Stem-KIT: An interdisciplinary approach to learning physics and computer science

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***Abstract*—Contribution: This study aimed to develop, test, and evaluate an educational kit for high schools that fosters a multidisciplinary bond between physics and computer science. Grounded in constructionism, the kit encourages students to take a more practical approach towards STEM subjects by using simple Arduino-based boards and sensors to measure physical quantities during simple experiments. The project was a collaborative effort between the University of Trento and Level Up, a local company that produces innovative educational materials related to physics and science for schools. The study involved 16 high schools with over 300 students and about 20 physics and informatics teachers. The kits were validated through questionnaires and interviews, with an emphasis on assessing changes in student motivation, interest in STEM subjects, and practical experience.**

Background: The learning-by-doing approach is central to constructionism, which emphasizes the importance of hands-on, experiential learning in education. This approach is often neglected in the Italian school system, which tends to prioritize theoretical studies that are distant from real-world problems and applications. Part of the problem is the lack of experimental sets available to each student.

Intended outcomes: First, to create an educational kit that high school teachers could use to provide their students with practical experience in their physics curricula and enable them to apply their knowledge of computer science to arrive at better results. Second, to measure a change in students' interest in STEM subjects once they experience a more practical approach using the educational instrumentation created in the project. Another goal was to increase their motivation and engagement in the learning-by-doing process and to help them understand the importance of a multidisciplinary approach.

Findings: The students who participated in the project were asked to complete two questionnaires regarding their approach and motivation towards STEM subjects, both before and after using the educational kit. The answers were divided by gender to determine if there were any differences in approach. The study recorded a very positive response from the students and a growing motivation towards this type of hands-on method used during classes.

***Index Terms*—STEM, educational kit, high school, computer science, programming**

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I. Introduction

STEM education is critical in the 21st century due to the increasing demand for STEM skills in the workforce [2]. However, traditional teaching methods often fail to engage students and cultivate interest in these subjects.

Historically, STEM education has been characterized by rote memorization and theoretical teaching methodologies [1]. These traditional methods often fail to provide students with real-world context and practical applications for the concepts they are learning. As a result, many students find STEM subjects abstract, difficult to understand, and ultimately, uninteresting.

Moreover, the lack of experiential learning opportunities in traditional STEM education presents another barrier to student engagement. Research has repeatedly shown that hands-on, applied learning experiences increase student interest, comprehension, and retention in STEM subjects [3], [5]. Despite this evidence, many educational systems continue to emphasize theoretical instruction over practical learning experiences.

Furthermore, the interdisciplinary nature of real-world STEM problems is often not reflected in STEM education. Instead, science, technology, engineering, and math are frequently taught as separate, isolated subjects, which can prevent students from understanding the interconnected nature of these fields [4].

To tackle these issues, this project focused on the development, testing, and evaluation of an innovative educational kit designed to bridge the gap between physics and computer science in high school education. This endeavor was the result of a partnership between the University of Trento and Level Up, a company specializing in creating educational materials for physics and science.

The educational kit employs Arduino-based boards and sensors to enable students to conduct simple experiments and measure physical quantities, thereby offering a hands-on approach to learning. This strategy is a marked departure from the traditional Italian education system, which leans heavily towards theoretical instruction, often at the expense of real-world application.

The project's primary objectives included creating a tool that would enhance the practical aspect of physics education and allow students to leverage their computer science knowledge to optimize results. We also sought to gauge changes in students' interest in STEM subjects and their motivation levels when exposed to a more practical, hands-on approach.

Over the course of the project, we developed and distributed the educational kit to 16 high schools in the Trentino region of Italy. The design of the kit encourages cooperative learning, with two or three students working together to assemble and operate the instrument, test its functions in varying situations and environments, and even devise an experiment to verify a physics law from their curriculum.

This study is grounded in the learning theory of constructionism, which posits that learning is most effective when students are actively involved in a constructive process [7]. This theory emphasizes the importance of hands-on, experiential learning, a concept often neglected in traditional education systems. Our work aligns with this theory, as we advocate for a learning-by-doing approach to foster a multidisciplinary bond between physics and computer science. The use of hands-on activities in science education has been shown to be an effective way to engage students and enhance their understanding of complex concepts. Additionally, learning is more meaningful and relevant when connected to real-world applications and problem-solving. Our goal was to shift the focus from rote learning towards an experiential, problem-solving approach using our educational kit.

Since our kit is based on new technologies, i.e. Arduino and a set of sensors, we are framing our work inside the "Technological, Pedagogical and Content Knowledge" framework [6] [8]. Specifically, we are interested in the study of the intersections between Technology Knowledge (Arduino), Content Knowledge (Coding and Physics) and Pedagogical Knowledge.

In this paper, we explore the use of the Stem-kit, a ready-made educational kit that allows students to conduct experiments and analyze data in a hands-on manner. We examine the experiences and perspectives of thirteen high school physics and computer science teachers who used the kit in their classrooms. By analyzing their feedback, we aim to shed light on the strengths and limitations of the kit, as well as its potential for promoting constructionist learning in science education.

Findings from the study indicated a positive response from the students, with a notable increase in motivation and interest in STEM subjects. This project underscores the potential benefits of a more practical, experiential approach in STEM education, setting a strong case for its broader application in the educational system.

II. Background and Significance

The main objective of this project is to promote the development, research, and experimentation of innovative interdisciplinary teaching methodologies in STEM fields. Specifically, the project aims to bring together two disciplinary areas - physics and computer science - which are normally taught separately, encouraging collaboration and hands-on experimentation.

The project primarily targets high school students (from 8th since 12th grade) and STEM subject teachers (mathematics, sciences, physics and computer science). Its main output is an interdisciplinary teaching path based on educational research in computer science and physics. This path leverages new technologies related to low-cost sensors (such as Arduino) and methodologies typical of makerspaces and Fablabs to investigate the world from a physics point of view.

The purpose of this path is to promote technical-scientific culture in the school world, with the collaboration of both physics and computer science laboratories. Specifically, this path consists of the following components:

- A specific kit designed by the University of Trento and a local firm specializing in educational products, Level Up. The kit is composed of hardware systems, sensors, and instrumentation aimed at facilitating the realization of personal experiments using easily available and low-cost components.
- Documentation for teachers and worksheets for students, which illustrate the possibilities offered by the kit and encourage personal exploration.
- Training activities for teachers on the use of the kit and associated teaching methodologies, led by trainers from partner organizations.

This path (kit, activities, training) enables the exploration of physical phenomena through the combination of physics, technology, and computer science. It allows for the construction of instrumentation, including its programming, which is necessary for conducting experiments.

One of the strengths of the project is its ability to introduce computer science paths in school contexts where coding paths are often lacking. This is particularly important in the present digital context, where a lack of computer science education is unacceptable.

A. Kit design

The Stem-kit, developed during the project, consists of an Arduino Uno board, five different sensors, and various materials created using typical Fablab machinery. All the educational materials for students and teachers, including scripts and an introductory manual for learning about Arduino, its software, and the available sensors, can be found on the Level Up website (https://leveluptrento.com/kitmisura/). In addition, the design files to independently create the various parts that make up the kit can also be downloaded from the website.

The instruments created during the project focused on the broad measurement aspect in STEM subjects (science, technology, engineering, and mathematics) and the challenges associated with obtaining accurate measurements and constructing an optimal experimental apparatus. The objectives chosen for the kit are twofold: firstly, to bring the study of measurement closer; secondly, to enable laboratory work with an experimental approach closer to that of a researcher's work method.

In addition to the objectives previously mentioned, the kit also has several positive aspects. Its hands-on structure and small volume make it highly practical and portable. Moreover, the educational materials already prepared for the teachers to use are highly beneficial, especially for those schools that do not have physics and computer science as curricular subjects, or lack a physics laboratory and the necessary instrumentation to carry out experiments. Thanks to the kit, these schools are able to have an almost complete physics laboratory in their own classroom. The only object not included is a computer for every group of students, however, this tool is now available in almost every school. Overall, the kit provides an effective solution for schools with limited resources to offer students a high-quality STEM education.

The kit delves into the different stages of the scientific method and the laboratory research methods, drawing inspiration from the daily activities of a physics laboratory in a university setting. Students are encouraged to think like researchers, who are investigating a poorly understood phenomenon. To accomplish this, they must construct their own measuring instrument from the ground up, utilizing the Arduino Uno and one or more sensors. After creating the tool, they must grasp its functionality, limitations, and usefulness in studying the selected physical phenomenon.

The project has developed eight experiments that can be carried out progressively throughout high school years. Teachers can choose to address a specific topic at any point or jump from one topic to another, depending on their preference. Here is a list of the experiments:

1) Reproducibility
2) Calibration
3) Range and Sensitivity
4) Responsiveness
5) Comparison of measurements: Beer-Lambert's law
6) Measuring the invisible by studying polarization
7) Measuring variations: the coefficient of friction
8) Measuring moving objects: analysis of sliding motion along an inclined plane

The first four experiments are related to the concept of measurement. The initial experiment prompts students to consider what constitutes a scientifically accurate and accepted measurement, specifically the idea of reproducibility. Students contemplate experimental equipment and setup, as well as external factors that may impact a measurement and ways to take these factors into account or limit them when possible. The second experiment helps students reflect on the calibration of a measuring instrument and presents alternative solutions in case calibration is too challenging to achieve. In the third experiment, students are encouraged to understand the limits of their instrument, including range, sensitivity, and minimum measurement. Finally, the fourth experiment prompts students to reflect on the responsiveness of a sensor, which can negatively impact measurements made in certain types of experiments, such as those measuring very rapid phenomena or moving objects. These activities can be carried out using almost all the sensors available in the kit.

The next four experiments are complete investigations that require the application of the concepts learned in the previous activities. These experiments aim to study a physical phenomenon taking measures under different conditions and using various approaches. In the fifth experiment, students use the photoresistor to study Beer-Lambert's law, which is typically not covered in the curriculum, with the goal to observe an exponential trend in a graph. The sixth experiment explores the phenomenon of light polarization and the associated trigonometric law. In the seventh experiment, students measure the coefficient of friction of different materials using a gyroscope, while the eighth experiment involves analyzing the sliding motion of an object on an inclined plane.

III. Methodology

The study was conducted in two northern Italian regions, namely the Autonomous Province of Trento and Veneto. During the development of the first prototype of the kit, a pilot test was conducted in five different groups of high school students to improve the materials and experimental setup. The activity's duration varied among the schools to study the effect of adapting the same activity to different time constraints. These initial meetings were critical in evaluating students' autonomy, the necessary time for each phase, and identifying the most interesting topics requested by teachers. The goal was also to ensure that the materials were easily accessible and low-cost. As part of the pilot test, students were asked to provide feedback on the kit's usefulness and impact via a survey.

After developing the kit, 16 high schools in the area were selected to receive 10 units each and test them under the guidance of an expert. Prior to commencing the testing phase, three training sessions were held to acquaint teachers with the use of the new equipment, which was unfamiliar to most of them.

A. Students' sample and data collection

Pre- and post-meeting surveys have been conducted to collect feedback from students who participated in the project.

A brief introductory questionnaire was administered before the expert arrived in class to gauge previous experience with Arduino, self-assess students' skills, and interest in STEM subjects, particularly physics and computer science. The pre-meeting questionnaire yielded a total of 385 responses, with all students completing it as assigned homework. The survey was organized into two sections. The first section asked students basic questions about their school, class, and gender. The second section focused on their interest in STEM subjects and willingness to learn about coding and Arduino.

The post-meeting questionnaire was conducted in class at the end of the activity, resulting in 324 responses from students. Of these, 188 identified as male, 122 as female, and 14 (less than 5%) did not specify their gender. Due to the small number of unspecified gender responses, this data was excluded from analysis. The second survey focused on the impact of the activity on the students, including whether it changed their minds about STEM subjects and their appreciation of these types of classes.

Of the 324 responses, a significant majority of 73.7% were from students attending a scientific high school (Liceo Scientifico), whereas 12.6% attended a humanities high school (Liceo Classico and Liceo Scienze Umane), 10.4% a technical school, and 3.3% attended an artistic high school (Liceo Artistico). This bias towards scientific high schools can be attributed to the greater interest among teachers working in those institutions, where more time is dedicated to the teaching of physics. In contrast, in technical schools, computer science is an important subject, while physics is primarily taught only in the first few years. Humanities and artistic high schools have little to no exposure to computer science and very limited time dedicated to physics.

From the point of view of age, the examined sample was highly diverse, with students from every age group. The largest group was composed of first-year high school students, accounting for 38% of the total number, while the smallest group was made up of fifth-year students, accounting for only 4.9% of them. The remaining students were distributed as follows: second-year students made up 22.8%, third-year students made up 15.7%, and fourth-year students made up 18.5%.

B. Teachers' sample and data collection

In addition to the data collected from anonymous student questionnaires, teachers were also invited to share their opinions on the Stem-kit to help identify areas for improvement and to evaluate the strengths and weaknesses of the educational materials. Due to the large geographic area covered by the project, the interviews were conducted online to efficiently gather data within a limited timeframe. The questions were designed to focus the teachers' responses on topics of greatest interest, while still allowing them to express their opinions freely. The interviews were kept to a maximum of 30 minutes to avoid becoming overly detailed, which would not serve the purpose of the project. Participation in this phase of the research was voluntary, and while all 28 teachers were contacted, interviews were conducted only with those who were available.

Thirteen teachers, comprising 9 females and 4 males, agreed to participate in the interview. Most of them teach physics and mathematics, while one teacher specializes in systems and networks, and two teachers focus on computer science. To maintain the anonymity of the data, each teacher is interviewed individually, even if some of them belong to the same school. The collected data are then aggregated using cluster analysis. About 69% of the interviewed teachers come from scientific high schools, which aligns with the majority of the students' schools. The remaining 31% is equally split between artistic and technical high schools.

The interview was structured into three phases. In the first one, the teachers were asked questions about their daily teaching practices. The second one focused specifically on the Stem-kit and its implementation in their school. Finally, the third and last phase explored the buying habits of schools and how schools choose to allocate their resources.

IV. Result and discussion

A. Students' feedback

The students showed a high level of appreciation towards the activity conducted in class with the Stem-kit, with 65% of the responses rating it above 4 on a scale of 1 to 5, where 1 indicated ”not interested at all” and 5 indicated ”very interested. This scale was used in the whole survey, pre and post meeting. The difference in responses between males and females is negligible: the curve for males is slightly skewed towards grades 4 and 5, while for females, it is shifted towards grades 3 and 4. The peak of the response for both genders is recorded at grade 4.

One of the essential aspects that we investigated was how well the students assessed their competences in the subjects covered by the kit. The first question focused on their proficiency in physics (Figure 1). The results from the pre-meeting survey show that neither gender expressed a high level of confidence, with both genders peaking at rating 3. In particular, the female gender tended to indicate a medium-low rating regarding their preparedness on physics, with ratings 2 and 3 accounting for around 37% of the votes. Conversely, the male gender showed a pyramidal trend centered on rating 3.

In the post-meeting survey, it was evident that the students were more confident in their competences on the physics topics covered during the activity (Figure 2). The peak for both genders shifted noticeably towards rating 4. The male gender showed a generally lower distribution, which was more evenly distributed among ratings 3, 4, and 5 and less peaked than the previous responses. On the other hand, for the female gender, there was a significant difference in the results. The peak of the distribution was at rating 2.5 before, but now it is at rating 4 with a remarkable increase of almost 20%, compared to less than 5% previously. Moreover, rating 2 had a drastic drop from 38% to 16%.

The researchers also investigated the students' preparedness in computer science topics. The initial survey results revealed a trend of average-low grades for both genders, with females scoring lower (Figura 3). This pattern could be attributed to the absence of computer science as part of the curriculum in many schools. However, after using the Stem-kit, students realized that the required computer knowledge was achievable (Figura 4). Consequently, both genders showed an improvement in their grades, with the female gender peaking at grade 3 and the male gender slightly higher at grade 4. It appears that males feel more confident and comfortable in dealing with the demand for computer science knowledge, while females, despite an improvement, still feel generally less prepared in these topics.

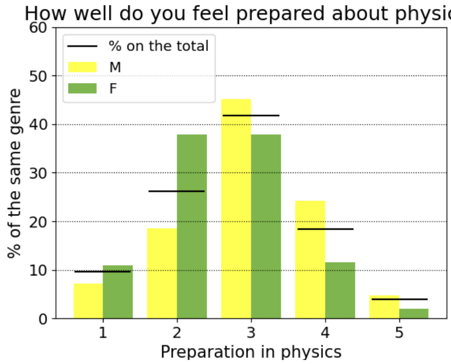

Fig. 1. The self-assessed proficiency of the students in physics *before* the activity with Stem-kit.

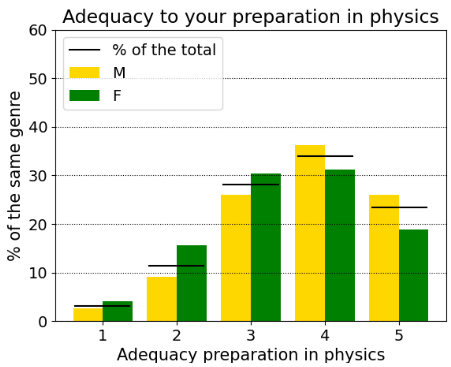

Fig. 2. The perceived proficiency of the students in physics *after* the activity with Stem-kit.

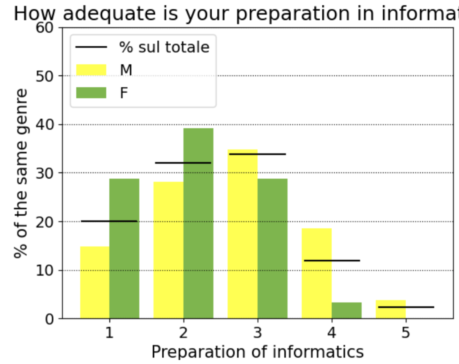

Fig. 3. The self-assessed proficiency of the students in computer science *before* the activity with Stem-kit.

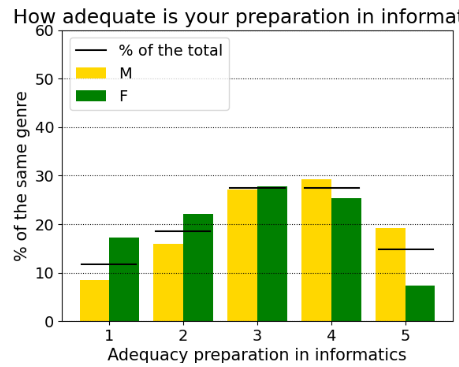

Fig. 4. The self-assessed proficiency of the students in computer science *after* the activity with Stem-kit.

Another aspect investigated was whether the students' liking for computer science was influenced by the use of the Stem-kit. The pre-meeting survey data revealed a significant gender disparity, with the male gender showing a peak of votes at 4 and the female gender having a pyramidal distribution centered on 3 (Figura 5). However, after the activity, the distributions became more similar (Figura 6). The male gender distribution remained mostly unchanged, with a slight decrease in votes at 4 and an increase in votes at 2. On the other hand, the female gender distribution shifted significantly towards higher votes, with over 40% of female students giving a score of 4 or higher. By showing female students that they are capable of mastering computer science concepts, the kit may have increased their confidence and sense of belonging in the field. This increased confidence may have translated into a greater enjoyment of the subject matter.

The survey included questions about the students' level of engagement and interest during both the regular classes (Figura 7) and the activity with the Stem-kit (Figura 8). The results indicated a medium to high level of interest, with male students showing a peak at mark 4 and female students at mark 3, although the overall distributions were quite similar. In the post-meeting survey, a marked shift towards higher scores was observed for both genders, especially for male students.

One of the key questions in the survey was the level of interest in STEM subjects that each student had and how the use of the Stem-kit affected their interest. The pre-activity data revealed two similar distributions for both genders, with peaks at mark 4 (Figura 9). The male responses were slightly shifted towards higher marks, while the female responses were flatter, with 30% of marks equal to or less than 2. After the activity, the male responses remained almost unchanged, while the female responses showed a large plateau between marks 2, 3, and 4, and a significant decrease in marks 5 (Figura 10). The peak shifted to mark 3. The second survey question was ”Do you feel more curious about scientific subjects than before?” The data suggested that the male gender recorded greater interest and curiosity towards STEM subjects after engaging with the Stem-kit, whereas the female gender did not feel equally stimulated by the proposed activity. The pre-meeting data confirmed that female students were already quite interested in STEM subjects, and their interest remained unchanged.

B. Interviews with teachers

Several teachers were interviewed, and they explained that their yearly curriculum is determined by both the ministry's plan and their institute's internal planning at the departmental

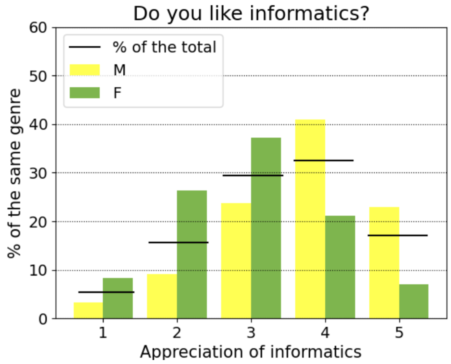

Fig. 5. The interest of the students in computer science *before* the activity with Stem-kit.

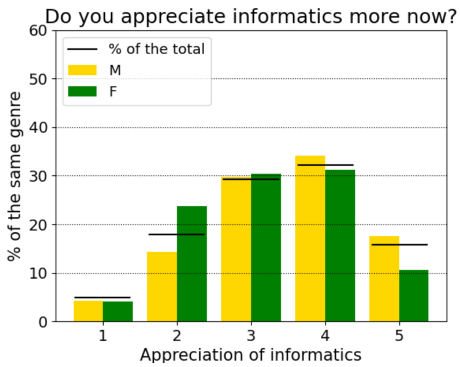

Fig. 6. The interest of the students in computer science *after* the activity with Stem-kit.

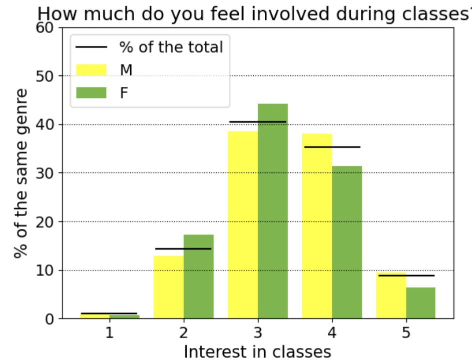

Fig. 7. The level of involvement and interest of the students during classes *before* the activity with Stem-kit.

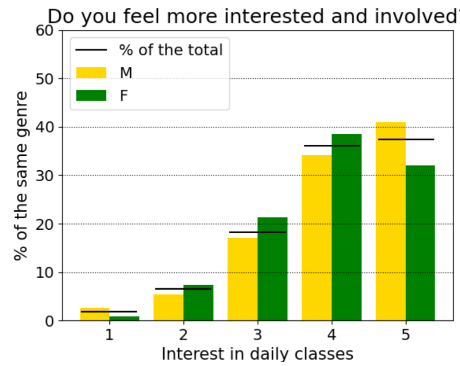

Fig. 8. The level of involvement and interest of the students during classes *after* the activity with Stem-kit.

level. The internal planning is designed to ensure a consistent progression of classes and to guarantee that parallel tests are conducted between classes of the same year. However, the teachers also pointed out that the number of topics covered during the year can be overwhelming, which affects the amount of time dedicated to practical activities and the use of laboratories. Despite this, the teachers acknowledged that practical methodologies are the most effective in engaging and retaining students' interest in the subject matter. To strike a balance between theoretical and practical lessons, many teachers try to alternate between them to involve students more effectively. However, the availability of time remains a significant obstacle in implementing this approach.

Around 50% of the interviewed teachers aim to utilize the laboratory once a month for each topic covered in their curriculum. However, there are two distinct approaches adopted by teachers towards laboratory-based activities. Some teachers conduct relatively complex experiments either at their desk or with the assistance of a laboratory technician, while the students observe and record the data for later analysis either in class or as homework through report writing. On the other hand, some teachers prefer to engage their students in more hands-on activities, where they themselves carry out the experiment, sometimes with the help of a pre-compiled laboratory sheet, especially in the first two years of high school. The latter approach is often due to the limited availability of equipment that students can utilize or the lack of sufficient equipment to cater to an entire class. While experiments carried out by teachers at their desk are more effective than theoretical frontal lessons, they can be less engaging for students, thereby reducing their effectiveness in understanding the concepts related to the activity.

Many teachers are fortunate to have access to a wealth of technological teaching materials, often acquired through various grants that support laboratory equipment renewal and teacher training. These materials include software simulators that allow students to conduct virtual experiments while modifying input parameters and analyzing the results obtained with their computers. In addition, teachers use various software programs to analyze data and create graphs, as well as microcontrollers such as Arduino, Raspberry, and Microbit to design simple experiments, which are not always related to the physics or computer science curriculum. These microcontrollers are often used in extracurricular activities, such as robotics and IoT.

However, despite the availability of such tools, a significant number of teachers are not using them effectively. One reason for this is the lack of proper training, which is necessary to

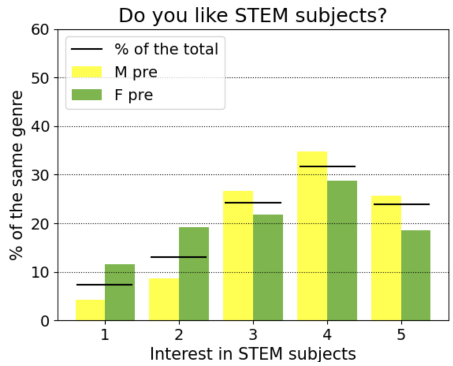

Fig. 9. The interest in STEM subjects *before* the activity with Stem-kit.

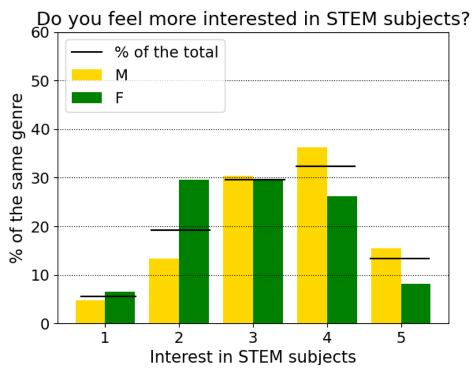

Fig. 10. The interest in STEM subjects *after* the activity with Stem-kit.

use these tools effectively. Many teachers feel that they are not adequately equipped to use these tools independently, which often leads to their reluctance to integrate technology into their teaching practice. As a result, only a small proportion of the teaching staff uses these advanced technological tools.

Regarding the Stem-kit activity, more than half of the interviewed teachers decided to participate because it allows students to put their knowledge into practice, conduct experiments from start to finish and receive technological materials that remain available to the school. Almost half of the teachers also acknowledged the multidisciplinary aspect of the kit as an attractive feature, which distinguishes it from other materials available in the market. In addition, some teachers emphasized the importance of discovery activities, which are possible with the Stem-kit, as an essential aspect for students.

According to the teachers, the level of student engagement with the Stem-kit activity was generally similar to that of traditional laboratory activities. Some students exhibited greater motivation, especially those who typically have more difficulty paying attention and are less interested in the subject matter, although not all teachers shared this opinion. Several teachers observed differences in attitude between male and female students. They noted that girls tended to be more cautious when it came to the computer aspect of the activity, fearing mistakes. However, once they understood the task and felt more comfortable, they often achieved better results. Male students on the other hand, tended to be more eager to participate and more willing to take risks, sometimes overlooking the need to fully understand the task before diving in.

The majority of teachers (8 out of 13) confirmed that the Stem-kit is comprehensive in terms of both materials and didactic instructions. However, the remaining teachers had differing opinions. Some felt that the instructions were too lengthy and detailed, leading students to skip over them. Others pointed out that some requests were not explained clearly enough. Two teachers suggested that interactive sheets be provided for completion, as it would be helpful for students, particularly those in their first two years of study, to have a guide to follow when writing their reports.

The interviewed teachers have expressed overwhelmingly positive opinions about the Stem-kit, particularly in comparison to other available kits in the market. The experiments found in these kits were often found to be poorly defined and lacked appropriate references to the concepts covered during the school year. In contrast, the Stem-kit was highly praised for its strong educational content, which allowed for hands-on experimentation with the ability to apply learned concepts. Another significant benefit of the Stem-kit is its portability, which enables teachers to perform experiments in the classroom, especially useful for schools that do not have a dedicated laboratory and adequate instrumentation. Finally, the aspect of interdisciplinarity was highly appreciated, as it allowed students to work collaboratively in small groups, building experiments and accompanying students in the personal discovery of the activity.

V. Conclusion

In conclusion, the development and evaluation of the educational kit proved to be a successful endeavor in promoting a more practical approach towards STEM subjects among high school students. The kit enabled students to gain hands-on experience in constructing and operating instruments while learning about the close relationship between physics and computer science. The multidisciplinary aspect of the kit encouraged students to think creatively and solve problems in a collaborative setting, increasing their motivation and engagement in the learning process. The positive response from students and teachers validates the effectiveness of the kit in promoting a more practical and engaging approach towards STEM education. This project could serve as a model for other schools and institutions seeking to promote hands-on, interdisciplinary learning in their curricula.

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