Design of STEM Activities and Study of Their Motivation Efficacy

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Abstract – **Perception towards Science, Technology, Engineering and Math was studied in children, before and after four activities were done. The topics of the activities were locomotive system, circulatory system and nervous system. Each topic was introduced with questions related to the students' daily life, then animated videos were shown, and tasks and challenges were done by the participants. At the end of each session, conclusions and reminders were obtained with complementary activities. The kids took active part in the process and approached the knowledge in different forms. Quantitative and qualitative data were acquired through a survey, before and after the activities. Quantitative data were analyzed showing significant differences and trends in better attitude and improved self-confidence towards the disciplines. Analyses were done for gender and grade for each question and for the constructs. Qualitative data was quantified showing the importance of the students' context in their education and, the value of this kind of activities in low-income students.**

Index Terms – Motivation, STEM activities, student interest

INTRODUCTION

In the scouting activities of the University of Los Andes, it has been detected that some last grades high-schoolers show not only lack of interest in Science, Technology, Engineering and Mathematics (STEM) disciplines, but also rejection towards them [1]. Unfortunately, at that point the student already has a certain attitude towards STEM and therefore an intervention in this regard should be done earlier [2].

It is necessary that young people are interested in pursuing careers in STEM, because these professionals can use their knowledge to "approach the world, understand it critically, explore it and commit to it and the ability to change it" [3]. Thus, it is necessary to boost the interest for those areas before the students are faced with the decision of what they want to study in the university.

In Colombia, there is currently a deficit of 15,000 engineers and it is estimated that by 2018 the deficit will be 93,000 [4]. This trend towards the deficit also occurs internationally [5], [6]. The areas in which professionals are lacking in Colombia are those related to agriculture, electrical energy and technology [4]. To meet this demand, more young people need to be interested in STEM disciplines.

It is important to solve the problem posed because STEM education develops, preserves and disseminates knowledge and skills that bring personal, economic and social benefits [7]. The STEM disciplines provide skills and knowledge that are increasingly based on the professions and trades of a technology-based workforce [8]. Higher education provides the advanced skills needed in the current economic scenario, which is based on rigorous, globally integrated and innovation-based knowledge [7].

Advances in science and technology determine the rapid transformation of the global economy, with profound effects on people's lives and culture [7]. The different perceptions of these changes, regardless of their technical or scientific bases, affect the social acceptance of innovations and people's attitude towards science and technology [7]. This is of great importance because it endorses the need to have more people interested in STEM and young people who consider these disciplines as an option for their higher education.

Students' attitudes towards science are influenced by the methods of learning and teaching, curriculum, assessment, and the quality of teaching they experience [9]. The major barriers for STEM reception are:

- Low quality teaching that prevents students from returning and staying committed to STEM.
- The perceived difficulty of STEM materials.
- Disappointment in the transition from primary to secondary.
- The negative view on success and unacceptable stereotypes about STEM. [10].

This context determines the relevance of promoting and motivating in children, the interest for STEM disciplines. To do so, the research question raised was:

How does the perception of children age 7 to 11 change towards STEM through activities based on the students' interests?

To answer this, the objective of the project was to design STEM activities to achieve a change in the perception of students from 7 to 11 years of age towards the STEM disciplines.

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METHODOLOGY

I. Study model

The present study is of quantitative type with mixed data and quantification of qualitative data [11]. The design is quasi-experimental because it is necessary to contrast a relationship before and after the intervention and this is done in a natural environment where no random assignment can be made [12]. The participants filled out the survey, where pre-tests were measured. Then the STEM activities were done. After these activities, the survey was conducted again (post-tests).

This approach is used to determine the perception towards STEM, in which the instrument has a qualitative question for the pre-measurement and two qualitative questions for the post measurement.

II. Participants

Two data sets were taken. The participants of take 1 were invited to participate by the Academic Coordinator of the Educational Institution who selected among the ones who offered. This school offers education and training to underprivileged children at preschool, primary, secondary and technical media levels. The purpose of the Institution is to educate children and young people with limited economic resources in the ethical, social, civic, scientific, artistic and technical aspects of education as persons and to successfully join higher education and the productive sector, so that they are respectful, critical and participative citizens in their social and labor environment. No sampling was done, all the data obtained were analyzed. The study population size was 30 students between 7 and 11 years old. Informed consent was signed by 29 parents.

A second data collection was made within the framework of the course Conoce y Aprende (Learning and Knowing), which was offered at the University of the Andes, during the inter-semester period of 2016, aimed at children from 6 to 11 years interested in knowing and having fun with the sciences and biomedical engineering. The following is the description of the course:

> "Conoce y Aprende: School of Sciences and Biomedical Engineering. The Science section within this Children's School is focused on continuing to demonstrate the astounding and fun side of Science with new experiments as well as taking advantage of subtly introducing notions that can serve the student in the future. Again, we will learn to perform very simple experiments, we will make a tour through all the sciences; This is how they will explore topics in biology, microbiology, chemistry, physics, astronomy and geology.
>
> In the section of Biomedical Engineering, as an integration of the principles of engineering with medicine and natural sciences to create solutions to medical and biological problems, we will have an approach in a simple scientific language through experiments of some systems of the human body, to introduce us to the world of engineering at the service of health." [13]

In this activity 24 children participated, from 6 to 13 years. Informed consent was signed by 16 parents.

III. Data analysis plan

Mixed data were collected by means of a survey with closed and open questions. A normality test and a comparison of central tendencies were performed to analyze differences between factors such as gender and grade. In addition, answers to the open questions were quantified to analyze frequencies in words and topics used by students. Qualitative results were analyzed from the emotional and disciplinary parts expressed by participants.

IV. Instrument design

The measurement instrument was consolidated and complemented by qualitative research. The qualitative approach "Case Study" [14] was adequate because it allowed the determination of how the participants related to the instrument and its use was validated at these ages. The instrument obtained was used to acquire quantitative and qualitative data applying the instrument immediately before and after STEM activities.

The instrument used is based on the Student STEM Attitude Test [15]. The test consists of four validated constructs. It uses a five-point Likert scale to measure student attitude toward science, math, engineering and technology, and 21st century skills. The test also contains a section that measures students' interest in STEM careers in the future of the student and a section that inquires the students how well they expect to do in their Spanish, arts, mathematics, and science classes; if they plan to attend college; and if they know any adults who work in STEM fields.

The test has eight items in the math section, nine in the science section, 11 in the 21st century skills, and nine in the engineering and technology section. The STEM career interest section in the future contains 12 professional fields, each with its description of what professionals are doing in that field. This instrument was translated into Spanish. The question about ethnicity was suppressed because it does not apply in the context that the data were taken. The 21st century skills section was deleted to make it shorter. Because each of the constructs explores particular items [16], removing one of the constructs does not affect the robustness of the instrument for each construct. In the "About yourself" section the question on performance in English class was changed for performance in Spanish class, to make it consistent with the language of the instrument.

V. Design and description of activities

Three subjects were covered: locomotive system, circulatory system and nervous system. In general, for each topic, motivational questions related to the daily life of the children were asked, then an animated video was shown and later activities were done in which the participants took an active part, concluding the themes with alphabet soups or drawings where parts should be located.

For example, for the locomotive system, participants were asked if they know how many bones an adult has, how many bones we are born with and if someone has broken a bone. Then they watched an animated video in which a doctor and a little kid travel inside the body and explore some bones. Later, the facilitator described the main bones of the body and the kids learned the names as they located them. This was supported by a human model doll. Next, the children built a bone-like structure with cardboard and scotch tape and each structure was loaded until failure. Then, recommendations were given to take care of the bones and at the end, a drawing to locate the main bones and a letter soup was solved.

RESULTS

I. Pilot of the Instrument

The first version was applied to a group of volunteer children. At the beginning the informed consent was read and words that the child did not understand were explained. As the child was responding to the survey, notes were taken on the questions or comments he/she made. It became evident that the order in which the survey was to be answered was not clear and/or how to mark the response. For this, the pages were numbered and arrows were added, indicating the order to be followed. It was difficult for the youngest to understand the Likert scale, so emoticons associated with each level were inserted as shown in Figure I.

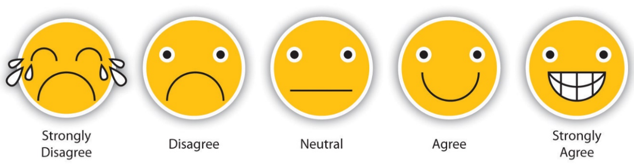

FIGURE I
EMOTICONS

The survey was printed with one of the boards cut, so some children did not remember the Likert scale. For this, each table was printed on one page.

The following interview was designed to apply when each child finished the survey.

- Were the questions clear?
- Is there something you did not understand?
- Is there something missing to ask?
- What did you like to tell me that I did not ask you?

The first three questions were asked to the child to reflect on the survey he/she had finished answering. In the fourth question, two children told anecdotes, which reinforces that the interviewer "... should be a patient explorer who facilitates and estimates the expression of his interviewee..., to address dimensions more related to the objectives of the research" [17]. It was decided to leave the last question as part of the instrument, since it was necessary to collect data for the study.

From the observation and analysis of the children responding to the survey and with the answers to the questions, modifications were made to the perception measurement instrument to obtain the final version.

II. Quantitative Results

Normality of the data was checked and the results did not have a normal distribution. The data was analyzed with the Wilcoxon test, which is the analogue to the paired t-test and can be used when it is assumed that the data are not normally distributed. [18]

First, the Wilcoxon test was performed for each question and then the construct analysis was performed.

For the first data collection, pre and post analysis were done for each question with all participants and then differentiated by gender and grade. Subsequently, the construct analysis was performed for all participants and then discriminated by gender and grade.

From the first data collection, when analyzing pre and post for each question, there was a significant difference for question 11 in the section Your future ($p = 0.048$), this indicates that the participants show a greater interest in work related to energy and electricity, after the activities. Trends were observed in Questions 6 of Mathematics ($p = 0.063$) and 12 of Your future ($p = 0.083$). This shows a non-significant difference in that participants feel that in the future they could make difficult math problems (Math question 6) and show a tendency for greater interest in engineering work post-activity (question 12 of Your future).

Separated analyzes were done for girls and boys. For the girls, there was a significant difference for questions 9 in Science ($p = 0.042$) and 6 in Your future ($p = 0.043$). This means that girls feel that in the future they could do more difficult jobs in science and that medical work interests them more after the activities. There was a trend in questions 8 in Mathematics ($p = 0.091$), Your future 1 ($p = 0.097$), 8 ($p = 0.091$) and 11 ($p = 0.091$), this shows a non-significant difference but a tendency in that girls feel they are good at math after the activities, as well as showing greater interest in jobs related to physics, computer science and energy/electricity. For the boys, there was a tendency in Mathematics question 6 ($p = 0.059$). This expresses a non-significant difference in the fact that boys feel that in the future they could make difficult math problems, after the activities.

Later the data were analyzed by courses. For second-graders there was a significant difference for question 6 of Engineering and Technology ($p = 0.043$) which shows that second-year students are more curious about how electronics work after activities. There was also a tendency for Mathematics questions 2 ($p = 0.067$) and 3 ($p = 0.051$) and for About yourself questions 2 ($p = 0.067$) and 7 ($p = 0.067$). This means that after the activities, there is more interest in choosing a job that uses mathematics when they are older and that mathematics are easier. Also, they feel they will do better in math in the school year and recognize more adults who work as mathematicians. For the third graders, there was a significant difference for the questions of Your future 1 ($p = 0.043$) and 11 ($p = 0.043$), reflecting a greater interest in physics and energy/electricity jobs after the activities. There was a tendency for questions 6 ($p = 0.079$), 9 ($p = 0.067$) and 10 ($p = 0.067$) for Your future, which expressed a non-significant difference with a greater interest in medicine, medical sciences and chemical studies. For the fourth graders, there were no significant differences or trends when comparing pre and post for each question.

After analyzing pre and post for each question, a construct analysis was performed. The results for the analysis of all students were significant for Your future section ($p = 0.005$). This shows a greater general interest in the future work, which is seen also by gender: The results for the girls were significant for the section Your future ($p = 0.044$) and the results for the boys were also significant for the Your future section ($p = 0.051$). For boys, there was also a trend towards science ($p = 0.068$). For the second-grade participants, the results were significant for Math ($p = 0.027$) and Engineering and Technology ($p = 0.012$) and tendency for About yourself ($p = 0.086$). For the third graders, the results were significant for Mathematics ($p < 0.001$) and Your future ($p < 0.001$). For the fourth-grade students, there were no significant differences or trends.

Because there was no change for children in grade 4, a pre-comparison between second and fourth grade was performed, finding a significant difference in questions 1 ($p = 0.045$), 4 ($p = 0.043$), and 9 ($p = 0.043$) of Your future and in 4 of About yourself ($p = 0.01796$) and when doing the analysis by construct, the difference was significant for Engineering and Technology ($p < 0.001$) and Your future ($p < 0.001$). This means that second-graders show a greater general interest from the start, by STEM, when compared to children in the fourth.

For the second data collection, pre and post analysis were done for each question and construct analysis for all participants. Data were not discriminated by gender or course due to the low number of participants.

By question, significant results were obtained for Mathematics question 6 ($p = 0.046$) which shows that participants feel that after the activities, in the future, they could make difficult math problems. There was a tendency for question 8 of About yourself ($p = 0.067$), which means that after the activities they knew more people who worked as technicians, without being a significant difference.

By construct the result was significant for science ($p = 0.029$), indicating that the interest for this discipline increased and trend for Mathematics ($p = 0.062$), showing a non-significant increase in interest in this area.

Table 1 summarizes which constructs shows significant differences regarding groups, and gender and grade for the first group.

TABLE I
SIGNIFICANT DIFFERENCES BETWEEN GROUPS AND REGARDING GENDER AND GRADE WITHIN GROUP 1

Construct	Between Groups		Gender		Grade		
	G 1	G 2	Fem	Male	2	3	4
Math		T			*	***	
Science		*		T			
Eng. & Tech.					*		
Future	**		*	*		***	
Self					T		

T Tendency to change ($p<0.1$) between pre and post
* Significant difference ($p<0.05$) between pre and post
** Significant difference ($p<0.01$) between pre and post
*** Significant difference ($p<0.001$) between pre and post

III. Quantification of qualitative data

In data set 1 the children wanted to be asked about their future occupation or what they want to be in the future. This is repeated 16 times in the pre and 9 times in the post. This does not happen in the data set 2.

About what the students learned, table II shows the summary:

TABLE II
TOPICS LEARNED

	Data set 1	Data set 2
Bones	24	7
Heart/Circulatory system	20	7
Brain/Nervous system	17	10
Care/How to protect the body	12	0

DISCUSSION

The significant difference between pre and post for the analysis for girls in questions 6 and 12 of Your Future (relating to Medicine and Engineering) can be justified considering Maria Puig de la Bellacasa's feminist perspective of care on scientific thinking. This perspective seeks to privilege characteristics such as care and affection, generally associated with the feminine aspect [18]. This theory of care supports the percentage of women who are enrolled in Biomedical Engineering, 51%. This can be compared with the percentage in Mechanical Engineering that is of 12.7%, being the Department of Mechanical Engineering where the Biomedical program originated. It also supports the percentage of women in Environmental Engineering, another career related to care, where 53% of students are women. For the entire Faculty of Engineering of the University of Los Andes, 32% of the students are women and 68% are men [19].

There was no change for fourth graders. In making a pre-comparison between the second and fourth grade, the significant differences found favor STEM interest in second-graders. This demonstrates a fact that has already been documented: by the time students reach fourth grade, one-third of boys and girls have lost interest in science [20]. The same source reports that by the eighth grade, nearly 50 percent have lost interest or considered STEM irrelevant to their education or future plans. At this point the incentive capacity in STEM disciplines has been cut in half. That means millions of students have disconnected or lacked the confidence to believe they can do science [20]. In order to re-engage the children, it is necessary to structure STEM motivational activities, formal, non-formal and informal, in such a way that it is the whole context around the child (school, extracurricular activities, family, media), the one that motivates for the STEM disciplines.

In the construct analysis, the significant outcome for all and for boys and girls separately in the Your Future section reflects what they answered in what they were not asked about "what they want to be when they grow up." The activities may have helped them clarify and/or strengthen what they like, and thus determine some career. Activities like this one are of great value for children like those of this educational institution that generally do not have higher education roles in their families or near environment [21]. Through these experiences they can expand what they know about careers for the future. Limited visions of jobs opportunities, like those of these children, play a conclusive role in the choice of career and can cause difficulty in conceptualizing work as a means of self-determination and source of satisfaction [22].

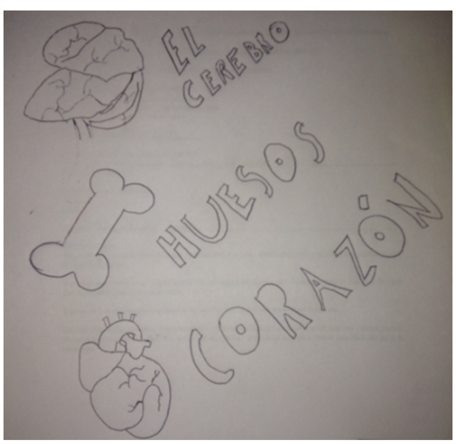

FIGURE II
DETAILED DRAWINGS

As for the disciplinary part, according to Bloom's Taxonomy, participants were able to remember the topics that were discussed during the activities, which is evident in their responses. For example:

"We learned about taking care of the body like the bones and muscles and caring for the skull. About the circulatory and bone system."

"I learned about the heart and the brain. The heart makes us have blood running through our veins. The brain controls our emotions, what we are going to do and controls our 5 senses."

Some students remembered in detail the images of the heart and brain as shown in figure II.

One participant showed declarative learning as shown in figure III:

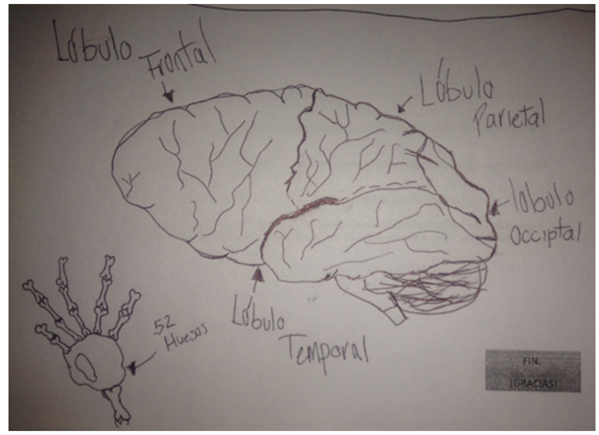

FIGURE III
DRAWING SHOWING DECLARATIVE KNOWLEDGE

Other participants achieved a cognitive process, a higher level than remember, as it is understanding:

"I learned about the hollow bones and that the birds have them, so they can fly."

The participants of the first data set were more extensive in their responses. This may be due to the context in which the activities were done. In the first session, the participants were invited by the Academic Coordinator of the institution and the activities were carried out in the school, which makes the context more formal and the students feel doing an activity related to the school. In the second set of activities, the participants attended voluntarily, came from different schools, the age range was higher and other science activities were done. The context in this case was less formal, bearing in mind that the activities were done during the student vacation period. In taking the first set of data, the role of the researcher was of an external guest, while in taking the second, the role was a teacher of activities.

The notable difference in the question about the future profession between the first and second data collection may be due to the fact that the participants in the second data collection are used to the fact that the university is a fixed step once high school is finished and that they can study whatever they want. This is because they are related to the university environment as a relative or acquaintance of an employee. It is evident how the student's social context affects his relationship not only to STEM but also to education in general. According to Bedmar Arroyo [23], the social context is defined as in which each person lives, learns and develops. This environment consists of people (families, neighbors, the same students) with knowledge, values, and experiences. They are not only "inhabitants", but active elements and with their own value. Thus, the relationship between what is learned outside and within the school is also sought, trying to have a two-way agreement between family and school, taking advantage of informal learning and compensating for deficiencies.

CONCLUSIONS

The STEM perception of the children participating in this project changed significantly for some of the questions and constructs. These results, show that the activities accomplished change the perception of the participants towards STEM, noting greater interest and capacity to address challenges and access education and work in STEM. These changes are due to the way the topics were dealt with, and how the activities were addressed, by making the student the main protagonist of his/her learning process and the content consolidation through different ways of meeting the knowledge.

The activities carried out increased STEM interest in the participants. Although this change was evaluated in the short term, as future research it is important to analyze whether these changes are permanent in the long term and to determine how longer interventions could influence the changes. In addition to innovative activities, comprehensive resources are needed to achieve a successful approach to STEM, which includes: committed and active teachers, strong identity regardless of gender or race, STEM courses and systematic career exploration opportunities [22]. Integrating these factors will enable to develop, determine and know STEM skills and maintain and cultivate interest in becoming a scientist or engineer.

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