Advances in Science, Technology and Engineering Systems Journal
Vol. 8, No. 5, 55-61 (2023)
www.astesj.com
Special Issue on Innovation in Computing, Engineering Science & Technology

ASTES Journal
ISSN: 2415-6698

The Graded Multidisciplinary Model: Fostering Instructional Design for Activity Development in STEM/STEAM Education*

Mauricio Flores-Nicolás*, Magally Martínez-Reyes, Felipe de Jesús Matías-Torres

Universidad Autónoma del Estado de México – Centro Universitario Valle de Chalco, Estado de México, 56615, México

ARTICLE INFO

Article history:
Received: 01 August, 2023
Accepted: 30 September, 2023
Online: 30 October, 2023

Keywords:
21st Century Skills
Gamification
Process Model
Middle School
Educational Technology

ABSTRACT

In a challenging and increasingly technological world, it is important to promote critical thinking, multidisciplinary problem solving, and collaboration through STEAM education; however, there are important economic, administrative, and especially pedagogical management limitations for its implementation at the secondary level. Therefore, this paper presents systematic recommendations for an effective and sustainable implementation of STEAM education in educational institutions through the Gradual Multidisciplinary Model (GMM), which allows the identification and specific adaptation of STEAM knowledge through the topic of logic gates related to the representations of disjunction and conjunction in Boolean algebra (university content) to its physical representation in Minecraft (high school content). The quasi-experimental method allows to evaluate the results through the application of a pre-test designed to measure logical-mathematical thinking and a post-test designed to measure the level of understanding of practical skills and the students' perception of the learning experience. The results obtained by t-student show that there is a significantly high difference between the means and suggest that the educational intervention orchestrated by the GMM had a significant impact on the performance and skills of the participants, since different levels of understanding (gradualness) and perception of the concepts related to logic gates could be identified; while the qualitative assessment shows the group's willingness and enthusiasm to work with a practical and meaningful activity using Minecraft, which allows them to specifically apply their skills in science, technology, engineering, art and mathematics.

1 Introduction

STEAM education is an educational approach that integrates the disciplines of science, technology, engineering, arts, and mathematics into the teaching and learning process. This strategy aims to foster an interdisciplinary view of knowledge and encourages students to approach problems and challenges holistically and creatively [1]. STEAM education has now gained greater recognition and acceptance in various education systems around the world. It has been documented that schools and teachers are trying to adopt this approach to prepare students for the current and future challenges of the labor market. This is due to the promotion of 21st century skills such as critical thinking, problem solving, and collaboration, as well as preparing students for future careers that require STEAM [2, 3].

There are a number of benefits that STEAM education offers, which are described below: Focus on problem solving, this is promoted through hands-on projects and activities designed to address authentic challenges, which helps students develop critical skills and find innovative and creative solutions; Inclusion of the arts and humanities, their importance in the holistic education of students has begun to be recognized, as greater interaction between STEAM disciplines has been promoted to foster a broad and balanced understanding of the world [2, 4]; Increased use of technology, STEAM education incorporates digital tools and resources in the teaching-learning process, as it enhances experimentation, simulation and collaboration, as well as facilitates access to up-to-date information and data [5, 6]; and focus on gender equality, with the development of specific programs that promote gender equality in the participation of girls and women in the various areas of STEAM [7, 8].

In addition, STEAM education is important at all levels of education [6], especially at the secondary level, where the focus is on preparing students to work in technical fields and develop innovative solutions, as it is essential that they acquire these skills in a society increasingly driven by technology and innovation. Developing critical thinking, problem solving, and creativity is

*This is an expanded version of the article published in the 2022 IEEE Mexican International Conference on Computer Science (ENC)
*Corresponding Author: Mauricio Flores-Nicolás, México, mfloresn90@icloud.com

also important because it enables them to analyze complex situations and develop new ways of approaching problems or projects. Meaningful, hands-on experiences increase their motivation and understanding of abstract concepts and scientific and mathematical principles [4, 9, 10, 11].

Beyond the benefits and importance of STEAM education, it faces several challenges, such as the high cost of materials, the digital literacy of teachers and the technological infrastructure in educational institutions [1, 6, 12, 13], as well as the lack of guidelines or standards that allow for the development and implementation of these types of activities in a satisfactory manner depending on the educational level. For example, at the secondary level [9, 10, 14], they mention that one of the main difficulties teachers face when teaching STEAM activities is time management and the pressure to follow the curriculum. That is, teachers are squeezed between authentic learning, student engagement, and multiple pathways with lesson plan deadlines, especially because a change in the way of teaching would affect the number of ways to assess.

Similarly, teaching basic science concepts at a lower level of education can be valuable in stimulating early interest in science, preparing students for higher education, and encouraging critical thinking. This provides a broader context for how science works in practice and makes the subject relevant; however, it is essential to assess the readiness and maturity of students and to balance and tailor science-based instruction to provide appropriate motivation and support. In addition, it is important to recognize that not all students will be interested in science, so it is important to draw on diverse academic aspirations in the classroom [15, 16].

It is for this reason that the purpose of this paper is to present the GMM in its two stages: first, how to design and build a STEAM activity with the elements described in [1]; and second, to execute such activity effectively and efficiently with secondary school students with a data analysis that proves a significant learning in the students on the topic. It is emphasized that STEAM education is not limited to a specific educational level, therefore the effectiveness of the GMM will be through the topic of logic gates, which is strongly linked to the basic laws of Boolean algebra (disjunction, conjunction, and negation), addition and multiplication (which will serve as a starting point), with the aim of enabling students to develop STEAM skills. The application of this content at the secondary level is of paramount importance because of its potential to fully prepare students for the technological and globalized future. At this stage, young people are eager to discover their passions and talents, and STEAM education offers an interdisciplinary approach that allows them to explore different fields of knowledge in creative and meaningful ways.

This paper discusses a quasi-experimental field study of the implementation of STEAM education in an educational setting using the GMM. The introduction provides an overview of the STEAM approach and highlights its benefits in developing key skills and competencies in students. The materials and methods section describes the design of the study, including the selection of educational institutions and educational resources. The development section describes the pedagogical strategies, practical activities, and classroom implementation. The results present empirical evidence and student testimonies on the impact of STEAM education on the learning process. The discussion analyzes the findings in light of the existing literature, highlighting the strengths and challenges of STEAM implementation in the educational context. Finally, the conclusions synthesize the findings and provide recommendations for effective and sustainable implementation of STEAM education in educational institutions, highlighting its potential for fostering critical thinking and creativity and preparing students for an increasingly technological and changing world.

2 Material and Methodology

The previous research in [1] has provided a valuable starting point, establishing the methodological foundations on which the present study is built. The GMM is designed not only to address current challenges in education, such as the need to effectively integrate technology into the teaching-learning process, but also to promote learning through the design of activities with graded and multidisciplinary approaches. This model draws on several existing pedagogical methodologies and learning strategies, such as constructionism, conceptual change, simulations, gamification, and problem-based learning, but is not limited to these alone, as content adaptation requires simplification, contextualization and careful consideration of students' skills and maturity levels. This includes ensuring that students have a solid foundation of basic concepts related to the topic, motivating them with relevant examples and applications, and providing resources and appropriate instructional support. Similarly, the topic of logic gates in [1] is aimed at undergraduate students, so adaptation is required to understand the characteristics and needs of the target audience, simplify complex information, adapt the language, focus the content, present it clearly, and contextualize it to make it relevant, meaningful, and interesting.

For this reason, this research was carried out in two parts. First, the construction of the activity, which consists in following the triple process of the GMM that starts with a hypothetical learning path (imaginary design or plan that describes the progress and learning process that the individual could follow in a certain subject or area of knowledge [1, 6]), analyzes and adapts the available technological infrastructure (the Minecraft Education software and an IntelNUC) and concentrates the information in an educational planning (it consists in designing and structuring the curricula, contents, methodologies, resources and evaluations to achieve the educational objectives effectively). And second, the evaluation stage, which involves collecting data from secondary school students by observing the learning process and the students' performance while they participate in the activity. The pre and post-test measurement technique was used because by comparing the results it is possible to determine if there has been a significant change in a variable of interest.

In addition, the following research questions will be specifically addressed to provide a deeper and more rigorous understanding of the implementation of GMM in secondary STEAM education: 1)

What is the level of students' mathematical knowledge and competence before and after participating in a STEAM activity; 2) How can STEAM education be effectively and sustainably implemented in educational institutions; and 3) How do students perceive the STEAM learning experience and what are the perceived challenges and benefits? These research questions will serve as a fundamental guide to explore the effectiveness of GMM in teaching logic gates in their deep context (Boolean algebra and electronic symbology), as seen from its representation for high school students using Minecraft.

2.1 STEAM activity design and construction

First of all, an adaptation of the hypothetical learning trajectories proposed in [1, 6] has been carried out, since in these has already been carried out a disciplinary analysis on the subject applied to high school students, it only remains to adapt the presentation for secondary school students, remaining as follows: 1) Science, logical propositions are introduced through philosophical and logical approaches; 2) Technology, a map created in Minecraft Education helps in the exploration and construction of structures with similar function to the main firebrand; 3) Engineering, works intermediate-advanced topics through truth tables, algorithms and real applications; 4) Art, a way to develop creative skills is with the topic of schematic diagrams, allowing students to apply decision-making in the design of electronic circuits; 5) Mathematics, starting with concepts of addition and multiplication and moving to their representation in the context of Boolean algebra.

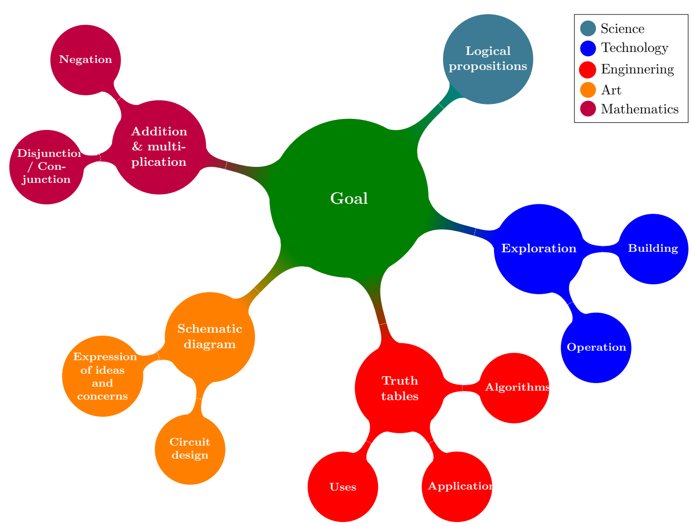

Figure 1: Hypothetical learning trajectory, classified by STEAM discipline and distributed by complexity. Own elaboration based on [1, 6].

The distribution of content is shown in figure 1, with the main theme at the center and branched into different disciplines to facilitate the implementation of STEAM activities. The objective of the second stage of the GMM is to analyze the technological infrastructure in the educational institution and align it with the pedagogical objectives, ensuring that solutions are selected that respond to specific educational needs and goals. It also optimizes their use to enhance teaching and learning and provide meaningful and effective experiences for students.

	Minecraft	**Minecraft Education**
Price	\$6.99 – \$39.99, depending on the device	\$5.04 per year (institutional management required) or \$12 per year (independent educator)
Does it fit in the budget?	Yes, if you have at least one compatible device	Yes, it is appropiate to carry out institutional management for the licenses
Risks	That it becomes a distraction	
Suggestion	Controlling its use	
Collaboration	Yes, in local network and online (requires additional subscriber)	Yes, in local
Trial version	14 days	26 logins
Educational elements	No	Camera, portfolio, tutors, materials (periodic table, control of actions within the map, among others)
Functioning in the institutional computer (Intel-NUC)	Best	
Additional requirements	No	Internet connection
Minimum training for its use	Included in the set	
Minimum teaching qualifications	Not available	Minecraft Learn with over 100 lessons
Examples of STEAM educational activities	Not available	Included in-game or in Minecraft Education
Can i share my own game files	Not available	Maps can be imported / exported and .pdf files of the evidence can be generated.
Are there educational resources to facilitate the development of the activity?	Not available	Yes, at: https://bit.ly/3rY76J8 (Official), How to create a map in Minecraft? & How to use Minecraft to teach high school level classes
Controllers	Joystick	Keyboard, mouse and/or joystick
Download	Xbox 360, Xbox One & Xbox series S|X, available in your online store Playstation 3, 4 y 5, available in your online store Nintendo Wii U, Switch, available in your online store Android, available in your online store	PC / macOS / Google Chromebook, Minecraft Education iPhone o iPad, available in your online store Android, available in your online store

Figure 2: Minecraft software analysis report [6].

Some of the advantages of using GMM analysis are that some of the previously created content can be reused, allowing learning to be personalized, resources and tools to be adapted to different learning styles, and leading to a more enriching and relevant education. A report of the software to be used is shown in figure 2, which provides detailed and accurate information about the operation of Minecraft and Minecraft Education IntelNUC computer equipment. Part of the information included in this report is the technical specifications, such as operating systems and compatible devices, examples of activities on similar topics, risks, suggestions, costs, and most importantly, where and how to get trained in this technology if you want to implement it in the classroom.

The third stage of the GMM provides an educational planning format that organizes the ideas, materials, goals, strategies, and pedagogical methods to achieve success during the educational process to achieve significant and lasting results. In figure 3 shows the planning format for activities in STEAM education, which aims to integrate teaching in its five disciplines with a multidisciplinary approach. In this process, teachers can design their activities and hands-on projects that foster critical thinking, problem solving, and creativity by drawing on the results of the previous two stages of the GMM. Clear learning objectives are set, and resources and digital tools are selected to indicate how and when they will intervene in the session in a way that enriches the educational experience. This format promotes collaborative work and meaningful learning, allowing students to explore, investigate, and apply concepts and skills in real-world situations.

Project	Is it possible to add and multiply in Minecraft?			
Goal	Have students build structures with the equivalent operation of logic gates or the fundamental laws of Boolean algebra. Participants can respond by using switches of buttons on the technology resource to see if the practice matches the theory.			
ISTE Standards				
1.3 Knowledge Builder. Students critically evaluate a variety of resources using digital tools to construct knowledge, produce creative artifacts, and develop meaningful learning experiences for themselves and others. **1.5 Computational Thinker.** Students develop and employ strategies to understand and solve problems in ways that harness the power of technological methods to develop and test solutions. - 1.5.c. Students break problems into component parts, extract key information, and develop descriptive models to understand complex systems of facilitate problem solving.				
Level of technology insertion				
Substitution (X)	Augmentation (X)	Modification (X)	Redefinition (X)	
Pedagogic methodology	Constructionism			
Learning strategy	Conceptual change; Problem-based learning; Simulation; Gamification.			
How to apply it?				
Science	**Technology**	**Enginnering**	**Arts**	**Mathematics**
Use and development of logical-mathematical and logical-computational thinking, basic fundamentals of circuit theory.	To favor the decision-making process with the choice of the technological tool that will allow you to solve the problem.	Know the fundamentals of electronic component manufacturing, such as design, simulation, fabrication and testing.	Designers use their creativity to create complex circuits that solve specific problems, and the circuit design itself is visually appealing process.	Theoretical verification of the operation exposed in the technological tools, used to describe the relationship between inputs and outputs of a digital circuit.
Didactic sequence				**Materials**
Opening (20 minutes) 1. Teacher's presentation to the class. 2. Ask students if they are familiar with Minecraft. 3. Ask students about logic gates. 4. Resolve pre-test. **Development (50 minutes)** 1. The teacher presents the objectives of the activity. 2. It briefly explains about Minecraft and the basic logic gates trainer. 3. Definition and importance of logic gates. 4. Theoretical-practical definition and operation of the NOT gate in its Boolean algebra ($\neg$), mathematical ($\bar{A}$) and electronics (IC 74LS04). 5. Solve doubts and errors. 6. Theoretical-practical definition and operation of the AND gate in its Boolean algebra representation ($\wedge$), mathematical (*) and electronics (IC 74LS08). 7. Solve doubts and errors. 8. Theoretical-practical definition and operation of the OR gate in its Boolean algebra representation ($\vee$), mathematical (+) and electronics (IC 74LS32). 9. Solve doubts and errors. 10. Resolve post-test. **Closing (15 minutes)** 1. Summarize what was covered in class, highlighting the importance of logic gates for everyday life. 2. Ask about their experience using Minecraft and the basic logic gates trainer in the classroom. 3. Farewell.				• Diagnostic evaluation (pre-test). • Final evaluation (post-test). • IntelNUC with Xbox 360 controller configured and the videogame Minecraft Education (basic logic gates map). • Basic logic gate trainer (electrical extension, power supply, banana plug male to banana plug male cables). • Slides.
Evaluation	Data collection through pre-test and post-test, with algebraic and mathematical operations exercises using technological tools for verification.			

Figure 3: Planning format. Own elaboration based on [1, 6].

2.2 STEAM activity implementation and evaluation

The evaluation of the STEAM educational activity was carried out on a group of 43 high school sophomores in Mexico through the application of a pre-test designed to measure mathematical reasoning and a post-test designed to measure the students' level of understanding, practical skills, and perception of the learning experience. The data obtained were analyzed using a student's t-test to determine if there were statistically significant differences between the pre and post-test scores.

To design the pre-test measurement instrument, a questionnaire was developed to specifically assess students' logical-mathematical thinking prior to participating in the experience. This questionnaire includes questions on basic mathematical concepts such as addition and multiplication, problem solving skills, and logical reasoning, with the goal of establishing a baseline for the participants' level of mathematical knowledge and competence.

On the other hand, the post-test measurement tool was designed to assess the understanding and impact of the STEAM activity on the students. This questionnaire includes questions that assess the knowledge gained during the activity, the practical skills developed, and the overall perception of the STEAM learning experience. In addition, open-ended questions were included to allow students to express their opinions about the activity, its challenges, and perceived benefits, which will provide more detailed feedback on the teaching process and the level of learning achieved.

Together, these pre and post-test measurement tools provide a comprehensive view of students' progress in mathematical-logical thinking, understanding, and perception of STEAM activities. The combination of these instruments allows for analysis of the impact of the activity on the development of mathematical skills and the learning experience, which facilitates the identification of areas for improvement and informed decision making for future implementation of STEAM activities.

3 Comments on the experience

Some important observations were made while teaching logic gates:

1. Abstract concept. Logic gates are abstract concepts that may be difficult for some students to understand, especially those without a strong background in mathematics or logic. This is due to the use of symbols and logical operations that may seem unfamiliar.

2. Relationship to other disciplines. The topic caused some confusion among students who are not familiar with electronics or computer science concepts. For example, some confused logic gates with physical gates or similar concepts in logic. Also, at first it was not clear to them that the "sum" in the OR logic gate is different when there is 1 + 1 in its truth table, until it was clarified with the existence of binary numbers or simply transferring it to logic disjunction, where true $\vee$ (disjunction) true is true.

3. Supplement with examples. It was useful to provide examples of logic gates in Minecraft because, by using a different context, their translation to scientific knowledge, which is the goal of the activity, was not complex.

4. Encourage logical thinking. Teaching logic gates in secondary school is an opportunity to develop logical thinking and problem solving. Teachers can design activities and exercises that challenge students to apply their logic and reasoning skills.

Figure 5 shows the group of students excited to work together in the school lab. They have the Minecraft Education video game at their disposal, which the entire group can see on a projector. The atmosphere is dynamic and lively as the students collaborate and discuss ideas to solve STEAM activity problems. Likewise, a teacher is also present in the center, providing guidance and support to the students in their learning process. The students' expressions are one of enthusiasm and excitement as they are immersed in a meaningful, hands-on experience that allows them to apply their skills in science, technology, engineering, art, and math.

(a) Secondary school team 1/2.

(b) Secondary school team 2/2

Figure 5: Educational experience orchestrated by the GMM. Own elaboration.

4 Results and discussions

Qualitative interpretation of data from the STEAM activity on basic logic gates in high school students reveals interesting findings. After analyzing the students' responses from the pre-test, post-test, and observations during the activity, different levels of understanding (gradualness) and perception of the concepts related to logic gates could be identified.

Some students showed a solid understanding of how logic gates work and how they relate to the mathematical operations of addition and multiplication. They recognized the AND gate to a multiplication operation in mathematics and the conjunction in Boolean algebra, as well as how the OR gate relates to addition. These students were able to make clear connections between logic gates and mathematical operations, indicating a deep understanding of the concepts. On the other hand, students who remained confused in connecting logic gates to mathematics and algebra may have mixed concepts or made inaccurate comparisons between operations. These findings suggest the need to present some previous fundamentals, such as binary numbers and digital signals, during the teaching of logic gates. In addition, during the activity, it was observed that the level of participation and collaboration among the students was higher than in a traditional classroom, which means that they can work together and solve problems as a group. Overall, the qualitative data from this STEAM activity on basic logic gates provided a more holistic and detailed view of students' understanding and experience with the topic.

Now, to address the quantitative data, the Student's t-test for independent samples will be used, this is applied when there is a data set with two different samples, in this case it is so because the pre-test focuses on measuring the students' mathematical reasoning skills before the intervention, while the post-test measures the knowledge acquired after the intervention, and it is necessary to determine if there is a significant difference between the means of the two samples. The bilateral formulation of the null and alternative hypotheses in this test focuses on two possibilities, which are presented below.

$$H_0\colon \mu \text{ pre-test} = \mu \text{ post-test}$$

$$H_1\colon \mu \text{ pre-test} \neq \mu \text{ post-test}$$

The null hypothesis (H_0) states that there is no significant difference between the means, while the alternative hypothesis (H_1) states that there is a significant difference between the means. During the t-test process, a value of t is calculated and compared to a critical value to determine whether the null hypothesis is rejected. If the value of t is greater or less than the critical value, it is concluded that there is a significant difference between the means and the alternative hypothesis is accepted. On the other hand, if the value of t is not sufficiently extreme, the null hypothesis is accepted, indicating that there is no significant difference between the means.

Table 1: Values of Student's t-test assuming equal variances in the high school group. Own elaboration.

	Pre-test	Post-test
Mean	6.710963455	2.373285629
Variance	2.092797252	2.069731766
Observations	43	43
Pooled Variance		2.081264509
Hypothesized Mean Diff.		0
Pooled Variance		2.081264509
df		84
t Stat		13.94160851
P($T <= t$) one-tail		$7.22784e^{-24}$
t Critical one-tail		1.663196679
P($T <= t$) two-tail		$1.44557e^{-23}$
t Critical two-tail		1.988609667

The table 1 shows the results of the Student's t-test, describing the values as follows: Mean, in the pre-test, represents the average value of their logical-mathematical skills scores before the intervention, while the post-test represents the results obtained by the participants after the STEAM activity; Variance, indicates how far the individual scores deviate from the mean; Sample, there were 43 students who participated in the activity; Common variance, represents the average variance of both groups combined; Mean difference hypothesis, indicates that the difference between the pre-test and the post-test is equal to zero, meaning that there is no significant difference between the means of the two groups; Degrees of freedom, represents the number of data that are free to vary after taking into account the restrictions imposed by the study design, in this case it is obtained by subtracting 1 from the total sum of both samples; t-statistic, with a value of 13.94, indicating that the sample means are far apart, indicating a significant difference between the pre and post-test means; P two-tailed value, is $1.44557e^{-23}$, close to zero, indicating a significant difference between the pre and post-test means; the critical two-tailed value is 1.98, which serves as a reference point to compare the t statistic, in this case the statistic value is much greater than the critical value, indicating that the null hypothesis should be rejected, and it is concluded that there is a significant difference between the pre and post-test means.

The results indicate that there is a significantly high difference between the means and there is sufficient statistical evidence to reject the null hypothesis. This indicates that the educational intervention provided by the GMM had a significant impact on the performance and skills of the participants:

1. Specific learning. During the educational intervention, students acquired specific knowledge about logic gates and their mathematical, algebraic, and electronic representation that could improve their future performance.

2. Practical Application. The STEAM activity gave students the opportunity to apply their logical-mathematical reasoning skills to practical contexts and real-world problems, which may have improved their understanding and performance on the post-test.

3. Reinforcement and practice. The educational intervention included examples and exercises that allowed students to reinforce and consolidate their skills and knowledge on the topic, which was reflected in the post-test.

It is important to note that this difference in means between the pre and post-test does not necessarily indicate that the educational intervention was ineffective. On the contrary, if students demonstrate an increase in specific knowledge and understanding related to the STEAM activity on the post-test, this could be considered a positive and desirable outcome in terms of learning. Furthermore, the results may be useful for adapting pedagogical approaches, providing additional support to students who are struggling, and promoting meaningful and effective learning of logic gates and digital logic in secondary education.

On the other hand, in the existing bibliography with the same purpose, such as [17, 18], they do not provide specific information on how these teaching-learning sequences can be adapted to different educational levels. This is done implicitly, inferring that the STEAM strategy that has different knowledge domains automatically has the capacity to adapt the content to different educational levels, which is not correct. It is important to keep in mind that the adaptation of a specific topic such as logic gates or any other topic should not be presented in its complex representation to students who have not developed a certain level of maturity, giving importance to the gradual characteristic of the GMM.

5 Conclusions

It should be noted that this study was conducted in a specific context and with a limited sample of participants. Therefore, the findings may not be generalizable to other populations or educational contexts. Although positive and significant effects of STEAM activities on participants' learning and skill development were found, it is possible that other factors not measured in this study may have contributed to these results, such as student motivation, instructional quality, technology acceptance, and content presentation. Therefore, further research using the GMM is needed to confirm the results of this study and to further explore the factors that contribute to the successful implementation of STEAM education in educational institutions.

Based on the data obtained from the t-Student test, we can affirm that the implemented STEAM activity had a positive and significant effect on the learning and skill development of the participants. The reduction in the mean of the post-test compared to the pre-test suggests that the students acquired new knowledge and skills relevant to the activity, which confirms the effectiveness of the orchestration of the STEAM activity through the GMM and its improvement of the students' performance on the assessed topic.

In addition, it was possible to determine the level of knowledge of the students through the pre-test and post-test to measure the logical-mathematical thinking, level of understanding, practical skills, and perceptions of the students after the STEAM activity. The results of these questionnaires were analyzed to determine if there were statistically significant differences between the scores. Regarding the sustainability of STEAM education in educational institutions, for the time being, further research with the GMM is suggested to further explore the factors that contribute to the success of STEAM education implementation, at least in this work, most of the challenges that have to do with the acquisition of materials can be solved with careful analysis and planning prior to an investment in technology. Finally, students expressed their opinions about the STEAM activity and perceived benefits through some open-ended questions, highlighting a sense of active involvement and relevance in their learning, as these activities are usually practical and meaningful, just as they appreciated the opportunity to apply academic concepts in a real context, which allows them to see the usefulness and concrete application of what they are learning. These attitudes, along with collaboration and team problem solving, also fostered a sense of community and an appreciation of diverse perspectives; overall, the activities orchestrated by the GMM tend to generate a lasting enthusiasm for learning and exploration in these areas, which can have a positive impact on students' future academic and career choices.

Future work Given that the STEAM activity had a positive and significant effect on learning, we make the following recommendations for future work: 1) Expand the sample, increasing the size will allow us to obtain greater representativeness and robustness in the results, providing greater confidence in generalizing the findings to a larger population of students; 2) Conduct long-term follow-up, this will allow us to evaluate whether the positive effects of the STEAM intervention are maintained over time or if there are long-term learning effects; 3) Conduct more interventions using the GMM; analyzing and comparing different types of STEAM interventions using the GMM would help determine if they are effective with the five disciplines in terms of learning and specific skill development, as well as help identify more efficient and effective pedagogical approaches.

Conflict of Interest The authors declare no conflict of interest.

Acknowledgment We are very grateful to the Escuela Secundaria Técnica 34 “Luis V. Massieu” (09DST0034Q), for allowing us to work with the high school group.

References

[1] M. Flores-Nicolás, M. Martínez, “The Graded Multidisciplinary Model: Fostering instructional design for activity development in STEM/STEAM education,” in 2022 IEEE Mexican International Conference on Computer Science (ENC), 1–7, 2022, doi:10.1109/ENC56672.2022.9882917.

[2] D. Aguilera, J. Ortiz-Revilla, “STEM vs. STEAM Education and Student Creativity: A Systematic Literature Review,” Education Sciences, **11**(7), 2021, doi:10.3390/educsci11070331.

[3] M. Conde, Rodríguez, C. Fernández-Llamas, J. Gonçalves, J. Lima, F. J. García-Peñalvo, “RoboSTEAM Project Systematic Mapping: Challenge Based Learning and Robotics,” in 2020 IEEE Global Engineering Education Conference (EDUCON), 214–221, 2020, doi:10.1109/EDUCON45650.2020.9125103.

[4] G. Ozkan, U. Umdu Topsakal, “Exploring the effectiveness of STEAM design processes on middle school students’ creativity,” International Journal of Technology and Design Education, **31**, 95–116, 2021.

[5] A. Leavy, L. Dick, M. Meletiou-Mavrotheris, E. Paparistodemou, E. Stylianou, “The prevalence and use of emerging technologies in STEAM education: A systematic review of the literature,” Journal of Computer Assisted Learning, **39**(4), 1061–1082, 2023, doi:https://doi.org/10.1111/jcal.12806.

[6] M. Flores-Nicolás, M. Martínez-Reyes, “A Theoretical-Practical Case Study on the Graded Multidisciplinary Model: Training of High School Students Through STEAM Education,” in Streamlining Organizational Processes Through AI, IoT, Blockchain, and Virtual Environments, 194–218, IGI Global, 2023, doi:10.4018/978-1-6684-8639-9.ch010.

[7] L. Ma, H. Luo, X. Liao, J. Li, “Impact of Gender on STEAM Education in Elementary School: From Individuals to Group Compositions,” Behavioral Sciences, **12**(9), 2022, doi:10.3390/bs12090308.

[8] S. Aydın Gürler, O. Kaplan, “Attitudes Towards STEAM, Critical Thinking Disposition and Decision-Making Skills: Mediation and Gender Moderation,” Journal of Contemporary Educational Research, **10**(1), 210–223, 2023.

[9] N. Arís, L. Orcos, “Educational Robotics in the Stage of Secondary Education: Empirical Study on Motivation and STEM Skills,” Education Sciences, **9**(2), 2019, doi:10.3390/educsci9020073.

[10] Y. Rahmawati, A. Ridwan, T. Hadinugrahaningsih, Soeprijanto, “Developing critical and creative thinking skills through STEAM integration in chemistry learning,” Journal of Physics: Conference Series, **1156**(1), 012033, 2019, doi:10.1088/1742-6596/1156/1/012033.

[11] E. Yilmaz Ince, M. Koc, “The consequences of robotics programming education on computational thinking skills: An intervention of the Young Engineer’s Workshop (YEW),” Computer Applications in Engineering Education, **29**(1), 191–208, 2021, doi:10.1002/cae.22321.

[12] D. Herro, C. Quigley, “Exploring teachers’ perceptions of STEAM teaching through professional development: implications for teacher educators,” Professional Development in Education, **43**(3), 416–438, 2017, doi:10.1080/19415257.2016.1205507.

[13] S. Belbase, B. R. Mainali, W. Kasemsukpipat, H. Tairab, M. Gochoo, A. Jarrah, “At the dawn of science, technology, engineering, arts, and mathematics (STEAM) education: prospects, priorities, processes, and problems,” International Journal of Mathematical Education in Science and Technology, **53**(11), 2919–2955, 2022, doi:10.1080/0020739X.2021.1922943.

[14] C. F. Quigley, D. Herro, A. Baker, Moving Toward Transdisciplinary Instruction: A Longitudinal Examination of STEAM Teaching Practices, 143–164, Springer International Publishing, Cham, 2019, doi:10.1007/978-3-030-04003-1_8.

[15] Z. Yang, “The challenges of personalized learning and their solutions,” Chinese Science Bulletin, **64**(5–6), 493–498, 2018.

[16] M. Á. Conde, F. J. Rodríguez-Sedano, C. Fernández-Llamas, J. Gonçalves, J. Lima, F. J. García-Peñalvo, “Fostering STEAM through challenge-based learning, robotics, and physical devices: A systematic mapping literature review,” Computer Applications in Engineering Education, **29**(1), 46–65, 2021.

[17] I. M. Greca, J. Ortiz-Revilla, I. Arriassecq, “Diseño y evaluación de una secuencia de enseñanza-aprendizaje STEAM para Educación Primaria,” 2021, doi:10.25267/Rev_Eureka_ensen_divulg_cienc.2021.v18.i1.1802.

[18] M. Queiruga-Dios, E. López-Iñesta, M. Diez-Ojeda, M. Sáiz-Manzanares, J. Vázquez-Dorrío, “Implementation of a STEAM project in compulsory secondary education that creates connections with the environment (Implementación de un proyecto STEAM en Educación Secundaria generando conexiones con el entorno),” Journal for the Study of Education and Development, **44**(4), 871–908, 2021, doi:10.1080/02103702.2021.1925475.