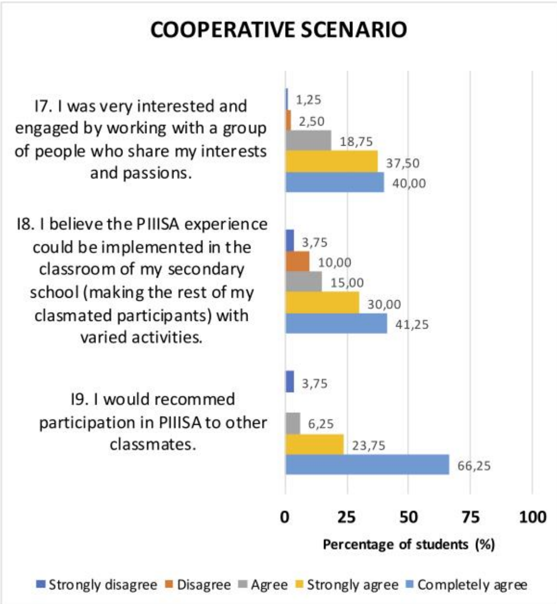

Figure 7. Students' Perceptions of the PIIISA Cooperative Working Scenario (I7, I8 and I9).

Hence, 96.25% of the students found themselves interested and engaged by working with a group of people who share their interests and passions (*I7*). This perception was also supported by comments such as: "What I have appreciated the most is the fact that we have worked as a team" (girl, aged 15 years old); On the other hand, 86.25% of the students believe that the PIIISA experience could be implemented in their secondary school classrooms (*I8*). Finally, and satisfyingly, 96,25% of the students agree about recommending participation in PIIISA to other classmates (*I9*), which was reflected in comments on the students' blogs such as: "I admire that you trust a little group of 15-16 years old students for helping you in your investigation, which I think must be very important for you" (boy, aged 15 years old); "I think this is a unique experience. It is a privilege to be able to research something that has not been researched before" (girl, aged 16 years old); "I have learned so much in such a short time from my scientist (polite but serious). The boys and girls in my group seemed clever than me, but I have learned a lot" (boy, aged 15 years old).

The teaching staff recognised the potential of the cooperative working scenario to challenge students' achievement in science in similar terms, stating for example: "Yes, the classes are less tedious, and they experiment. Whenever students manipulate something, "they become more rational students who ask and wonder, the why of things" (*T3*); "I think they can develop certain scientific competencies related to an increase in rigour in their analysis of reality" (*T20*).

Thus, both teachers and students enhance the significant value of the learning growth benefits promoted from interacting with research centres, developing abilities of the team created by the students-teachers-scientists collaboration, as a key aspect.

Discussion

Concerning the students' inquiry skills, this cooperation succeeds in promoting students' science learning around various domains. Thus, about scientific research (a resource and procedure to achieve the approach to the methods of scientific activity and the acquisition of attitudes and values for personal training) and communication of science (to transmit knowledge, findings, and processes adequately). Also, in relation with the scientific knowledge such as understanding the function of microorganisms in their role as live specimens for conducting trials on living things as well as knowing the scientific basis of devices and instruments involved in microbiology research (incubation chamber, haematocytometer, microscope and magnifying glass, micropipette, and autoclave).

Relative to interdisciplinary learning outcomes of science education through the PIIISA programme, both teachers and students enhance the significant value of developing abilities of the team working created by the students-teachers-scientists collaboration, as a key aspect. Thus, engaging tasks to solve real problems throughout scientists, teachers, and their students may achieve contextualised knowledge by contextualising instruction, with some support for doing so. Perhaps supported by scientists, these challenging problems in teachers' identities, making them part of the scenario rather than observers, has promised to motivate them (Gardner & Tillotson, 2019). Also, this connection brings the interests and motivations of students recognising synergies between their cultural backgrounds and the authentic science settings, recognising the difficulties and efforts in the work and life of scientists and research, and promoting metacognitive skills.

An overall balance of these results may consider both the contribution of the TP in the PIIISA framework to positive students' and teachers' perceptions of the students' inquiry skills and the promotion of greater predictors to vocational careers. Thus, the epistemic work inherent to science and technology involved in this scenario helped the teaching staff in learning spaces by providing scaffolds or references of interest through mutual collaborations with scientists (Mansour, 2015). The tasks made by scientists and teachers (figure 1) facilitate the teachers to focus on teaching aspects involving these mutagenic problems in their overall understanding of the students' genetics (Ylostalo, 2020) and its social function.

Teachers were conscious of the challenges around the limited teaching practice of STEM curricula associated with their beliefs and perceptions. These difficulties were related to classroom management or temporality to address the extension of the curriculum, or consider that only is suitable for highly skilled students (Margot & Kettler, 2019): "They learn that there is another way of doing science that they like more, but they see that reality is different, and the classes at the institute are too academic" (*T10*); "The secondary school teacher should change his way of teaching somewhat" (*T14*); "I hope that is the case, but if we return from the project and the classes are taught as always, the project will remain as a simple anecdote" (*T11*); "Interesting but the benefit/effort ratio must be studied carefully" (*T2*). However, the teachers being in charge of the planning necessary to tackle a STEM project (Margot & Kettler, 2019) and helping them on the pedagogical treatment and the implementation required in the training actions and lessons plan (figure 1) focusing on the students´ scientific competencies (figure 3).

Thus, the use of context in which the STEM projects were inserted, starting from analysing real situations or problems (*why are mutagenic effects important? what sort of problems could the pathogenic agents have for living beings? what is the relationship with daily life?)* is a motivating aspect for students. Nevertheless, at the same time, it represents a new challenge for teachers related to pedagogical content knowledge and content knowledge to build learning (Philip & Taber, 2016) around key concepts (table 2) and skills to solve the problems (table 3).

In this sense, we may consider that the design principles of our TP programme had several factors to contribute engaging tasks to solve real problems and may achieve contextualised knowledge by contextualising instruction, with some support for doing so, closing epistemic scientific work, with features that help STEM Education:

- Using relevant concepts in the Steam projects for both inquiry learning and functional students' competencies allows for hands-on activities and evokes the understanding of content processes or causal relationships. Teachers found that pupils were strongly engaged in hands-on activities and that these activities also positively influenced their engagement in tasks. Also, these hands-on activities facilitate comprehension of the concepts and their context and experiment to find out the circumstances that influence genetic processes.
- Teachers professionalisation. A good allocation of tasks between scientists and teachers was critical and supportive. Perhaps, the challenging problems in teachers' inquiry competence were helped by scientists, making them part of the scenario rather than observers, which has promised to motivate them (Gardner & Tillotson, 2019). Also, the availability of materials. Almost all teachers kept engaged throughout the content and the teaching materials, which provided meaningful feed activities.

Conclusion

We have successfully designed and implemented a STEM inquiry-based TP to develop students' science learning throughout genetic problems by a PIIISA cooperative working scenario with several conclusions. However, we are aware that these results should be treated with caution, given the low number of students and teachers involved in the STEM projects.

Also, we may consider several contributions of this programme to science education, in line with Eilks and Hofstein (2015) approaches, where the visions of the individual, society, and vocation are contemplated.

Our STEM inquiry-based scenario has allowed a methodology based on students-teachers-scientists collaborations bringing together the context and content regulating their learning and contributing to their acquisition of scientific knowledge used faced with real problems to favour the development of their scientific skills and competencies, together with other key competencies (OECD, 2017).

Thus, the collaborations established between secondary schools and research centres also supported the sense of community among participants, enhancing in this way their emotional attitudes towards science and its practising, which has also allowed students to gain insight into social implications of science, bringing the vision of the life of scientists closer and new opportunities to further collaborative learning scenarios for science education.

Likewise, and very significantly, we highlight their instructional contribution to vocational predictors in S and T, bringing students information about STEM areas and their capacities related, offering them academic and professional guidance that can help them develop a realistic vision of future career options ((Lupión-Cobos et al., 2019).

Recommendations

Our results will help teachers deepen the teaching analysis of changing to approaches with a more active methodology for teaching science through specific and relevant "contexts" such as mutagenesis processes by STEM projects with inquiry teaching competence promoters of truly epistemic scientific practices. However, we are conscious of the diversity challenges in our educational systems that encourage us to keep working on the search for active strategies promoters of these scientific practices, using integrative STEM approaches (Margot & Kettler, 2019). In this sense, two possible lines of work are offered of interest to continue from this work. Firstly, to investigate this type of experience in interdisciplinary teaching teams where expert exchange from different areas might promote confidence and effectiveness in the teaching performance of the design and execution of applied STEAM projects. Secondly, we understand that by exploring the emotions experienced by the participants, both teachers and students could provide information of interest to integrate more powerfully the connections between knowledge, skills and attitudes, in a framework aimed at the formation of active citizenship, fulfilling the current demands of our society. These joint actions would facilitate students to apply their knowledge in social and personal real situations, offering, in short, opportunities to promote scientific vocations of our future generations.

Limitations

We consider that this scenario will help teachers on their professional development, improve self-efficacy with inquiry teaching competence promoters of truly epistemic scientific practices, and decrease teaching anxiety to engage classroom practices. Nevertheless, we are aware of the necessity of improving data collection regarding teaching staff and scientists from research centres, using validated questionnaires to know their impressions in a more objective way.

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Authorship Contribution Statement

Lupión-Cobos: Conceptualization, design, data acquisition and analysis, writing. Girón-Gambero: Editing/reviewing, supervision. Girón-Gambero: Conceptualization, design, data acquisition and analysis. García-Ruiz: Conceptualization, design, data analysis, writing, editing.

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Appendices

Appendix A - Students' Evaluation of The Learning Process (Survey)

Dear student,

In order to evaluate your experience in the PIIISA program, please choose one of the next values for each statement: 1 (strongly disagree), 2 (disagree), 3 (agree), 4 (strongly agree) and 5 (completely agree)

Male/Female: Age:

STATEMENTS

I1. I learn more with hands/minds-on or learning through doing than with theory in the classroom.

I2. I think that the TP is a good way to introduce me to and to increase my understanding of the methods in professional scientific research.

I3. After this experience I feel that I have gained the capacity for the discipline, synthesis, creativity and work ethics necessary to carry out a successful scientific investigation

I4. I feel it is very motivating to work with real scientist in their real work environments (labs)

I5. The practice of crossing boundaries engages me more in the learning process.

I6. I would like to dedicate my professional future to scientific investigation.

I7. I was very interested and engaged by working with a group of people who share my interests and passions.

I8. I believe the PIIISA experience could be implemented in the classroom of my secondary school (making the rest of my clasmated participants) with varied activities.

I9. I would recommed participation in PIIISA to other classmates.

Appendix B - Teachers Semi-Structured Interviews

QUESTIONS

Q1. Do you think that students' attitudes towards research could change after participating in a PIISA project? For example, they would prefer to find out why something happens by experimenting instead of being told by the teacher or reading it in a scientific journal, etc.

Q2. After participating in a PIISA project, do you think students could adopt scientific attitudes? For example, being curious about the world around them, enjoying reading information that does not follow their ideas, repeating experiments to verify that the results are correct, etc.

Q3. Do you think students have a greater social involvement toward science when they participate in a PIISA Project? For example, they would say that it is good to spend money on scientific research, that science helps make life better, that science is not an enemy of man, etc.

Q4. Do you think that students who have participated in a PIISA project will show a greater interest in studying science careers? For example, they would like to become scientists; they would work in a research laboratory; they would think that science careers are not boring, etc.