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Published by
IATED Academy
iated.org

ICERI2025 Proceedings
18th annual International Conference of Education, Research and Innovation
10-12 November 2025
Seville, Spain

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DOI: 10.21125/iceri.2025
ISBN: 978-84-09-78706-7
ISSN: 2340-1095

Book cover designed by J.L. Bernat

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These proceedings are published by IATED Academy. The registered company address is Plaza Legión Española 11, 46010 Valencia, Spain.

Bibliographic Information

Book Title
18th annual International Conference of Education, Research and Innovation

Book Series
ICERI Proceedings

Editors
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Publication Year
2025

Publisher
IATED Academy

Publisher Address
Valencia, Spain

Book ISBN
978-84-09-78706-7

Series ISSN
2340-1095

DOI
10.21125/iceri.2025

Conference Name
ICERI2025

Dates
10-12 November 2025

Location
Seville, Spain

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Topics
Education
Educational Research
Educational Technology

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THE EFFECT OF STEAM EDUCATION ON PROBLEM-SOLVING CONFIDENCE AND DESIGN THINKING SKILLS: A COMPARATIVE STUDY BETWEEN GIFTED AND NON-GIFTED STUDENTS

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Abstract

Over time, the expectations of societies from the future labor force and, therefore, from education are changing and transforming. In this context, developing higher-order thinking skills, which are prominent in 21st-century skills, is considered an important goal. In order to achieve this goal, a strong STEAM education proposal in which Science, Technology, Engineering, Art, and Mathematics are used together comes to the fore. This study examined the effectiveness of interdisciplinary STEAM education based on real-life problems developed for the education of gifted and talented (GT) and average students. As a result of the application, it was determined that both average and GT students' design thinking skills increased significantly. In addition, it was observed that the problem-solving confidence of average students increased significantly, but there was no significant change in the problem-solving confidence of GT students. In addition, it was determined that both student groups were very positive about the application and stated that they received positive results regarding many developmental aspects. For the effectiveness of the education, the precautions to be taken according to the target student group were also discussed in the study.

Keywords: STEAM Education, Gifted and Talented Students, Design Thinking skills, Problem Solving Confidence.

1 INTRODUCTION

In the age we live in, the knowledge, skills, and performance capacities expected from individuals are becoming more and more complex. Many different institutions and organizations are trying to draw the framework of skills that individuals should gain in schools under the title of 21st-century skills. In this context, 21st-century skills are used to define what students should know and be able to do in the workforce participation and decision-making processes in the modern world ([1]). However there are different classifications in the literature, it can be said that all reports are united in cooperation, communication, ICT literacy, social and cultural skills, and also creativity, critical thinking, design thinking, and problem-solving skills have an important place in a significant number of reports ([2]). In addition to the differences in these reports, a strong STEM education proposal in which science, technology, engineering, and mathematics are employed together stands out as a way for students to receive the required education ([3]).

STEM education, which is a relatively new approach, shows some differences in terms of its instructional design and implementation due to its rapid development and change. In the studies on STEM education, different practices stand out on the basis of the approaches taken as a basis for the integration of disciplines and the disciplines included in the process. In the literature, STEM education has taken different names with the disciplines included in the integration process, for example, STEAM/STEM+A with the inclusion of art ([4]), E-STEM with the inclusion of entrepreneurship as a discipline ([5], [6]), STEMM with the inclusion of medical subjects ([7]), E-STEM with the inclusion of goals related to environmental education ([8], [9]) and STEM+C with the inclusion of programming ([10]). Furthermore, in terms of the integration of disciplines, it is stated that integration can be made at four different levels: disciplinary, multidisciplinary, inter-disciplinary and trans-disciplinary, which are shaped according to the sharp distinction of disciplinary boundaries and the blurring of these boundaries and the foregrounding of real-life problems ([11], [12]). In this process, integration can take the curriculum beyond the constituent parts and create a meta-discipline above the disciplines included in the integration ([13]). However, it may not be sufficient to focus only on the content knowledge of disciplines or the meta-discipline that can be created. For successful integration, it may be important to focus not only on content knowledge but also on the development of students' problem-solving and inquiry skills ([14]). Despite

the significant efforts of teachers, these skills can be accessed at a high level in very few courses ([15]). For this reason, it can be said that the curriculum to be implemented will play a key role in developing students' higher-order skills, such as problem-solving, inquiry, and design thinking. Instead of teaching content and skills with the relatively old approach and hoping that students will see the connections with real-life applications, it may be a better practice to provide an appropriate context for students to find connections between STEM subjects and learn the content with a newer integrated approach ([16]). The design and use of real-world problem scenarios in the classroom with the integrated model can help students develop positive attitudes towards STEM careers, as well as make significant contributions to self-regulation, collaboration, and communication skills along with knowledge construction ([15]).

Encouraging students to think in a design-oriented way and to be able to think in a design-oriented way can enable them to produce new ideas by going beyond the mold ([17]). For this reason, the STEAM approach, in which art is included in the integration process for the development of engineering and design skills while developing high-level skills such as problem-solving, can be seen as an effective option. However, gathering information about the details of shaping the curriculum with an interdisciplinary approach may be important in terms of reproducing good practices. In addition, it may be important for the curriculum to produce findings related to intelligence as a factor that is generally ignored. Considering the intelligence levels of the students, there are many questions that need to be answered about the effectiveness of the curriculum for two groups of students: those who have been diagnosed as gifted and talented (GT) and those who do not have such a diagnosis and are considered to be at average intelligence level. It may be important for instructional designers and practitioners to know whether the benefits of the same program differ for both GT and average groups. In this direction, in this study, answers to the following questions were tried to be sought:

1 Is there a significant difference in the problem-solving confidence levels of GT and average students participating in the interdisciplinary STEAM education application before and after the application?

2 Is there a significant difference in the design thinking skill levels of GT and average students participating in the interdisciplinary STEAM education application before and after the application?

3 What are the opinions of GT and average students about the interdisciplinary STEAM education practice?

2 METHODOLOGY

2.1 Research design

In this study, in order to make a deeper examination, mixed research method, which allows qualitative and quantitative data to be interpreted together, was used. Johnson and Onwuegbuzie [18] state that mixed research can be classified according to time (simultaneous, sequential) and emphasis (dominant method, equal emphasis). In this study, quantitative data were collected before and after the experimental procedures, and qualitative data were collected after the completion of the experimental process. In this context, the data were collected sequentially, first quantitatively and then qualitatively, and interpreted with equal emphasis. While the quantitative data of the study were collected with the measurement tools applied before and after the implementation of the designed teaching plan, the qualitative data were obtained through semi-structured interviews with the participant students after the implementation.

2.2 Particpants

A convenient sampling method was used to determine the participants of this research. Convenient sampling is the method of determining the research group based on access to easily accessible groups compatible with the research purpose and voluntariness ([19]). The student group of this study, which did not have any diagnosis of giftedness and talent, was determined to be 18 fourth-grade students who were studying in a private school in Porto, Portugal. It is known that the students are in the middle class according to their socioeconomic status. The school where these students are studying was preferred because it is one of the partners of the 'STEAMing Ahead' Erasmus+ project, access opportunities and opportunities to collect detailed information during the research. It is known that the students in the class participating in the application do not have any diagnosis of giftedness and intelligence but are students studying at average intelligence levels. The student group of the research with a diagnosis of giftedness and talent was determined as 11 fourth-grade students who were studying in the science and art center where GT children are educated in Ankara province of Turkey. It is known that the students are in the

middle-lower class in terms of socioeconomic level. This institution was chosen as a partner of the 'STEAMing Ahead' Erasmus+ project because of its ease of access and the fact that STEAM activities allow data collection on students in the gifted group.

2.3 Developing STEAM Curriculum

Five progressive steps were followed to develop the STEAM curriculum to be implemented in the research. These are needs assessment, determination of objectives, selection of content, creation of 7E lesson plans and determination of evaluation activities as shown in Figure 1. Firstly, a literature review and expert opinion were taken to conduct a needs assessment of the target group. In line with the results obtained, the needs assessment was completed and the objectives were written in line with the identified needs. In the following steps, content selection was made. In this direction, the themes of 'War' and 'Saving Water' were determined due to their inclusive structure and compatibility with the needs of the time.

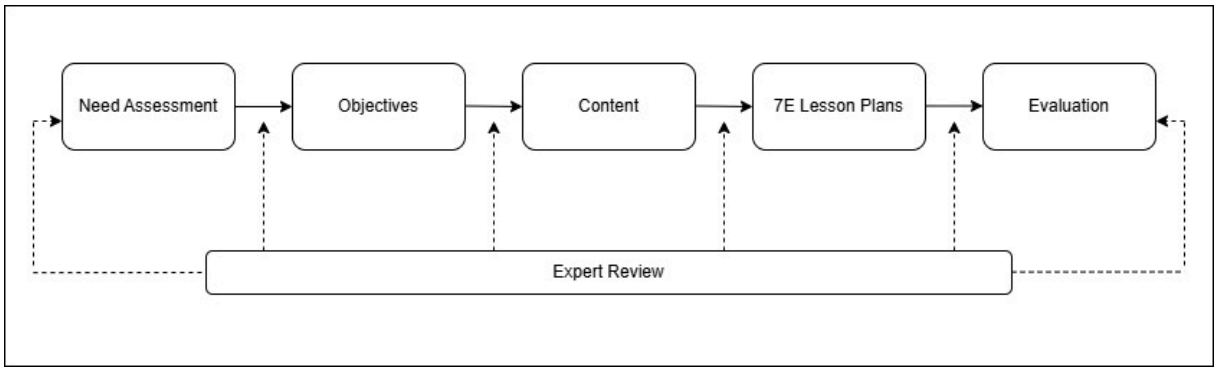

Figure 1. Development phases of STEAM curriculum

Following the determination of the content, the preparation of the activity plans was started. This stage was theoretically based on the 7E (Elicitation, Engagement, Exploration, Explanation, Elaboration, Evaluation and Extension) model. In this respect, five lesson plans were developed under the theme of 'Water Conservation', while four lesson plans were developed under the theme of 'War'. In the last stage, the tools and methods to be used in the evaluation phase were determined in order to reach the implementation results of the developed curriculum. In this direction, design thinking skills scale, problem solving confidence scale and semi-structured interview forms were used. At each step of the STEAM curriculum development process, expert opinions were taken and revisions were made in the problematic sections. The revised sections were included in the final study if they passed the second expert evaluation. The developed curriculum are available as open-course content.

2.4 Implementation process

The implementation of the nine STEAM lesson plans developed in two different themes was carried out at similar times in the 2022-2023 academic year in the determined implementation institutions of the two countries. In the Portugal implementation school, each lesson plan was implemented two or three days a week for four weeks, with one lesson plan per day during school class time. In the Turkish implementation school, the activities were implemented in a total of four weeks, with one or two activities per day on weekends outside of school class time. Before the implementation of the activities, the necessary course materials in both countries were kept ready in the implementation classrooms by checking the list in advance. In addition, the students in the experimental process were asked to answer the Problem-Solving Confidence Questionnaire and the Design Thinking Mindset Scale before and after the application. After the implementation processes had ended, focus group interviews were conducted with both groups using a semi-structured interview form. The responses to the quantitative scales were recorded on printed papers and the focus group interviews were audio recorded.

2.5 Instruments

2.5.1 Problem-Solving Confidence Questionnaire (PSCQ)

Problem Solving Confidence Questionnaire was used to measure the problem solving confidence of the participants before and after the application. The measurement tool developed by Gök [20] has a two-factor structure: low problem-solving confidence and high problem-solving confidence. In the scale, items such as 'I do my best to be successful in problem-solving' were included in determining students' problem-solving confidence levels. In the scale developed in 5-point Likert type, students are expected to mark each item by choosing one of the responses as '1=strongly disagree, 2=disagree, 3=undecided, 4=agree, 5=strongly agree'. In the process of preparing the Turkish and Portuguese forms of the scale, one language and one field expert took part in the translation process. According to the reliability analysis performed on the scale, the Cronbach alpha value of the Turkish adapted form was calculated as .947, while the Cronbach alpha value of the Portuguese adapted form was calculated as .993.

2.5.2 Design Thinking (DT) Mindset Scale

DT Mindset Scale was used to determine the design thinking skill levels of the participants before and after the application. The scale developed by Vignoli et al. [21] consists of 31 items with ten sub-factors. In the scale, items such as 'I actively involve users in diverse phases of the design process' were included to determine the design thinking levels of the students. In the scale developed in 5-point Likert type, students are expected to mark each item by choosing one of the answers as '1=strongly disagree, 2=disagree, 3=undecided, 4=agree, 5=strongly agree'. In the process of preparing the Turkish and Portuguese forms of the scale, one language and one field expert took part in the translation process. Cronbach alpha values of the Portuguese scale and the Turkish scale were calculated as .992 and .978, respectively.

2.5.3 Semi-Structured Student Interview Form

In order to collect the opinions of the students participating in the application, a focus group interview technique was used. In the application of this technique, a semi-structured student interview form was used as a data collection tool. This interview form was developed by the researchers and finalized based on expert opinion. The form included questions to reflect students' views on the implementation of interdisciplinary STEAM education. The questions were prepared as main questions, additional questions, and elaborative questions. The main questions are aimed at revealing the students' evaluations of applied education in general. Additional questions were included to elaborate on the data obtained from the main questions, while detailed questions were included to describe the data obtained in a practical way.

3 RESULTS

3.1 Results on problem-solving confidence

The problem-solving confidence levels of both the groups of students diagnosed with GT and those without such a diagnosis were measured before and after the application process. It was analyzed whether there was a statistically significant change in problem-solving confidence levels. The results of the analysis are presented in Table 1.

Table 1. Comparison of pre and post-problem-solving confidence of the implementation groups

Average Students	***n***	***Mean Ranks***	***Sum of Ranks***	***Z***	***p***
Positive Ranks	14	9.04	126.50	-3.031	.00
Negative Ranks	2	4.75	9.50		
Ties	2				
		GT Students			
Positive Ranks	4	6.07	42.50	-.845	.40
Negative Ranks	7	5.88	23.50		
Ties	0				

The analysis showed that the problem-solving confidence of the group, including students with average intelligence levels, differed significantly in favor of the post-test ($p<0.05$). During the implementation process, the confidence of average students in problem-solving improved. However, it was determined that there was no significant change in the problem-solving confidence of the group of GT students ($p>0.05$).

3.2 Results on design thinking skills

Before and after the application, measurements were made to determine the change in the design thinking skill levels of both students diagnosed with GT and students with average intelligence levels. It was statistically analyzed whether there was a change in the pre-test and post-test scores of the measurements. The results of the analysis are presented in Table 2.

Table 2. Comparison of pre and post-design thinking skill levels of the application groups

Average Students	***n***	***Mean Ranks***	***Sum of Ranks***	***Z***	***p***
Positive Ranks	18	9.50	171.00	-3.829	.00
Negative Ranks	0	0	0		
Ties	0				
		GT Students			
Positive Ranks	9	6.44	58	-2.224	.03
Negative Ranks	2	4	8		
Ties	0				

According to the results of the analysis, it was determined that the pre-test and post-test design thinking skill levels of the students with average intelligence levels differed significantly in favor of the post-test ($p<0.05$). During the application process, students improved in terms of design thinking skills. Similarly, the design thinking skill levels of students diagnosed with GT increased significantly in favor of the post-test ($p<0.05$). During the implementation process, it was determined that students with giftedness and talent also improved in terms of design thinking skills.

3.3 Results on student opinions about the application

The data obtained from the opinions of the students about STEAM education were analyzed under three headings. These are the general opinions of the students about STEAM education, the aspects of this education that they consider different from the education they received at school, and whether they want to change this education with the education at school.

3.3.1 Students' views on STEAM implementation

It was observed that the opinions of the two student groups in which the implementation was carried out differed at some points and crossed at some points. It was determined that both the GT group and the group with average intelligence levels showed positive development regarding the development of their skills and their awareness of environmental issues. In addition, the group GT also stated that they gained awareness about social problems. The categories and codes generated by the students' opinions are presented in Table 3.

Tablo 3. Codes and categories created regarding students' opinions about STEAM education

	Average Students		***GT Students***	
Category	***Code***	***N (Student)***	***Code***	***N (Student)***
Skill development	Creativity	4	Creativity	4
	Solving problems	4	Critical thinking skills for solving problems	4
	Artistic perspective	4	Multidimensional perspective	4
	Scientific process skills	4	Self-confidence for investigating	3
	Coding	2	Research skills with the internet	4
	Engineering	4	Technology-use self-efficacy	3
	Math skills	3		

Environmental awareness development	Gaining awareness about the environment	2	Gaining awareness about the environment	5
	Understanding how nature works	3	Being more sensitive to the environment	5
Raising awareness of social issues			Approaching social problems more carefully	5
			Empathizing with the suffering of other societies	5

It was found that the opinions of both students regarding application were mostly on skill development. However, while average students stated that their problem solving skills improved, GT students stated that their critical thinking skills for problem solving improved.

Another point where the opinions of average and GT students regarding the application differed is that while average students stated that they gained artistic perception, GT students stated that they gained a multidimensional perspective. In addition, the skills that average students thought they developed during the application period are scientific process skills, coding, engineering, and maths skills. On the other hand, GT students thought that Self-confidence in investigating and technology self-efficacy developed. It was determined that both student groups agreed that their environmental awareness improved. Besides, only GT students stated that their social awareness improved.

3.3.2 Students' opinions on the different aspects of STEAM education from the education they received at school

Both groups of students who participated in the application were asked about the points where the education they received differed from the education at school. It was seen that both average and GT students responded to the question in terms of the advantages provided to them by the learning process and interdisciplinary structure of the courses. The codes and categories related to these opinions of the students are presented in Table 4.

Table 4. Points in which students find STEAM education different from the education they receive at school

	Average Students		***GT Students***	
Category	***Code***	***N (Student)***	***Code***	***N (Student)***
In terms of the learning process	Makes learning like an adventure	1	Fostering curiosity	4
	Fun	3	Instilling a sense of responsibility	5
	Active learning	4	Trigger about the environment	5
	Feeling of learning	4		
In terms of interdisciplinary approach	Realizing that every subject learned is related to many lessons	4	Realizing that every subject learned is related to many lessons	4
	Realizing the importance of artistic perspective	4	Realizing the importance of artistic perspective	4
	Realizing that many courses together contribute to the solution of problems	3	Realizing that many courses together contribute to the solution of problems	4
In terms of self-expression	opportunity to use different knowledge	3		
	opportunity to use different skills	3		
	opportunity to show creativity	4		

In line with the opinions expressed by the students, it was inferred that average students evaluate learning as an adventure, find it fun, actively participate in the process, and feel that they have learned.

GT students stated that learning with STEAM education, unlike the learning process at school, is a way to satisfy their curiosity rather than a task, helps them gain responsibility, and triggers them to do something about environmental issues.

It was determined that both student groups shared the view that STEAM education was different from the education they received at school in terms of its interdisciplinary structure. In this direction, the students stated that they realised that the subjects they focused on in the lessons were related to more than one discipline and that they used the knowledge of many disciplines in the problem solving process.

Unlike GT students, average students also emphasised that STEAM education is different from education at school in terms of allowing them to express themselves.

3.3.3 Students' opinions on adapting the education they receive at school completely to the STEAM approach

The students were asked whether they would like to change the education they attended if they had the opportunity to change the education they attended with the education at school and the reason was asked. While all of the group of average students answered 'yes' to this question, 'no' and 'undecided' responses were also received from GT students. The responses received are presented in Table 5.

Table 5. Students' opinions about replacing the education they received at school with STEAM education

	Average Students		***GT Students***	
Answer (Y/N)	***Reason***	***N***	***Reason***	***N***
Yes	Fun	3	Every step of the lesson is more important than the result	3
	Taking many courses together at the same time	4	Taking many courses together at the same time	2
	Active learning	2	Effective group work when finding solutions to problems	3
	Deep learning	1		
	Learning with multiple senses	1		
Undecided			Activities take a long time	1
No			The constant research and learning are exhausting. inability to shirk	1

While average students stated that the reasons why they wanted to see the application in all courses were that they found it fun, active, and supportive of deep learning, GT students focused on group work and the interdisciplinary nature of the application. Nevertheless, not all GT students were equally positive; for instance, one student reported being undecided due to the long duration of the activities, whereas another expressed that conducting extensive research for each task was exhausting and that he would not prefer such practices to replace the regular school learning process.

4 CONCLUSIONS

The impact of the integrated steam education model on problem-solving confidence levels was examined for both average and GT students. Findings showed that average students' confidence improved, which is consistent with previous research ([22], [23], [24], [25]). This improvement can be attributed to students' active engagement as problem solvers and designers in the learning process, which provided them with richer experiences. Supporting this explanation, several studies have reported that the frequency of experiences in stem contexts positively affects students' self-confidence in problem solving ([26], [27]). In focus group interviews, all average students also emphasized that they felt they had learned throughout the process, and this perception of learning appears to have contributed to their confidence, since confidence is closely tied to students' belief in their ability to apply skills ([28]).

By contrast, no significant change was observed in GT students' problem-solving confidence. One explanation may be their tendency to evaluate themselves in relation to their equally talented peers, which can foster feelings of inadequacy despite their strong abilities ([29]). Although confidence is recognized as an important predictor of problem-solving skills ([30], [31]), it does not consistently determine performance in all contexts. Thus, the lack of improvement in GT students' confidence may not reflect weak problem-solving skills but rather their perfectionism and high standards of achievement ([32], [33]).

In terms of design thinking, both groups demonstrated significant progress. The integration of original and challenging tasks alongside opportunities to apply design processes appears to have fostered this improvement, which is in line with previous research emphasizing the role of active participation and meaningful experiences ([34], [35], [36]). In this study, the content was deliberately structured to promote design thinking, and students reported that their creativity developed as a result.

Focus group interviews further revealed predominantly positive perceptions of the steam experience. Students highlighted the development of multiple skills and increased environmental awareness,

although GT students tended to stress relatively more complex competencies. For example, while average students emphasized problem-solving, GT students reported growth in critical thinking within problem-solving processes. Similarly, average students mentioned artistic development, whereas GT students described the acquisition of multiple perspectives, including artistic ones. This reflects the flexible and complex cognitive profiles of GT students ([37], [38], [39]). Another difference concerned social awareness: whereas average students did not comment on social issues, GT students stated that they gained awareness of such matters, possibly linked to their emotional intelligence ([40]).

When asked whether they would prefer to replace traditional school learning with steam, all average students agreed, while one GT student was undecided and another disagreed. Their reservations were related to the long duration of activities and the demanding research load. These concerns may stem from GT students' critical thinking and perfectionist tendencies ([41]), but also from structural factors. In Türkiye, where this study was conducted, the education system is highly exam-oriented, relying on central multiple-choice assessments. This context may have led GT students to view steam as time-consuming and misaligned with exam preparation. Such findings illustrate why integrating rich learning experiences like steam can be particularly challenging in developing education systems.

ACKNOWLEDGEMENTS

This research was conducted within the scope of the KA220 ERASMUS project. (Project number:2021-1-PT01-KA220-SCH-000029409)

✦ *Ethics approval and consent to participate*

All procedures involving human participants were performed in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki, as well as its later revisions or equivalent ethical guidelines.

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