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PHYSICS APPLICATIONS: THEIR IMPACT ON STUDENTS' MOTIVATION AND PERSPECTIVE OF STEM

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Abstract

In physics classes, the pedagogical implementation of activities based on real life problems has been proved fundamental in the knowledge acquisition from behalf of the students. As many generations before them, today's students have a very significant restlessness related to the practical application of their knowledge. Being able to relate classroom contents with their professional, or even day-to-day lives, can never be underestimated in the students' learning, but this doesn't mean it is any less of a challenge for teachers.

It is important to understand the relation between practical knowledge and the intrinsic motivation in the students. A student that understands that his learning goes beyond a single class (or a single topic) and that has a better understanding of the practical applications is going to be motivated and therefore, more willing to learn new concepts.

The authors have designed and implemented an activity in which they present a simplified version of a stay-cable bridge. The physics students would create a pre-design of the structural elements based on their knowledge of Newton's First Law of Movement viewed in class and compare their results with a structural model in a software. The activity is similar to the exercises that Civil Engineer students face in their studies. The objective is to show them how the book-based problems seen in physics (or even in math) are just the first step they have to take in order to understand a much larger amount of concepts once they've reached a college level of physics or even in their future jobs as engineers.

In this paper, the authors are going to present a qualitative investigation of the student's perception of the real-life activity. The objective of this research is to find out if this activity has had an impact on the student's ability to see the bigger picture of their studies and, by consequence, increase their motivation to study the topic. This investigation will be based on high school students, specifically 12th grade. These students are a year away from entering college and choosing their career path, so the understanding of the purpose of their current high school studies is highly relevant.

Key words: Educational innovation, STEM, K-12, physics education, educational narrative.

I. Introduction

Students' motivation is an intrinsic aspect of learning and yet one of the most difficult to guarantee. Students are constantly asking themselves what the use of their classroom learning is. Most teachers are familiar with the questions: "when will I use this again?", "why are we learning this?", "what is it for?". In order to answer these questions in K-12 levels, we need to go beyond the simple answer "you are going to use it in college" [1]. It's important that students understand that they are not learning a set of individual topics in the class. They are developing the academic competencies that allow them to go beyond the singularity of the topic and connect it to a global picture of knowledge.

The narrative in which teachers present the applications of their class activities is highly relevant. Siew et al., [2] proposes that an important factor of the reduction of STEM interest is the method in which teachers approach the topics in class. Students leave the classroom with a perception that the STEM topics are too hard, too boring and not worth the effort. Over the last years many educational tendencies, such as Competencies Based Learning, gamification [3] and storytelling, have emerged in order to avoid this misleading situation. These tendencies have explored the increase in students' motivation by simply changing the way in which a topic is presented.

To change the narrative, it is necessary to leave aside the "textbook problems" and focus more on the analysis of applications, especially when the subject corresponds to an experimental science. Creating activities that are related to experiences, examples and context about challenges outside the classroom environment has proven to have a positive effect on the students' attitudes towards STEM in the future and increasing the students' problem solving skills [4][5]. Tenti et al., [6] and Permana et at., [7] consider that the integration of STEM education has a significant effect on student learning. They agree on the fact that this approach allows the student not only to focus on the methodological aspect but also on critical thinking.

In these types of subjects, such as physics, it is important to emphasize its applicability, use and relevance for activities that are visible to the context and daily life of the student. This allows students to perceive that the knowledge acquired has a direct impact on their context and, in turn, can arouse interest due to its relevance. It is important to understand that real-life applications are often complex, however, there is always a way to simplify them to give a general idea of the function of the element, even if it is not entirely accurate [8].

In Fig. 1 we can observe this concept applied in the activity regarding this paper. It is important to avoid some technicalities and show them a general picture to capture their attention, once they show interest they can create designs in great detail during their specializations in the area.

II. Research motivation

According to Andrade [9] interest in STEM areas has declined in recent years in Mexico, this can be noted by the decreasing number of participants entering the programmes. The authors of this article believe that the importance of inspiring and motivating children in high school cannot be underestimated. It is common to hear among students that STEM careers are difficult as the approach they have with them tends to be theoretical and reduced to contexts that may not be of interest. On the other hand, conceptions derived from social structures foster a bias, for example, that STEM areas are "for men only."

As reported by Kember et al., [10] investigations, the solution to this problem can be solved "by a course which revealed a curriculum map showing the application of basic material in more advanced courses, or by early periods of exposure to professional practice in professional programmes" (p. 249). It is important for teachers to understand that they do not necessarily have to involve high school students in highly complicated engineering processes in which students do not possess the technical knowledge that is required. But, they can start by involving them in the early stages of some design or in a simplification of it to attract their attention. Once this is achieved, professors could expand the scope of the activity and design one that has more similarities to a complete engineering design, or even exceed expectations through the transversality of knowledge and, therefore, create a new interest in students pursuing STEM careers.

The purpose of the authors of this paper is to obtain an idea of the change in the perception of the students towards STEM activities once they find the usefulness of it.

III. The activity

In class, the students have been studying Newton's First Law which consists of analyzing objects in equilibrium. Finding the tension of the cables on a traffic light or in the ropes of a piñata were problems that they managed on a daily basis. However, these types of problems are intended for the student to focus their attention on the procedural part of the content rather than the exploration and exploitation of the context, that is, these types of problems do not promote the dialectic between the theoretical and the application. The activity consisted in using the knowledge obtained on those problems (which can hardly be useful) and taking them to a context closer to the student. Students had to implement Newton's First Law to design a simplification of a stay-cable bridge, taking as a reference one under construction in the vicinity of the classroom.

In the early stages of designing a bridge it is important that civil engineers gather a general idea of how the bridge is going to look like, obtain some general dimensions and define the geometry. In these first steps the engineers do not consider many fundamental factors such as material deformations or earthquakes, these considerations come later on. Is in this moment when we can involve high school students in the true design of the bridge without all the technical knowledge they would need in further phases of the design.

As specified by Jiménez [11], STEM education promotes an approach in which learning is centered on the students and they seize knowledge, through interdisciplinary environments and relevant experiences, which allows them to associate all the concepts that generally remain isolated and disconnected. STEM based education promotes in students investigating, thinking critically and creatively, of seeing beyond the conceptual and being able to contextualize it with its environment. Because of this, an important factor when designing the activity was taking into consideration the context of the student. The way in which this was done was to take into consideration a construction site that was being developed in the city, and which directly adjoins the location of the campus. The construction was a bridge with a design very similar to the one posed in the activity problem. In addition, the teacher constantly highlighted during the explanations the similarity between the construction and the problem that was being solved in the activity.

Taking into consideration the proposal of Kember et al. [10] to establish relevance, we considered the following point in the design of our activity: (1) showing how theory can be applied in practice, (2) establishing relevance to local cases, (3) relating material to everyday applications and (4) finding applications in current newsworthy issues.

For the purposes of this paper, the authors implemented an activity as follows:

First of all the tasks are designed to be completed in small groups of 3 or 4 members. In the beginning, each one of the members should choose a role for 4 main activities which are: performing math calculations by hand, performing the calculations using the software, integrating a written report, or recording a video explaining the activity. Roles can be shared by pairs of students and it is explained that all can participate in each one of the activities. The roles are useful to design a member who must ensure that the deliverable meets all the requirements. After the roles are assigned the students read an introduction about the social, economic, and architectural importance of bridges. Then the calculations by hand are performed. For this part, the design used is described as a stay cabled bridge with two columns and five supporting cables. Each one of the structural elements of the design are explained and described. The bridge design used for this activity is shown in the next figure.

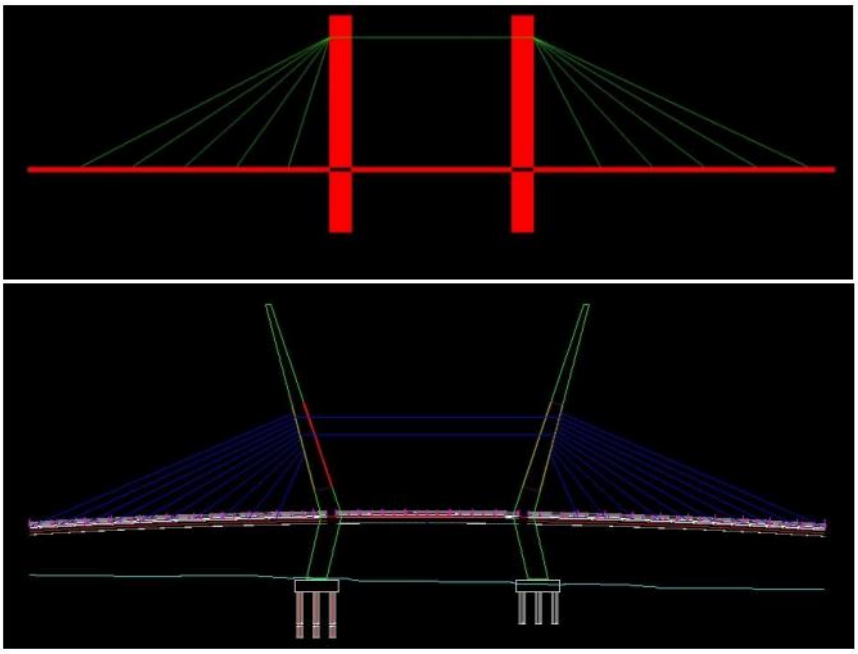

Fig. 1. Comparison of the sketch of a stay-cable bridge provided to the students for the activity and the real structural project

The data that is provided to the team are the most important and indispensable measurements, as well as the loads of weight that each of the cables have to support. Each team is assigned different loads of weight in their bridge to support, this ensures that each team is working on a problem with different results but with the same overall design. This designation of different loads to each one of the teams is made to avoid plagiarism between the teams.

With this information it is expected that the teams make the calculations by hand, determining the tension of each one of the cables of their bridge design and using the First Newton's Law. When the calculations of the tensions are at hand, the next stage is using a software that will generate a virtual model with the same information as in the problem. The use of this software allows the students to help to understand the problem because they can visualize the information on the calculus made by hand. Also the use of software verifies the universality of the scientific knowledge regarding Newton’s First Law because both written procedures and the model generated are consistent. Another use of the software was to double check the accuracy of the calculations and avoid mistakes on written procedures or the outputs of the model generated because both in the end have to get the same numbers.

The software used were two apps for cell phones and tablets, each one of the teams had to choose at least one. These apps are SW FEA 2D for Android devices and Strucmaster HD available for IOS devices. Having two apps in both of the most popular operating systems for mobile devices allows all teams to have the possibility of performing this phase of the activity regardless of the technology they have available. In this part, teachers provide detailed tutorials in the form of informative videos made with a demonstration and an example of a solution to the problem. An image of the bridge modeled by softwares is shown next. These images show in detail one of the sections of the bridge with the loads, tension on the cables and reactions of the elements and other information such as the measurements and the visual disposition of the bridge elements.

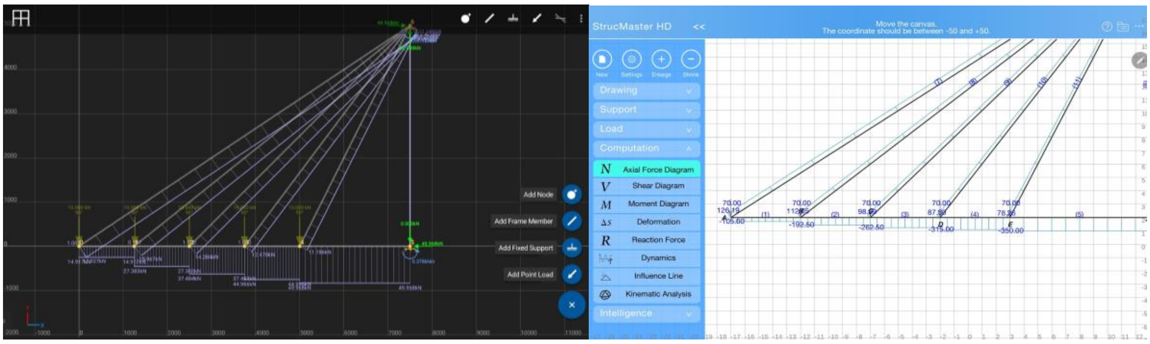

Fig 2. Examples of the stay cable bridge modeled in two different softwares

With the results of the tensions obtained from the last stage, the students are presented with a new concept: the tensile stress. Explanations are made on this topic by the teacher with the help of examples, and solving simple problems.

Then students are asked to calculate with the tensile stress equation the diameter of the steel cables and the torpedo that corresponds, given the cable’s force and the maximum stress of the steel. With this information in hand for each one of the cables, students must search in a real steel elements provider’s products catalog and determine which product is the most suitable for their specific bridge design. The next table shows an example of the results and calculations performed by the students and the application of the tensile stress in selecting the proper diameters of cables based on specifications of a vendor.

Element	Angle [º]	Force calculated [KN]	Area $[cm^2]$	Diameter of steel element [mm]	Type of element
Cable A	63.43º	3.35	0.176	9.5	OS
Cable B	53.13º	3.75	0.197	9.5	OS
Cable C	45º	4.24	0.223	9.5	OS
Cable D	38.65º	4.83	0.254	9.5	OS
Cable E	33.69º	5.43	0.285	9.5	OS
Cable F (horizontal)	None	14.98	0.788	20.6	OS
Torpedo	None	14.98	4.26	22.22	CS

Fig 3. Example of the results of calculations performed by the students and selection of cables for a bridge project.

The objective of this stage is to apply all the knowledge and results so far simulating the real life analysis and decision from an engineer that is designing a bridge, in this case selecting the real structural elements that are manufactured by a real steel provider.

Finally the calculations, software data, and the chosen steel elements are presented in a report where the teams also provide their conclusions and opinions about the activity, of which analysis will be carried out later. Also the information is presented in a video where the students release their bridge information explaining the process with their own words, and providing images, data tables, software screenshots or any other resource that they consider important. The video is asked to be informative and attractive to the viewer.

At the end of the process, the students answered some questions regarding the difference between a complete structural design and the oversimplification. Is fundamental that they understand that the job is not as simple as it looks and that analyzing a bridge as a static element is just a pre-design, not the final result.

IV. Tools and methods

In order to obtain the students' perception on their knowledge acquisition the authors created a survey via Google Forms that consisted of 13 questions. The students of the analyzed course are between the ages of 17 and 18 years old. They are in a semester in which they have to take the life-changing decision of choosing their career path. They usually have many questions and have some reservations about STEM careers. They are also at an age in which they have other priorities such as social and family lifes. This generation in particular has also been highly influenced by social media. So they don't always see the usefulness of topics such as math and physics in their daily lives.

It is important to mention that the students were in the course of Physics I, which is mandatory for each student regardless of their chosen professional career path. Therefore, a wide variety of interests can be found, which makes it even more interesting to analyze whether these types of activities have an impact on the perception of STEM areas, comparing, for example, with Physics II, which turns out to be optional and it is possible to observe a pre-existing interest in these areas.The objective of this paper is to answer the following questions:

- Do activities designed in an approachable context for the students, encourage the learning of content addressed in class?
- Do these activities motivate and encourage student interest in STEM areas?

Answering these questions will determine if the activity was successful for both academic and motivational purposes. Although the main focus of the activity is to change their perspective to a more positive one regarding the pursuit of STEM careers, we can forget about the class curricula and how this activity will help them achieve their semester goals.

V. Results and discussion

The results are obtained from applying a survey to a sample of 94 high school seniors. To this end, different types of questions were designed; in those items where the student must quantify, Likert scales from 1 to 10 were used, with 1 being the lowest and 10 the highest. It should be noted that the authors consider that a rating above or equal to 7 is a position in agreement and below in disagreement.

Questions of this nature can be classified into three groups: (i) evaluation of activity, (ii) evaluation of learning and (iii) perception of knowledge. In the first group, the student is sought to qualify the design of the activity and the application of similar in other stages of the course. The second allows the student to rate what they learned and can self-evaluate their performance and affinity to these types of problems. Finally, the third group collects the qualification regarding the knowledge acquired when compared with traditional problems.

Another group of questions have an open format, with the intention that the student formulates an answer and puts into practice his reasoning and experiences to be able to answer, especially, the student is asked to direct his answer in terms of what can be learned with this type of activities in contrast to traditional textbook or routine problems, in addition to valuing the use of software.

Finally, it was decided to add a multiple choice question with the intention of measuring the preferences of students in the framework of teaching practice, this for the purpose of improving the activity and the design of future ones.

For the purposes of this work, emphasis will be placed on the survey questions that allow answering the research question and that add value to the conclusions.

Knowledge acquisition

The first analyzed questions are the ones regarding the class topic Newton's First Law, and the corresponding acquired knowledge. In Fig. 4 we can observe that the students consider that the activity helped them with their comprehension of the topic, as we have 96.8% (n=91) of the results in the agreement area equal or beyond 7 points in the Likert scale.

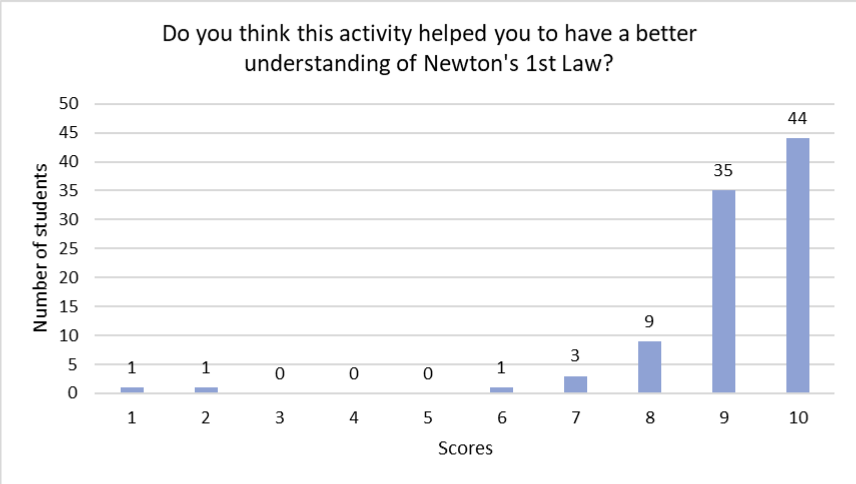

Fig. 4. Students' perception of their understanding of the course topics

In one of the open-ended questions, students are asked to submit a comment expressing how they would explain, in their own words, what can be learned from the activity to another student. They use common words for physics vocabulary, such as "stresses," "strength," "bridge," etc. It can be noted that students tend to consider traditional problems as situations that do not correspond to reality and that they greatly value the specific application, 74.46% (n=70) of the answers given agree with this. Thus, it can be observed that students identify the elements that correspond to the topic treated in class and interpret their applicability in the real context. It is important to note that a large number of students express that they "learn better" by solving the activity which is an indicator of understanding if contrasted with what they can learn with traditional problems.

Activity vs. textbook problems comparison

The first question analyzed which activity is prefered between real context or traditional textbook problems. In Fig. 5 it can be observed that 96.8% (n=91) expressed that they prefer activities that are linked to their context. In this case the activity applied by the authors is much more prefered than the traditional textbook problems. The students perceive that the problems that help their learning are characterized by being linked to their environment and the applicability of the contents in it.

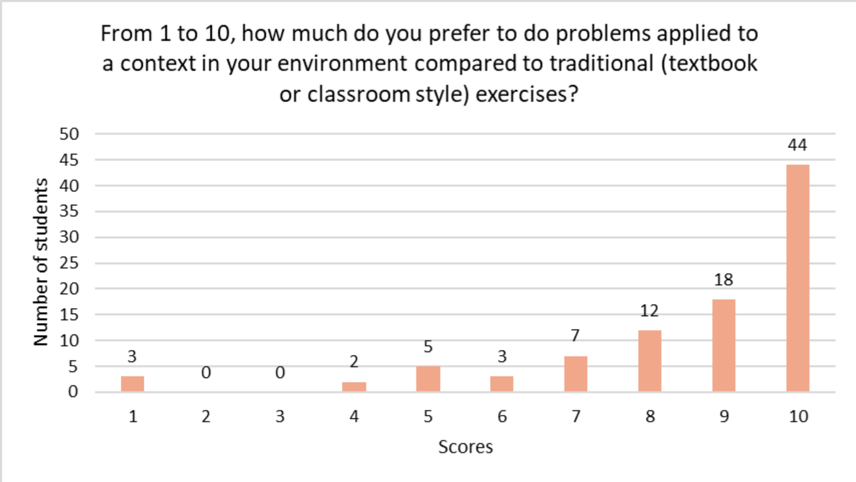

Fig. 5. Students' preferences of problem styles

On the other hand, other questions analyze if the activity applied by the authors increased motivation. In this case also a positive result towards the applied activity is observed. Fig. 6 shows that 91.5% (n=86) of students mentioned that their motivation has increased.

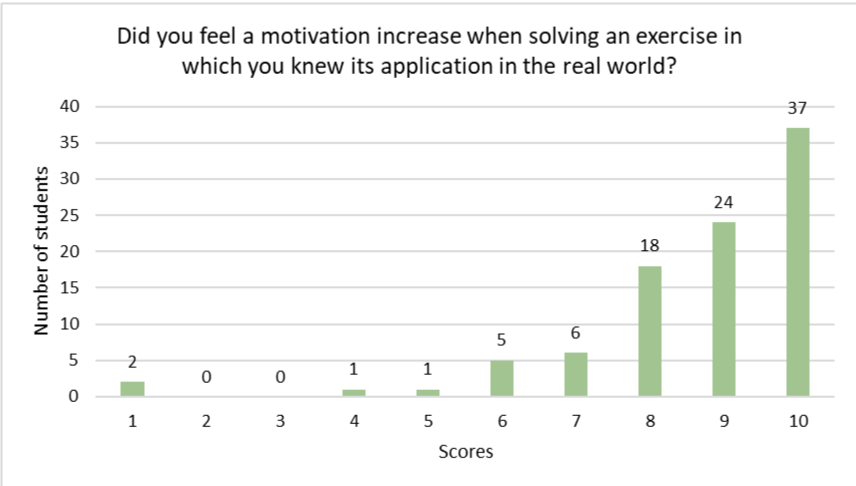

Fig. 6. Students' perception of their motivation increase

This is relevant to demonstrate that the activity increases motivation in the topic, regardless of the knowledge or skills acquired. In addition, interest and motivation in applied science topics is essential for students to explore and decide to enroll in STEM programs. Therefore, it is considered that the activity promotes a favorable attitude that brings students closer to choosing the STEM area, since they are at a stage in which they will soon have to choose their career.

In another question with open answers, students were asked how this type of activities that are linked to real world applications reinforced their learning. It was observed that 21.3% (n=20), almost a quarter of the students, cite that the knowledge learned in class could be applied in a "real life" or "daily" context. The authors interpret that the fact that students constantly mention their personal environment is an indicator that they find a relationship between the topics and their applicability or usefulness to their own context. This perception of students is a fundamental factor in the planning of similar activities. It should be noted that the bridge that served as an inspiration for this activity was being built very close to the Campus. The professors emphasized that the design, calculations and procedures that were being carried out were very similar to those that were being used in the real construction site.

It can be noted that the activity has prevailed over traditional activities such as textbook problems, and this has generated more preference, in addition to being more motivating for students. This is because they perceive a greater connection of the content with its real context, making it look more applicable and useful in the future.

Software use

On this topic, the students were asked to submit a comment about the relevance of using the software, as well as the intention of performing math calculations by hand and in the software at the same time. The question was open so they would be able to express their comments and ideas. Some of them answered that they were able to learn, practice and compare their results; they also highlighted the benefits of using technology, its ease and speed to do operations that by hand are difficult and take a long time to do. Most of them answered that using the software helped them to have a closer vision of the application of technology in real life problems because they could observe graphically the formulas and calculations of traditional problems that they do in a classroom which normally make no sense to them or that they have to trust blindly.

With the survey answers like “It is relevant to use the software because we can observe the forces graphically instead of calculating and imagining them” or “I liked using the software because it’s like using tools that are very similar to those used by professionals”, it can be noticed that students perceive that they are applying their knowledge in a real context by using these technological tools in class activities, that it does not stay in their notebook and they do not have to imagine it, they can visualize different things such as measurements and loads at the same time in graphic way and with this visualization students have a better understanding of what they are doing. It is important to emphasize that the use of the software in these activities gives students an approach to the different technological tools that are of common use in STEM areas.

In further applications of the activity the authors recommend making emphasis on the importance of comparing the results to the software. The authors noticed that the students were reluctant to obtain the results by hand once they had them in the software. The teacher should explain the clear objective of the use of the software, which is to demonstrate universality of the calculations, since this knowledge is scientific and can be demonstrated, as well as being a visualization aid to help students understand the problem.

Generation of STEM interest

As stated before, the intention of the activity is to increase STEM interest in students. One of the questions in the survey was regarding the interest generated by the activity in those areas. In Fig. 7, we can observe a highly interesting result. In comparison to the other analyzed questions, here we have a record low on positive answers, with 70.2% (n=66) of the respondents choosing the answers of 7 and higher. However, these results are still highly encouraging. First, they established that the students are answering honestly and not simply selecting the same answer over and over without giving a true meaning to the question. Second, the vast majority of the students actually developed a genuine interest in STEM areas.

Since the students who applied the activity have different profiles, as mentioned in previous sections of this paper, obtaining favorable results in the interest of STEM careers can be considered genuine and developed by the activity.

This question shows that this activity has generated STEM interest at a certain level. It is relevant to observe that this is a single activity in a single topic. Based on this information we could have the basis to propose more activities such as this one so we can perceive a higher motivation in these areas.

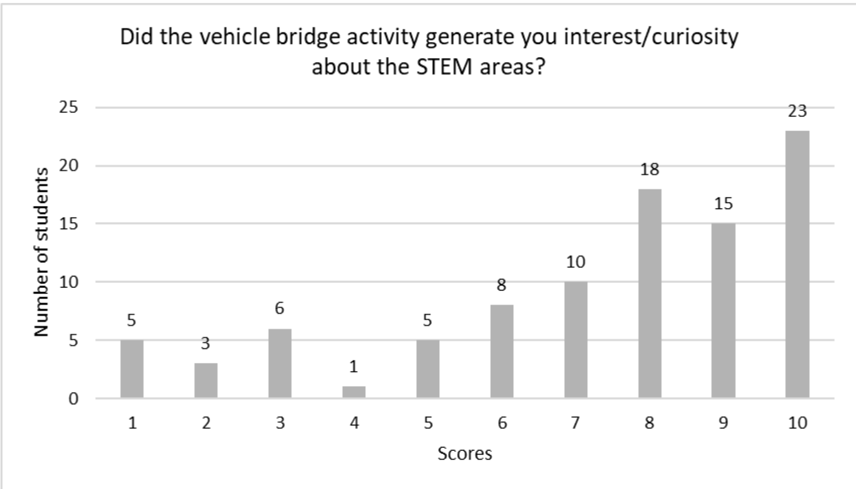

Fig. 7. Students' perception of their increased interest in STEM areas

To conclude this section, the authors would like to add the last question of the survey. The students were asked if the activity changed their perspective, enhanced their motivation or interest about learning about how things in their daily lives worked. The authors put an example in the question about the vehicular bridge that served as inspiration for the activity.

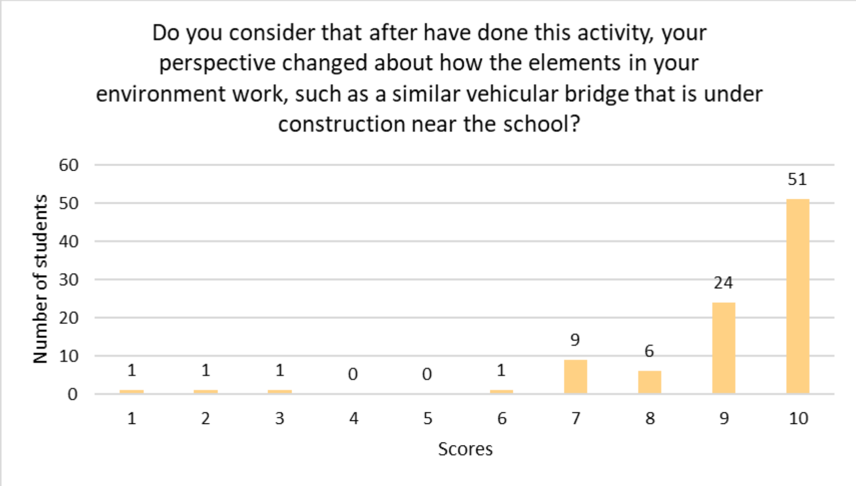

Fig. 8. Students' perception of their change in perspective about how thing work

In Fig. 8, we can see that 95.7% (n=90) answer with a positive score. Although these results were not repeated when talking exclusively about STEM (Fig. 7), it is relevant to mention it because as education professionals we can ignore creating an impact on the daily life of our students no matter the area. Even more so, in factors as fundamental to human beings as how things that surround us work.

VI. Conclusions and further work

This study has shown that activities that are directly related to an approachable context enhance students' motivation and allows them to develop competences related to the topic's objectives; as we were able to see by creating an activity with a tangible example, such as the construction of a stay-cable bridge near campus, that allowed students to experience in first hand what their classroom knowledge may achieve.

Students have expressed in the survey that they value the opportunity of finding the utility of their knowledge, as well as demonstrated that they have gained a better perspective of the topics. It's important to clarify that students don't seem to differentiate between the concepts "real life" and "daily life", so we may consider that they relate these two concepts to a general utility or usefulness rather than an actual quantity of applications in their life.

Activities that are context-based were found to be a motivating factor for students in STEM-related areas and they value the use of technology. An activity that takes as a principal element an object of the student's immediate environment and is able to apply the contents, gives a close vision and allows the student to link their knowledge in their circumstances. Because of this, it is natural to think that including activities of this nature facilitates interest in STEM subjects such as Physics II.

In this sense, considering the comments of the students, we can observe that in accordance with what Tenti et al., [6] and Permana et al., [7] point out, critical thinking is reinforced by getting the student to compare the theoretical results with the simulated practical results; in addition, it is found that this effect can be obtained because students are motivated in solving the problem. That is, the design of activities must consider that the context is motivating to allow the student to develop critical thinking.

The authors consider that this type of activities, which allow students to address the class contents based on their context, could change the narrative or even the conceptions that students have regarding STEM. For example, including in a transversal way the financial area to know the cost of construction, the forms of investment and even how to achieve a functional and aesthetic bridge giving rise to Architecture.

In conclusion, it is necessary to promote activities that allow to expand the perspective of students regarding STEM areas. It is useful for the student's learning to be able to contrast their knowledge with what they can have at their fingertips. In addition, an activity that promotes STEM areas, allows the student to know other tools and bring them closer to their reality. We must encourage students with our narrative, showing them that, in high school, they are developing the tools to solve, create or even discover things beyond their imagination. Therefore, it is the teacher who has the opportunity to work with his students on examples that are within their reach and allow observation and experimentation, which are the heart of Physics.

VII. Acknowledgments

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