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Design-Based STEM Activities in Teacher Education and Its Effect on Pre-service Science Teachers' Design Thinking Skills

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Abstract
This study aims to fill the gap in teacher education by examining the effect of design-based STEM activities on pre-service science teachers' design thinking skills and evaluating their design-based learning process experiences. An explanatory mixed design that includes both qualitative and quantitative data was used as the research method. The research was carried out within the scope of the Technology and Project Design course in the Department of Science Education. The research group of the study consists of pre-service science teachers of the Department of Science Education. A total of 46 students consist of the participant group of the research. Most of the participants are female students ($n=38$, 83%). The number of male students participating in the study is 8 (17%). Design Thinking in Teaching Scale, Design Evaluation Rubric and semi-structured interview form were used as data collection tools. Findings show that design thinking skills levels of pre-service teachers differ significantly after the application. The results highlighted the positive contribution of design-based STEM activities on the design thinking of pre-service teachers. Also, the design evaluation scores of pre-service teachers are high. Pre-service teachers have highlighted the necessity of using design-based activities and the design process in educational environments and course design.

Keywords Design thinking skills · STEM education · Pre-service teachers · Design applications · Instructional technologies

Introduction

Design refers to the entire production process aiming to create a product (Chen & Terken, 2022). According to Friedman (2003), design is a goal-oriented process for solving problems, meeting needs, improving conditions or producing new and useful things. Initially, design was defined as a field concerned with aesthetics, form and function, mainly in tangible products or visual outputs. However, the requirements in the business world have led to the emergence of a broader perspective of design thinking. Design thinking is an iterative process that defends a user-centred approach to problem-solving, integrating the needs of people, the possibilities of technology and the requirements for business success (Hennessey & Mueller, 2020). Unlike traditional design, which usually focuses on the final product, design thinking emphasizes the innovation process, which involves a series of steps such as empathizing with users, defining the problem, generating ideas, prototyping and testing (Razzouk & Shute, 2012). This approach marks a shift from creating objects to fostering a culture of innovation and a mindset of understanding and solving complex, multifaceted problems. With the world's leading technology companies interiorizing the design thinking approach, design thinking is now being taught and used in many schools (Dam & Siang, 2021). In preparing students for the future, the aim is to develop individuals who can tackle complex problems, think critically and innovate. The acquisition of design thinking skills and ways of thinking by pre-service teachers equips them with valuable competencies for the modern workforce (Kickbusch et al., 2020). Furthermore, it fosters adaptability and a commitment to lifelong learning.

Integrating design thinking into the teaching process creates learning environments that are dynamic, student-centred and aligned with the skills and mindsets needed for the twenty-first century (Lin et al., 2020). This will not only teach content but also enable students to develop a way of thinking and a range of problem-solving, collaborative and creative skills that they will take with them (Liudmyla et al.,

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2022). Design thinking makes learning more engaging and interactive (Pande & Bharathi, 2020). It encourages active participation and hands-on problem-solving instead of passive participation (Bender-Salazar, 2023). This not only makes learning more fun, but also deepens learning and retention (Griffith et al., 2024). The importance of design thinking is that it provides innovative solutions for students by putting the student at the focus of the education. Design thinking is based on the integration of learners' design processes into classroom practice to solve real-life problems (Felix et al., 2010). It is essential, and students' use of ICT to resolve design challenges is closely associated with the conceptions of meaningful learning with ICT (Howland et al., 2012). Design thinking in teacher education will help future teachers improve the way they teach and will also make the learning experiences of their future students better.

Design thinking required in teaching refers to cognitive processes that help teachers generate innovative solutions to effectively address teaching-related issues in educational settings. It is increasingly being interiorized in higher education contexts to support interdisciplinary, collaborative and networked learning and to help students graduate with qualifications ready for twenty-first-century challenges (Çeviker-Çınar et al., 2017; Matthews & Wrigley, 2017). Furthermore, the role of teachers is expected to be seen as a facilitator rather than an instructor (Noweski et al., 2012). In the design thinking process, the teacher provides a structure and context to include collaborative groups, tools and activities. Design thinking skills are also invaluable to teachers as they are expected to design opportunities for students to problem-solve creatively and collaborate in teams, preferably in authentic and situated contexts. In this respect, it can be stated that design thinking is important in teacher education.

Moreover, with the integration of design thinking into teacher education, pre-service teachers are expected to improve both their content knowledge and pedagogical skills (Ayaz & Sarikaya, 2021; Henriksen et al., 2020). The main reason for school leaders and teachers to apply design thinking in higher education is to teach empathy and support creativity, innovation and prototyping (Lor, 2017). Given the significance of design thinking for both teachers and students, this study, in which both pre-service teachers and undergraduate students are involved, is important. Faculties of Education is a place that trains future teachers; pre-service teachers are expected to think design-based and prepare appropriate environments (Sürmelioğlu, 2021). In this process, pre-service teachers will both gain design-based thinking skills and prepare activities for their students with these skills. Also, higher education research into design thinking practice in student-centred learning environments is still emerging (Beligatamulla et al., 2019). Despite the increasing recognition of the importance of developing design competencies among students, there is a general lack of studies in the field of teacher education (Koh et al., 2015; McLaughlin et al., 2023; Razzouk & Shute, 2012).

This study aims to fill this gap in teacher education and to examine whether the design thinking process has an effect on pre-service teachers' design thinking skills and design evaluation scores and evaluate their design-based learning activity experiences.

Research questions of this study are as follows:

RQ1: What is the effect of design-based STEM activities on pre-service teachers' design thinking skills?
RQ2. What is the effect of design-based STEM activities on pre-service teachers' design evaluation scores?
RQ3. What are the opinions of pre-service teachers on design-based STEM activities?

Conceptual Framework

Design Thinking

Design thinking (DT) is defined as an analytical and creative process used for experimentation, modelling, prototyping, collecting feedback and redesigning (Razzouk & Shute, 2012). It is also defined as a skill or approach that defines the process used by designers to produce creative solutions to problems (Chesson, 2017; Dorst, 2011). DT is a way of working and thinking beyond the design context and is consistent with pedagogical principles, methods and approaches (Atchia, 2023; Duman, 2007). DT is also at the centre of education where educators strive to create better learning outcomes (Henriksen et al., 2017). It provides opportunities for people to gain certain skills and knowledge. Design thinking has the potential to incorporate and develop digital competency skills (Vallis & Redmond, 2021). DT skills can be learned and developed through pedagogical approaches. Activities involving problem-based learning, project-based learning and inquiry-based learning can be fulfilled in the classroom (Girgin, 2019; Rösch et al., 2023; Zhu et al., 2024). To help students succeed in the digital world, educators focus on helping students develop design thinking, systems thinking and teamwork skills that enhance problem-solving skills and prepare them for college and career (Razzouk & Shute, 2012; Shute & Torres, 2012; Vardakosta et al., 2023).

DT is expressed as a structured guide to help teachers integrate pedagogical knowledge and contextual issues, design practical and creative teaching activities and increase their confidence in their teaching practices (Henriksen et al., 2017). In addition to facilitating students' learning of interdisciplinary knowledge, design thinking has pedagogical opportunities to develop students' creative capacities by using the knowledge they have learned, rather than accepting it as mere facts (Du Plessis & Webb, 2011; Koh et al., 2015; Sawyer, 2012). In curriculum-based design thinking, pre-service teachers are expected to gain skills such as collaboration, problem-solving and empathy (Carroll et al., 2010; Dukes & Koch, 2012; Hashim et al., 2019). Research has revealed the benefits of design thinking to teaching practices in different fields such as biology education (Henriksen et al., 2017), STEM education (Atchia, 2023; Wu et al., 2019), foreign language education (Crites & Rye, 2020; Matsui, 2020), programming education (Saritepeci, 2020), management education (Schlenker & Chantelot, 2014) and art education (Fletcher-Watson, 2015). A design thinking review study shows that it is mostly associated with skills in educational settings in terms of collaboration/teamwork, creativity, problem-solving and empathy (Guaman-Quintanilla et al., 2018). In addition, several outcomes have been observed, including the quality of solutions produced by design thinking, adaptability and flexibility and psychological benefits (McLaughlin et al., 2022). Design thinking is used in the context of curriculum requirements to develop flexible thinking skills, encourage self-learning and assessment, develop students' communication skills and raise responsible citizens (Davis, 1998).

Nowadays, DT is defined as an innovative new paradigm to produce solutions to problems in many fields, especially Information Technologies (Brooks, 2010; Dorst, 2011; Pande & Bharathi, 2020). It is stated that design-based learning (DBL) activities such as digital storytelling and interactive web page design will yield important results in IT education and its reflection (Saritepeci, 2020). According to Leinonen and Durall-Gazulla (2014), co-operation in different fields enables problems to be solved in a way that does not lead to other problems. This can be achieved when different perspectives from different disciplines are included in the design process. Carroll (2014) emphasized the mentoring model in teaching design thinking to both teachers and students. In the study, it is argued that the design thinking process provides a framework in which pre-service teachers learn how to create user-centred learning experiences while sharing their experiences as STEM professionals. Pre-service teachers are expected to be equipped with design thinking skills so that they can design effective lessons to meet individual differences and help develop design capacity among future students (Koh et al., 2015). Also, it is stated that design thinking education should develop not only technical skills but also skills that relate to social issues (Bang & Marin, 2015; McGowan & Bell, 2020). Design thinking curriculum offers an effective pedagogical approach for students to develop care and responsibility for ecological issues. McGowan and Bell (2022) argue that in the design process, students not only solve technical problems but also design more sustainable social and environmental designs.

Design Thinking and STEM Education

In the current attempt to develop and execute STEM education, design and design thinking have assumed a more essential role, as they are fundamental to innovation and skill (Li et al., 2019). The design process can be employed to address challenging and unique problems. Design thinking is an appropriate way to positively foster students' integrated STEM learning experiences with teacher support (Chiu et al., 2021).

Several integrated STEM education strategies inherently seek to foster design thinking through project-based learning (Chai et al., 2020). Many professional programmes or activity initiatives have concentrated on teaching STEM in an integrated way (Avcı, 2024; English, 2019; Retna, 2016; Ring et al., 2017). Literature has shown that students can learn through design and develop their design thinking through STEM education. There are some studies on how design thinking can help engage students and facilitate their learning of STEM content (Carroll, 2015; Ke, 2014; Kelly & Cunningham, 2019). Also, the design process integrated with STEM fosters students' spatial thinking and visualization abilities (Avcı, 2024; Lubinski, 2010), creativity and problem-solving skills (Yalçın & Erden, 2021), computational thinking skills (Avcı, 2024), colloboration and emptahy (Aflatoony et al., 2018) and self-efficacy and interest (Huang et al., 2022). Additionally, Johns and Mentzer (2016) highlight a relationship between design thinking activities and the scientific research process. Tae (2017) found the design thinking approach based on the STEAM curriculum indicates a change in students' affective attitudes, and students are satisfied with the activity. In addition, significant improvements in interest in mathematics and scientific technology and an increase in career preferences in engineering are observed. Briefly, design thinking activities can be a fundamental alternative in teaching (Saritepeci, 2020).

Design thinking integrating STEM often focuses on students solving problems that are complex and cognitively challenging (Johansson-Sköldberg et al., 2013). To this end, it is important to support students by developing their design thinking competencies and increasing their motivation to undertake complex tasks. Bequette and Bequette (2012) state that design thinking can serve as a bridge between STEM education. Moreover, how STEM education plays a role in design activities and different applications is also an important issue (Li et al., 2019). STEM-based design activities are an important topic in teacher education in terms of both process and thinking skills.

Design Projects in Teacher Education

Design projects are used for instructional purposes at many levels of education. These projects are substantial in terms of providing students with science and engineering skills. To increase the importance of creative and innovative thinking, the design thinking approach is used in the projects. Holistic thinking, imagination, creativity and visualizing problems and solutions are essential skills of a designer. The design thinking approach is used to transform these skills into active learning and to evaluate student development in the classroom (Chandrasekaran et al., 2014). In general, design thinking can be thought of as a teaching method that engages students in solving real-life design problems and reflecting on the learning process (Matere et al., 2023).

The design process is multifaceted and has an approach to generating new knowledge similar to the scientific research process. Design thinking provides a reason to learn science content by involving the student in design and using a natural and meaningful environment to learn both science and design skills (Reilly & Reeves, 2024). The collaborative nature of design provides opportunities for teamwork (Kolodner, 2002). The use of design thinking was implemented across many topics and grade levels, with its outcomes being assessed (Högsdal et al., 2021). Design thinking fosters collaboration among students and enhances teachers' capacity to assess learning results (Koh et al., 2015). An expert teacher is both a practitioner and a designer. The design aspect of teachers' work differs from the traditional view of teaching as the practice of teaching. Rather, the teacher is seen as someone who actively creates, devises, develops and designs the process of learning (Kirschner, 2015). In teacher education, design thinking has the potential to develop skills such as creativity, problem-solving, communication and teamwork and empathy with others (Retna, 2016). It allows schools to find solutions that are appropriate to their unique contexts (Diefenthaler et al., 2017). This approach enables teachers to become change leaders responsible for their students, schools and communities (Parker et al., 2021). Adoption of this approach and pre-service teachers who have a good command of these processes will contribute significantly to the development potential of schools.

Method

Research Model

An explanatory mixed design that includes both qualitative and quantitative data was used as the research method. The mixed model not only combines qualitative and quantitative methods but also includes comprehensive integration studies by using the strengths of these methods to support each other (Teddlie & Tashakkori, 2015). The mixed method design is employed to address research inquiries that cannot be adequately addressed using a single paradigm, particularly in the context of educational technology-based research (Spector, 2015). This method allows for the presentation of both qualitative information about the participants' viewpoints and quantitative scores using the measurement tool. In explanatory mixed methods research, qualitative data are collected and then used to explain or support quantitative data (Creswell & Plano Clark, 2011). The research was carried out within the scope of the Technology and Project Design course in the Department of Science Education. The research group of the study consists of pre-service science teachers of the Department of Science Education. A total of 46 students constitute the participant group of the research. Most of the participants are female students ($n = 38$, 83%). The number of male students participating in the study is 8 (17%).

Instruments

Design Thinking in Teaching Scale

The study utilized the Design Thinking in Teaching Scale, which was developed by Sürmelioğlu and Erdem (2021), to assess the design thinking skills of pre-service teachers. The scale comprises 25 items and measures a 4-factor structure, which includes relationship, process, ethical and individual. The Cronbach's alpha coefficient, which measures the internal consistency of the scale, was calculated to be 0.93. This value shows that the scale is reliable. The scale was developed for teachers. A reliability study of this scale was also undertaken for pre-service teachers, and Cronbach's alpha coefficient was found to be. 83. Then, the factor structure of the scale, whose availability was tested with confirmatory factor analysis (CFA), and the dataset agreed. The scale, which reached its final form after validity and reliability studies, consists of four dimensions: relationship, process, ethical and individual. The internal consistency coefficients for four dimensions were determined as 0.79, 0.77, 0.81 and 0.76, respectively. It shows that the scale is a valid and reliable tool that can be used to determine preservice teachers of design thinking in teaching.

Design Process Evaluation Rubric

In the evaluation of the design process of each group, the Design Process Evaluation Rubric used in engineering education in NASA (2015) and adapted into Turkish by Uzel (2019) was used. The design process evaluation consisting of 8 (eight) stages according to this rubric was evaluated based on three levels ((1) below the targeted level, (2) at the targeted level, (3) above the targeted level). These are identifying the problem, researching the problem, developing possible solutions, selecting the best solution(s), constructing prototype, testing and evaluating solution(s), presenting solution(s) and redesigning, respectively. Using the developed rubric, the researcher and an expert in science education scored the designs. The consistency of the scores given by the raters was analyzed using the simple correlation technique. The inter-rater reliability coefficient was calculated as. 792.

Semi-structured Interview Form

Semi-structured interview is defined as a qualitative data collection process that involves asking predetermined open-ended questions (Adeoye-Olatunde & Olenik, 2021). The researcher aimed to investigate the design development experience of the pre-service teachers. For this purpose, a semi-structured interview form was prepared. The researcher formulated questions within the scope of the purpose of the research and the context of the activities to determine the content of the semi-structured interviews. Ensuring the content validity of the questions in the interview is important for the studies. The content validity of the questions prepared for this purpose should be provided with expert opinions (Brod et al., 2009). For this purpose, one Science Education expert and Computer Science Education expert evaluated the questions, and the following two questions constituted the scope of the form. These interviews were conducted with 46 participants, and each interview lasted approximately 15 min and took place in a classroom setting.

> "What were the challenges you experienced on design process?"
> "How was this design process experience for you?" were used in the final data collection.

Data Analysis

Data, obtained by applying the Design Thinking in Teaching Scale before and after the process, were analyzed with the Wilcoxon signed-rank test after determining the normal distribution of the scores. The SPSS 25 Statistics programme was used for quantitative analysis. The opinion form, which was prepared by the researcher and examined by the expert opinion, was filled in by pre-service teachers at the end of the process. The form containing the views on activity was analyzed with content analysis.

Qualitative data were examined using content analysis by two researchers. Cohen kappa statistics were used for the reliability of the analyses. Cohen kappa coefficient is a statistical method that measures agreement reliability between two raters. In this study, the agreement between the raters was found to be 0.89. This rate indicates a very high percentage (Rau & Shih, 2021). Instances where the two experts had differing opinions were revisited, and after thorough deliberation, they reached a consensus.

Activity

The study was carried out as design-based STEM activities within the scope of the Elective Technology and Project Design course, one of the courses of the Department of Science Teacher Education. The study lasted 12 weeks. In the first week, the pre-service teachers were informed about design-based STEM activities, and it was conveyed to the pre-service teachers that activities can be done on the problems given. STEM integration approach can be applied to solve global problems on energy, health and the environment (Bybee, 2010) population growth, environmental problems, agricultural productions and many more. It requires a global approach supported by in-depth research in science and technology to address this issue (Thomas & Watters, 2015). Within this scope, the students were asked to do two projects of 5 weeks each. The theme of the first project was energy efficiency design, and the theme of the second project was smart irrigation system development design. In the last week, opinions about the course and data collection process were realized. Within the scope of the activities, pre-service teachers used Arduino or S4A tool and created their designs through this tool.

During the project development process, students carried out design-based STEM activities according to the design thinking model proposed by Stanford School. The design thinking model is expected to improve students' design thinking and problem-solving skills (Pratomo & Wardani, 2021; Saritepeci & Yildiz Durak, 2024). This model is a learning approach that can develop innovation skills and design thinking skills in students in various disciplines to solve life problems (Avcı, 2024). The Stanford model consists of five distinct phases of design thinking, also known as modes, which are systematically followed to arrive at a problem solution or resolution. The five phases are empathize, define, ideate, prototype and test. These modes are designed to be adaptable and iterative, allowing a designer to repeat or reassess a phase at any given point. The implementation process in this research is shown in Fig. 1.

The teaching in the process was based on the design thinking cycle proposed by the Stanford model (Henriksen et al., 2017). This design learning process involves five phases: empathize, define, ideate, prototype and test. The steps implemented during the projects are given in Table 1. Figures 2 and 3 show sample design images, sketches and code structure.

Findings

Design Thinking Skills of Pre-service Teachers

The Shapiro–Wilk test was applied to the pre-test and post-test scores of the design thinking skills scale applied to

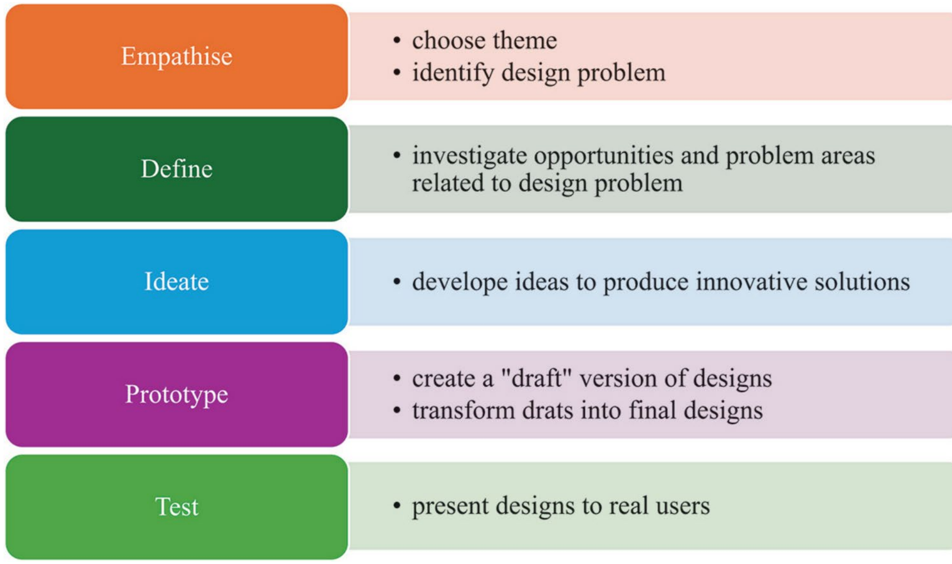

Fig. 1 Design thinking process

pre-service teachers to determine the normal distribution, which is a prerequisite for parametric tests. Test results are given in Table 2. When Table 2 is examined, as a result of the Shapiro–Wilk test conducted to determine whether the scores show a normal distribution, the values obtained from the design-oriented thinking scale are found to be meaningful for the pre-test ($p = 0.042$; $p > 0.05$) and post-test ($p = 0.006$; $p > 0.05$). It is seen that the values are below 0.05 and therefore do not show a normal distribution. It was determined that the results could be analyzed with non-parametric tests. The pre-test and post-test scores were analyzed with the Wilcoxon signed-rank *T*-test to determine whether the scores obtained by the pre-service teachers from the design thinking skills scale differed significantly. *T*-test results are given in Table 3. Table 3 shows that there is a significant difference between the scores of pre-service teachers from the design thinking scale ($Z = -5.485$; $p < 0.05$). It is seen that the mean of the post-test scores is higher than the mean of the pre-test scores. Pre-service teachers' design thinking skills improved at the end of the application.

Design Process Evaluation Scores of Pre-service Teachers

The product designs of pre-service teachers were evaluated with the Design Process Evaluation Rubric developed by NASA (2015) and adopted by Uzel (2019). The pre-service teachers were divided into nine groups of five people each to create their designs. The designs of the pre-service teachers were analyzed by two experts throughout the whole process and scored according to three performance levels. Expert 1, Expert 2, mean scores and Pearson correlation coefficient calculated to determine reliability are given in Table 4. It shows that there is a significant and positive correlation between the scores given to pre-service teachers' product designs by the experts ($r = 0.792$, $p < 0.01$). Table 4 shows that design process evaluation scores ranged between 17.50 and 22 among nine groups. The mean score of all groups was 20.06. This shows that the mean of the study group is at a high level. The scores of the two groups are below the mean and lower than the others. However, even the lowest score (17.50) in the group shows that they did not move far away from the mean. These scores show that the pre-service teachers completed the design creation process at an acceptable performance level.

The Views of Pre-service Teachers About Design-Based STEM Activities

The results obtained from the opinion form of design-based STEM activities are divided into two parts as challenges in the design process and experience of pre-service teachers and contribution to them in the design process.

What Were the Challenges You Experienced in the Design Process?

The responses of the pre-service teachers to their experiences during the design process were analyzed by content analysis and classified into seven categories. Table 5 shows that the software used is the most recurring category. The number of students who stated that they had difficulties is 11. There are eight pre-service teachers who stated that they had difficulty in algorithm and coding logic, five pre-service teachers who had problems with their group mates, four pre-service teachers who stated that the process was complex and two pre-service teachers who stated that they

Table 1 Design-based STEM activities

Learning process	*Activity*	*Sample*
Empathize	In accordance with the assigned theme, the pre-service teachers recognized an issue within their surroundings and devised solutions. Collaboratively, pre-service teachers discussed and generated design ideas via dialogues and design notes while seated in groups	Conducting research and collecting data on the needs of users "Water wastage" "Difficulty in understanding the different needs of plants" "Traditional methods are time consuming and inefficient"
Define	They were asked to identify possible solutions to this problem. The instructor introduced related concepts and demonstrated related skills every week. Also, the instructor explained the topic of the lesson and demonstrated relevant programme examples	Define the problem "Problem: In irrigation processes, users struggle to optimise the water requirements of different plant species, resulting in wasted water and low efficiency" "Objective: To develop an environmentally friendly and efficient irrigation system that can be customised according to the needs of the users"
Ideate	The participants were required to create and showcase their designs in response to the problem they had identified. The presentation included demonstrations of algorithms and flow diagrams, and participants were then instructed to develop their designs using these tools. During this procedure, prospective teachers devised their solutions using flow diagrams	Some innovative solutions after brainstorming "Developing automatic irrigation algorithms according to plant species" "A system that measures the moisture level of the soil with IoT (Internet of Things) based sensors" "Solar powered irrigation system" "Remote control and irrigation planning with application" "A system that reports water usage and makes recommendations"
Prototype	According to the algorithms and flow diagrams they prepared, the prospective teachers demonstrated them using electronic kits and Arduino tools. They were asked to explain their design goals and science topics. Pre-service teachers presented their designs in groups and explained how the concepts and elements were applied to the design	Prototype materials Sensors: device that measures soil moisture and transmits the data to the sensor Arduino programming: an interface where users can control the irrigation process Irrigation system: a device that operates automatically when the moisture level falls below a certain threshold
Test	After the feedback and reflections, the designs/products were evaluated	Some feedback and reflections "The sensors are accurate, but the application could be simpler to use" "The reporting feature made a big difference in saving water"

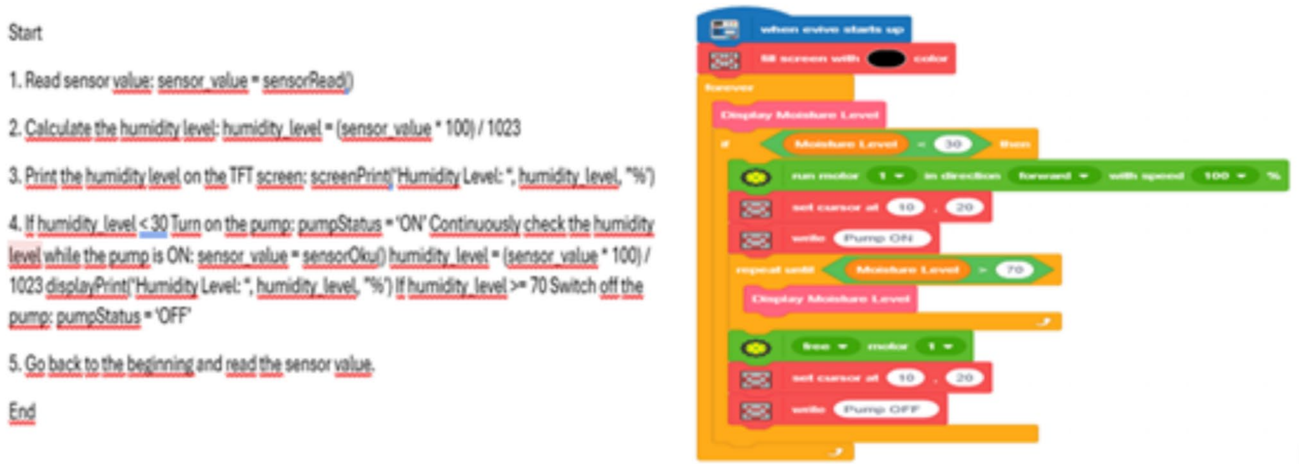

Fig. 2 Sample design sketch and code structure

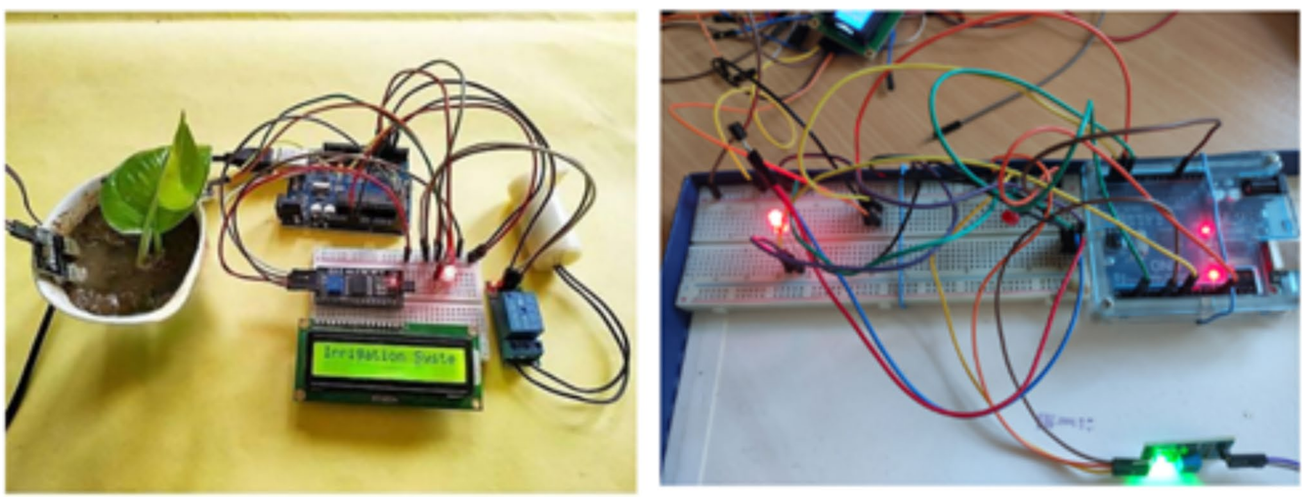

Fig. 3 Sample design products

Table 2 Shapiro–Wilk test results

		Pre-test	Post-test
n		46	46
Parameters	x	4.22	4.43
Shapiro–Wilk Z	Sd	0.454	0.395
p		0.042	0.006

Table 3 Wilcoxon signed-rank test results

Groups	N	X	Mean rank	Wilcoxon sequential signs	
				z	p
Pre-test	46	4.22	6.75	−5.485	0.00
Post-test	46	4.43	22.24		

Table 4 Design process evaluation scores of pre-service teachers

Group	Expert 1	Expert 2	Mean
Group 1	20	22	21
Group 2	19	21	20
Group 3	22	22	22
Group 4	21	22	21.5
Group 5	22	20	21
Group 6	18	22	20
Group 7	16	19	17.5
Group 8	17	18	17.5
Group 9	19	21	20
Total mean	19.33	20.78	20.06
Pearson correlation coefficient	$r = 0.792$, $p < 0.01$		

Table 5 The views of pre-service teachers about the challenges experienced in the design process

Category	N
Software used	13
No difficulty	11
Algorithm and coding logic	8
Group issues	5
Complexity of the process	4
Operating logic of circuit elements	3
Hardware elements	2
Total	46

Table 6 Design process experience of pre-service teachers and contribution to them

Category	N
Enjoyable and instructive	16
An innovative application in education	14
Understanding the design process	8
Different perspective to the project process	3
Gaining awareness of problem-solving with technology	3
New designs and transferring these designs to students	2
Total	46

had difficulties with circuit and hardware elements. Some sample statements are below.

> It was challenging for me to comprehend the Scratch for Arduino program, decipher the coding, and construct even a basic circuit. The fact that the language used to create the software is alien to them contributed to this.
> I struggled to grasp the S4A program's working logic and the placement and arrangement of circuit pieces. I was unable to be as engaged as I would have liked due to our group project and the little size of the program card.
> Class projects don't seem to have any particularly challenging parts. The only thing that can happen regularly is code errors.

How Was This Design Process Experience of Pre-service Teachers and What Contribution to Them in the Design Process?

The opinions of the pre-service teachers about their design process experiences and their contributions to them were analyzed by content analysis and collected in six categories. Table 6 shows that enjoyable and instructive ($n = 16$) are the most recurrent categories. The second category that is thought to contribute the most is "Innovative practice in education" ($n = 14$). Understanding the design process ($n = 8$), different perspective to the project process ($n = 3$), gaining awareness of problem-solving with technology ($n = 3$) and new designs and transferring these designs to students ($n = 2$) are listed as other important categories. Some sample statements are given below.

> The process of problem identification and the actions to obtain a solution were crystal clear to me. That is to say, the steps of the design process were brought up about my potential use.
> As a pre-service teacher, I believe I will be able to provide pupils with a more well-rounded understanding of the design/material by using technological tools in my course.
> We benefited greatly by being actively involved and contributing to the course
> In the institutions where we would one day work, this class helped us become useful members of society by preparing us to use the technology that our generation has brought to the table. Some of our other classes are more grounded in theory. Practical skills are the focus of this course.
> A creative education fit for the era. In my opinion, it is crucial. Students may make a difference in the classroom by building a basic smart greenhouse with resources like humidity and heat sensors while learning about photosynthesis, soil, and temperature.

Discussion

This study was conducted to determine the change in the design thinking skills and design process evaluation scores of pre-service teachers who participated in the design-based STEM activities prepared within the scope of the design thinking cycle and to obtain their opinions about this activity. The opinions of pre-service teachers, who created technology-based designs within the scope of design-based STEM activities in the Technology and Project Design course, about design-based robotic activities at the end of the 12-week process and the findings related to the evaluations of the designs they made at the end of this activity are discussed under this title.

Design thinking is used as a tool for producing and sharing physical prototypes or products (Siu et al., 2018), an innovation tool (Liedtka, 2014) as applied in design disciplines (Vallis & Redmond, 2021). Considering the findings, pre-service teachers' design thinking skills significantly differentiate at the end of the process. The fact that the difference between the pre-test and post-test was high and significant in favour of the post-test can be seen as a contribution to the design thinking skill. This was roughly in line with the results of previous studies (Hathcock et al., 2015; Tsai et al., 2022; Vardakosta et al., 2023).

In the learning process, design-based activities require the completion of products through cognitive difficulties and provide academic success with feedback (Avsec et al., 2023; Gupta, 2022; Ke, 2014). Considering the cognitive difficulties experienced by students in the feedback and algorithm processes during the learning process with design thinking, this can be explained as the reason for the development in teaching-oriented thinking skills. A teaching strategy planned for beginners in programming provides an environment for students to complete, modify and extend their designs (Chang et al., 2000). Design thinking activities prepared for this purpose both made the learning process more effective and improved design-based thinking skills. There was evidence of their progress and knowledge gain after the design thinking learning experience (Ke, 2014). The results showed that implementation provided students with clear learning outcomes and was helpful for the development of pre-service teachers' design-based thinking skills.

When the design evaluation scores of the pre-service teachers are analyzed, it is seen that they received acceptable scores from both experts ($X = 20.06$, Max. = 22.00). This value shows that the designs created are close to the 2nd performance level and at a good level. The importance of hands-on activities in the product design process is mentioned (Kara, 2022). It is important for pre-service teachers to carry out such a study both for themselves and for their future benefits and to involve them in the process of design thinking (Baran & Uygun, 2016). These processes allow students to use concepts repeatedly and develop skills such as programming to ensure effective learning (Tsai, 2024; Tsai et al., 2022). The scores related to design products are consistent with the opinions of pre-service teachers. In design-based projects, students work in teams. The good and high scores of pre-service teachers in group scores indicate the importance they attach to group work. The opportunity to experience real problems, communication with stakeholders, mastering the process as an expert and teamwork shows the importance of collaboration in the design process (Altan et al., 2016; Gómez Puente et al., 2013). The effectiveness of group work in design processes supports the importance of this process with the literature.

It is seen that pre-service teachers had difficulties mostly due to the software used, algorithm design and group problems. It is seen that a significant portion of the students stated that they had no difficulty ($n = 11$, 24%). Based on the findings, pre-service teachers found their experiences fun and exciting, because it offers a different learning approach throughout the process. These results are consistent with Azizan and Abu Shamsi (2022). Pre-service teachers express the activity as an innovative application in education. Zhang et al. (2021) say that design-based learning increases students' interest in learning; improves their team spirit, innovation ability, application skills and problem-solving ability and develops "innovative abilities" needed in the new era. The results obtained are similar to the results of Zhang et al. (2021). However, design thinking with digital tools is cognitively and creatively challenging (Micheli et al., 2019). The logic of algorithm and coding is in a similar framework with the cognitive challenge of students. Students used the words fun and hands-on several times, and this strong emotional and cognitive engagement helped them learn design thinking. Design thinking was considered a different type of knowledge and way of knowing from the conventional classroom format (Kim et al., 2015; Rowland, 2004). This different approach contributed positively to the learning process and experiences.

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Student opinions show that they understand the design process at a high rate ($n = 8$). This is similar to the findings of Vardakosta et al. (2023), who found that design-based learning experience in higher education showed that they understood the process of co-creation and design. Students also needed group work skills to collaborate through technology to complete activities. Design thinking process embedded in projects provides students with the opportunity to apply theory in practical schemes (Lee et al., 2010; Mistikoglu & Özyalçin, 2010; Gómez Puente et al., 2013). Student views on this hands-on experience based on design-based learning support the literature. The pre-service teachers stated that this process is an innovative new approach, understanding the design process and having different roles. It is similar to the results of Baran and AlZoubi (2023), who stated that pre-service teachers' designer, innovative and change agent characteristics are among their new roles.

Tae (2017) emphasizes that design thinking leads to significant improvements in students' interest in scientific technology and an increase in career preferences in engineering. The positive perceptions of pre-service teachers towards the whole process support this result.

The need to develop design thinking skills and design process competencies in the digitalizing world is an indispensable part of society. The spread of these activities can contribute to the importance of STEM robotic education, increased design thinking skills and design process competencies.

Conclusion

In conclusion, the study aims at the significance of design-based STEM activities in fostering pre-service teachers' design thinking skills. The results highlighted the positive contribution of design-based STEM activities on design thinking in educational settings. There is also evidence that there has been an improvement in the design process skills of pre-service teachers. Pre-service teachers have highlighted the necessity of using design-based activities and the design process in educational environments and course design. These insights align with prior research demonstrating the effectiveness of STEM-integrated methods in promoting thinking skills (Lee & Perret, 2022; Hallström et al., 2024).

The study also recommends expanding the scope of research to include diverse teaching activities and examples to further validate the effectiveness of design-based STEM activities, particularly in broader curricular settings. For instance, integrating 3D design tools in teaching experiments can provide deeper insights into their pedagogical impact (Greenhalgh, 2016). In terms of developing thinking skills, game design activities can be highly engaging and beneficial (Ejsing-Duun, & Hanghøj, 2019). Exploring the application of design-based STEM activities in game design processes can uncover innovative ways to enhance learning effectiveness and engagement.

These activities are expressed as being important both in terms of STEM and in terms of professional development (Aslam et al., 2020). Pre-service teachers who are taught design-oriented STEM activities can distinguish how the tools they use in their daily lives are related to which disciplines of STEM and they think that this will give them an advantage in their daily and future teaching professions.

Traditional approaches to teacher training have faced criticism for their inability to fully address the complexities of modern education. In contrast, STEM activities, complemented by data science, artificial intelligence and data mining tools, present transformative opportunities to address these challenges. By leveraging these technologies, teacher education programmes can develop innovative solutions to common pedagogical problems and better prepare teachers for contemporary classrooms.

Students who learn with the design-based thinking model develop their design skills more, their products are suitable for the needs and they improve students' competencies and way of thinking towards practice (Jiang & Pang, 2023). In addition, through the design-based learning process, students gained awareness about problems, learned basic engineering principles and applied their previously learned mathematics and science knowledge (English & King, 2019). Similarly, this study points to its importance in terms of its role focusing on both the design process and STEM education.

The design thinking approach is applied to train teachers in the process of integrating STEM education into schools (Diefenthaler et al., 2017). This training is evaluated within the framework of student-centred pedagogical approaches that are implemented in STEM education (Ellis et al., 2020). Pre-service teachers' design process development and their positive views towards the design process show that design-oriented thinking will draw an important framework in STEM education. Curricula and guidelines that focus on environmental problems through the design process can be planned.

Similar studies can be conducted with different age groups in primary, secondary and high schools. In addition, as indicated in the qualitative data of this study, studies can be conducted on its effectiveness on some variables such as academic achievement, motivation and interest. Design thinking has an important place in fields other than education. Given the interdisciplinary nature of design thinking, studies that bridge educational sciences with fields such as engineering, psychology and business are highly recommended to broaden its application and impact (Menon, 2024). In summary, design-based STEM activities not only provide a robust framework for professional development in teacher education but also hold promise for interdisciplinary innovation, making them essential in the evolving landscape of education. The systematic use of design thinking activities in teacher education programmes helps cultivate pre-service teachers' design thinking mentality and their identity as teacher as designer.

Limitations

Some limitations of the research were pointed out. The fact that the study was conducted with 46 students in a single group may be a limitation. This study adopted a one-group pre-test-post-test design, and the absence of a control group is one of the limitations of the study. However, the problems were relatively avoided by using a valid and reliable analysis technique. In future studies, the number of participants can be increased, and participants can be divided into control and experimental groups. It will be important to consider these factors in terms of the generalizability of the results or future studies.

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Data Availability Data will be made available on request.

Declarations

Ethical Approval All participants voluntarily participated in this study after receiving their consent. Ethical permissions were obtained from official institutions before the research.

Competing Interests The authors declare no competing interests.

Statement Regarding Research Involving Human Participants and/or Animals The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

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