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COMMENTARY

The Significance of Integrating Engineering Design-Based Instruction in STEM Education

Dingliang Tan

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> *"Engineering is the closest thing to magic that exists in the world."*
> *-Elon Musk*

ENGINEERING design-based learning activities can successfully spark students' interest in real-world issues by motivating them to apply their disciplinary knowledge in mathematics, science and more to analyze and solve problems identified (Uzel & Bilici, 2022). Generally speaking, problem identification and problem solving are the two primary steps in the engineering design process. Researchers assert that engineering design-based instruction (EDBI) is a novel paradigm of teaching, particularly valuable in inquiry-based instructional practices (Cooper et al., 2015). Research finds that the enactment of EDBI for addressing open, practical issues is substantially beneficial for increasing the problem-solving and design abilities of primary and secondary students (Crotty et al., 2017; Capobianco et al., 2018), and that EDBI implementation in STEM education can significantly improve students' attitudes towards the STEM curriculum, promote their academic success, and support their 21st-century skills development (Moore et al., 2015).

Educators and researchers have actively engaged in practical explorations of applying EDBI to STEM education, especially to the science curriculum. For example, Aydoğan and Çakıroğlu (2022) experimented with using EDBI to help secondary school students to develop proper understanding of the nature of engineering for eliminating their misunderstandings and biases towards engineering and related professions and to enhance their interest in STEM study. Marulcu and Barnett (2013) integrated EDBI into fifth-grade science teaching by using LEGO materials to aid students in developing knowledge of basic mechanical theory and other scientific concepts. On the other hand, research also finds that engineering design is a complicated process, and that EDBI is subject to the influence of multiple factors. For instance, Aranda et al. (2018) discovered that even under the same EDBI modality, the variations in the teacher's dialogue tactics, classroom conversation patterns, and inter-student interactions may lead to different levels of student in-class engagement and learning outcomes. Hence, they recommended teachers to provide an environment that enables students to express their ideas, ask questions, and receive rich responses to their questions, which assists their construction or reconstruction of their understanding. According to Love et al.'s (2024) study, factors, including the number of course enrollments, the percentage of students with disability, the number of course preps, and the usage of tools with potential safety hazards, were associated with the incidence of accidents in EDBI. This finding serves as a caution to teachers that emergency plans and first aid training are imperatives for EDBI enactment.

Despite the widespread scholarly interest in the integration of EDBI into STEM education, there remains challenges in establishing it as a formal component of the school curriculum. The authors of *The Effect of Engineering Design-Based Instruction On 6th-Grade Students' Astronomy Understandings* in this issue adopted EDBI in their 6th-grade astronomy instruction and validated the effectiveness of the eight-week program. The research findings of the study reveal that the application of EDBI can significantly improve students' comprehension of core astronomical concepts (Başpınar et al., 2024). The study provides implications for how to incorporate EDBI into the current STEM curriculum, albeit that it has only investigated EDBI's promotive effects on the students' conceptual understanding without looking into its impact on other cognitive capacities of the students, such as critical thinking and creativity.

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COMMENTARY

Enhancing Educational Outcomes by Boosting Artificial Intelligence Application in Personalized Learning

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> *"The real question is, when will we draft an artificial intelligence bill of rights? What will that consist of? And who will get to decide that?"*
> *–Gray Scott*

AS THE social expectation of the standards of talent training increases, the society has become more aware of the limitations of the traditional one-size-fits-all education paradigm and has endeavored to develop educational paths that can better cater for individually different needs of the learner. Personalized learning, as an important instructional strategy in the new era, is intended to make education more pertinent to the unique needs, learning style, and ability of each individual student for the purpose of optimizing their educational outcomes (Kaswan et al., 2024). The rise of artificial intelligence (AI) makes changes to conventional education patterns and improvements in personalized learning possible as this technology can be harnessed to provide tailored learning materials to students, improve their information acquisition and retention, and thereby enhance their learning efficiency and educational experience (Chen et al., 2020).

Currently, a wide variety of AI-based educational technology applications have been introduced into personalized learning, such as the intelligent tutoring robot, adaptive learning system, learning path recommendation system, and more. These applications integrate machine learning algorithms, natural language processing, big data analytics, and other technologies to gather and analyze information to support individualized learning of the student. For instance, the intelligent tutoring robot is equipped with multiple AI technologies, such as speech recognition technology and emotion recognition technology (for analyzing facial expressions and intonation) (Yang & Zhang, 2019) and can serve as a virtual teacher or learning companion by providing the learner with an immersive learning experience. It also helps develop their social skills while heightening their interest in learning (Pataranutaporn et al., 2021). The adaptive learning system aids the student in seeking out the optimal learning path by tracking and break down data of their learning behavior (Cui et al., 2018), which substantially improves the efficiency and effectiveness of their learning processes and enhances their academic achievements (Van Der Vorst & Jelicic, 2019).

While AI technology offers huge potential for personalized learning, it also brings about challenges, such as the ethical concerns for data privacy, latent biases in AI algorithms, and difficulties in integrating AI into the established educational infrastructure. Issues like these warrant more cautious and informed solutions to the application of AI in personalized learning (Zawacki-Richter et al., 2019). Furthermore, successful application of AI-based educational technology necessitates advanced digital facilities, effective data extraction methods, and increased teacher digital literacy training (Kaswan et al., 2024).

The significance of AI technology for personalized learning has been generally acknowledged in the education world. A plurality of empirical research findings has corroborated the effectiveness of AI applications in personalized learning. A meta-analysis of existing quantitative research is highly necessary for a systematic evaluation of practical outcomes of AI-assisted personalized learning. *The Effect of Artificial Intelligence-Assisted Personalized Learning on Student Learning Outcomes: A Meta-Analysis Based on 31 Empirical Research Papers* in this issue synthesizes the research results of 36 experimental and quasi-experimental studies in this area, using meta-analytical techniques. The results of the meta-analysis reveal that AI-assisted personalized learning has a moderately positive effect on student learning outcomes (Hu, 2024). It is hoped that this study can spark further explorations of effective application of AI in individualized education as well as the avoidance of its potential risks.

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ORIGINAL ARTICLE

The Effect of Engineering Design-Based Science Instruction on 6th-Grade Students' Astronomy Understandings

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***Abstract**: Astronomy education is essential for STEM education in primary schools, and integrating engineering design-based science education enhances student engagement and achievement in the field of space science. Integrating engineering design into science education is essential for students to excel in astronomy and to meet the requirements of contemporary society. This study investigated the effect of engineering design-based instruction (EDBI) on the understanding of astronomy concepts among sixth-grade students. The study included a cohort of 37 sixth-grade students from a public school. It was carried out using a one-group pre-test, post-test experimental design. All participants received EDBI that was based on the objectives of the 6th grade "Solar System and Eclipses" unit. Statistical analyses were employed to ascertain the effect of astronomy instruction based on engineering design on students' comprehension of astronomy concepts. The results indicated a significant difference in the average scores of students' understanding of astronomical concepts before and after being taught using EDBI.*

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***Keywords**: Engineering Design-Based Instruction, Middle School Science Education, Astronomy Education, Experimental Research Design, Astronomy Understanding*

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Introduction

THE TWENTY-FIRST century requires more creative and innovative citizens; thus, countries should educate individuals, particularly young children, about the 21st-century needs to deal with evolving science and technology. Countries should prioritize science education to prepare people for 21st-century challenges such as information production, technology literacy, and innovation (Marrero et al., 2014). The significance of science education extends to both individual and societal levels, which significantly influences national objectives, including the advancement of science and technology and the enhancement of educational standards. In other words, scientific and technological advancements have highlighted the importance of revising national education policies (Tabaru, 2017) and directly influenced countries' perspectives on science education. Consequently, the majority of countries have found it necessary to update their K-12 science curriculum (Percy, 1998).

Engineering design-based science education has been proposed as a viable method for incorporating engineering practices into the science curriculum (Barnett et al., 2010; Hynes et al., 2011). The approach aims to provide science classes with processes to help them solve real-world problems. Furthermore, engineering design-based science education seeks to equip students with competencies that allow them to think like engineers when solving real-world problems (Daugherty, 2012). Engineering design-based science education improves students' 21st-century skills by requiring them to brainstorm, think critically, and communicate to complete the design process successfully. It also improves student success in science lessons and inspires them to pursue STEM careers (Hacıoğlu et al., 2016). The engineering design process (EDP) activities teach students to think like engineers, design products, and then develop these products to make them more useful. Design is a fundamental aspect of the engineering field. In other words, engineering cannot be completed without the design phase (Cunningham & Hester, 2007). The EDP allows students to use their theoretical understanding of science in practical contexts, which is especially important given the close relationship between engineering and science (Altan & Karahan, 2019). It includes a start and end interval for problem-solving, contributing to a need's emergence. This process creates environments where problem solvers can learn 21st-century skills such as scientific concepts, engineering insights, communication, idea generation, problem-solving, critical thinking, and information disaggregation (Schnittka et al., 2010; Wendell, 2008).

Engineering design-based science education is crucial to STEM education since it aims to establish interdisciplinary connections with other fields when designing products (Gencer, 2015). Engineering, as a component of STEM, is a profession with the ability and potential to positively or negatively impact people's quality of life. Although engineering products are ubiquitous daily, studies show that students struggle to understand what engineers do (Frehill, 1997). Understanding the students' perceptions of engineers and their perspectives on their work is also critical. Because these views shape students' preferences for careers in engineering (Knight & Cunningham, 2004), engineering-related applications should be implemented in elementary school classrooms to change this and improve students' engineering career interests. Students can also learn about the engineering profession and its diversity by collaborating with schools, engineering faculties at universities, and other institutions.

Astronomy Education

The first educational research on astronomy was carried out many years ago, and it focused on how students or people understood astronomical phenomena. Piaget began conducting scholarly research in early 1920 (Piaget, 1929). His books influenced subsequent research in this area. The following study examined local or global populations regarding astronomy education (Adams & Slater, 2000). According to the studies, many young children hold incorrect beliefs about fundamental astronomical concepts. Lanciano (2009) discovered that culture and mass media influence children's lack of or incorrect astronomical knowledge.

The research strongly argues that astronomy should be included in educational curricula. Before incorporating astronomy into the national curriculum, the researchers inquired: "Why is astronomy not included in the curriculum?" (Percy, 2003). The seven reasons given in this research's response to the question are: a) People do not think astronomy has anything to do with issues like health and the environment. b) Many teachers do not know the basics of astronomy. c) Most astronomical observations happen at midnight, and the tools needed are expensive. d) People in Western societies see astronomy as something only "Western" culture cares about. e) People's personal beliefs and facts about astronomy differ. f) Because of translation issues, undeveloped and poor countries cannot access available resources. g) Astronomy requires advanced technology.

Astronomy encourages curiosity, imagination, and exploration; the universe helps young people develop their imaginations (Percy, 2006). Engaging in inspiring astronomy issues allows young people to broaden their perspectives and develop a holistic worldview (International Astronomical Union [IAU], 2012). On the other hand, astronomy is a dynamic science contributing to advancing science, mathematics, and technology. The most exciting science news today is primarily about astronomy. It is an excellent tool for encouraging students to become interested in science and technology.

Space exploration and life beyond Earth are fascinating subjects in their own right. These subjects can be integrated into science and mathematics education and linked to engineering and technology studies. Similarly, according to Percy (2006), astronomy provides an integrative approach across disciplines. In this way, it promotes connections and learning across different curricula. Astronomy, for example, makes use of a variety of mathematical concepts. Students who study basic motions in the celestial sphere can use math-based positioning and timing tools. Furthermore, astronomy allows for applying scientific methods, particularly observation (National Research Council [NRC], 2012; Percy, 2006). It also includes numerous examples of simulation and modeling in science. Astronomy topics are an excellent and exciting way for young people to begin rational and logical exploration of nature (IAU, 2012). Göğüş (2010) argues that primary and practical applications of astronomy not only enhance learning but also make it more lasting.

In this context, astronomy has a dynamic structure that promotes the advancement of science, technology, engineering, and mathematics, as well as feelings of curiosity, imagination, and discovery, including topics such as our cosmic origin and our position in time and space. It also promotes interest in science, technology, engineering, and mathematics by using scientific methods, conducting rational and logical research on nature, and providing an integrative approach across disciplines. As a result, astronomy is a valuable resource for STEM education. In conclusion, due to the nature of the subjects involved in astronomy, it can be used as an effective tool for both STEM and engineering education processes because it has the characteristics of arousing interest in STEM fields, enabling applications that include the integration of science, technology, and engineering based on the history of science, the nature of science, and scientific methods, and supporting young people's career choices in STEM fields.

Significance of the Study

Although STEM education is used worldwide, science and technology are more popular than the other components in many countries. Engineering, represented by the letter "E" in the STEM acronym, is critical for developing people with 21st-century skills such as critical thinking and innovative thinking (Bybee, 2010; NRC, 2012). Many countries ignore the engineering component (E) by not incorporating engineering practices into their educational programs. However, the NRC (2010) recommends that nations educate students as future engineers in elementary and middle schools. Engineering activities have been integrated into the science curriculum; however, the goals of these applications are not clearly defined. Although younger ages have greater potential for developing engineering concepts, studies involving the administration of engineering design activities are typically conducted with older students (English & King, 2015). The current study investigated how to incorporate engineering design-based activities into 6th grade science classrooms. However, despite the high interest in incorporating STEM disciplines into lessons, there is little research on the best way to integrate engineering components into formal lessons (NRC, 2012). The current study aimed to fill this gap in the literature by developing engineering design-based activities that addressed various aspects of the engineering design process.

The current study incorporated EDBI into science course. When the literature on astronomy education was reviewed, countries began to prioritize astronomy education after developing space technologies, and as a result, they attempted to incorporate astronomy education into their educational curricula (Percy, 1998). As an elective or unit within the science curriculum, astronomy is often included in national science programs rather than being taught independently. Many countries recognize the importance of astronomy education but students still face challenges and misconceptions when it comes to astronomy (Adams & Slater, 2000; Keçeci, 2012; Lubben, 2009). The existing body of literature indicates that students at various academic levels encounter difficulties in understanding astronomy concepts (Baloğlu Uğurlu, 2005; LoPresto & Murrell, 2011). Additionally, there is evidence of misconceptions in the field of astronomy (Ekiz & Akbas, 2005; Göncü, 2013; Korur, 2015).

The present study focused on astronomy topics to enhance students' understanding and determine how their understanding of these topics could be improved. According to Arslan and Koparan (2020), astronomy education holds significant importance within STEM education in primary schools. Additionally, Acut and Latonio (2021) suggest that engineering design-based science education enhances student engagement and achievement in space science. So, it is evident that teaching science through engineering design is essential for students' academic success in astronomy and meeting modern world demands. Students can enhance their understanding of astronomy objectives while learning about the engineering design process (analysis, critical thinking, and brainstorming) through engineering-based astronomy activities (Voss & Dailey, 2012). Despite the fact that engineering design-based science instruction improves students' understanding of astronomy concepts, research into the development of engineering-based education focuses primarily on subjects such as the environment, electricity, and basic machinery (Cunningham, 2009). Given the dearth of research on the topic, the present study opted to focus on engineering design-based astronomy education, even though it is widely recognized that such an approach is well-suited to astronomy education and enhances students' grasp of astronomical concepts.

The purpose of this study was to investigate the impact of engineering design-based science education on sixth-grade students' understanding of astronomy concepts. Consequently, the study was driven by the following research question: What is the effect of EDBI on 6th-grade students' understanding of astronomy concepts?

Methods

The study aimed to investigate how engineering design-based science instruction affected sixth-grade students' understanding of astronomy concepts. A one-group experimental research design was used. The study's data was obtained using quantitative research methods. Due to insufficient participants in both the control and comparison groups, a single-group pre-test-post-test design was employed. The one-group pre-test-post-test design does not allow for participant randomization. According to Campbell and Stanley (1963), this method can be applied to samples that are not very large. The study's independent variable is EDBI, while its dependent variable is sixth-grade students' understanding of astronomy concepts.

Participants

The study comprised 37 6th-grade students enrolled in a public middle school located in a rural city in Turkey. Their ages ranged from 10 to 12 with a nearly equal distribution across genders within the class (19 females and 16 males). Accordingly, the convenience sampling method was used by the researchers. This technique involves selecting individuals readily available for the study and is widely used due to its ease of implementation and accessibility (Fraenkel et al., 2012).

Data Collection

The data were gathered through the Students' Understanding of Astronomy Concepts Scale (SUACS) (Ekiz & Akbaş, 2005). It was used to assess students' comprehension of astronomy concepts. This scale consists of ten open-ended questions divided into four sections, each focusing on specific topics such as the universe, solar system, stars and planets, and orbit.

Treatment

The experimental research design process was carried out with a single group. Each participant received astronomy education grounded in engineering design principles. The treatment process lasted eight weeks and consisted of a total of 26 hours of lessons. The first researcher conducted the instructional process by delivering EDBI. The data collection tools were administered as pre- and post-test. Participants were given these tools during the first and last weeks of treatment. Hence, the participants received six weeks of engineering design instruction. Before instruction, the researchers created three engineering activities titled "Meeting with Engineers," "Design the New World," and "Design a Spacecraft." These activities were developed based on the related science concepts for the topics in the 2018 Turkish Science Curriculum. While the first lesson plan introduces students to the engineering profession and the engineering design process, the final two lessons relate the "Solar System and Eclipses" concepts to the engineering design process. On the other hand, all lesson plans strive to engage students by actively discussing, brainstorming, and questioning; in addition to active participation, these lesson plans were created to pique students' interest in the topic.

The class instructions for "Design the New World" and "Design a Spacecraft" were developed based on engineering design activities that follow a sequential stage of the engineering design process. This process includes problem definition, identification of potential solutions, analysis, and selection of the optimal solution, testing of the chosen solution, and, if required, revisiting any preceding step. Students were assigned the challenge of constructing and evaluating a prototype as part of these activities, aligning with the implementation of Wendell et al.'s (2010) engineering design process. The researchers developed activity sheets structured around the engineering design process to facilitate the organization of instructional flow. To clarify, the instructions for "Design the New World" and "Design a Spacecraft" provided activity sheets that were centered on the steps of the engineering design process and the specific subjects of each activity. The activity sheets were designed to facilitate students' comprehension of the steps and enable them to navigate back to previous steps more efficiently, if necessary.

EDBI

In this part, the activities of the study are explained in detail. In addition, the table of instruction schedule was given. The table below shows a detailed instruction schedule (**Table 1**).

Meeting with Engineers. During the second week of treatment, students had the opportunity to meet with two distinct computer engineers. The guest engineers were selected, one being a female and the other being a male, in order to refute the prevalent notion that "the field of engineering should be exclusively pursued by men." The researchers planned the online meeting with the two computer engineers to align with topics concerning the characteristics of the engineering profession, engineers' experiences, and the

Table 1. Instruction Schedule.

Week	Administration/Duration	Tool
1st week	A pre-test was conducted using two distinct instruments to assess students' understanding of astronomy concepts.	Data collection Instruments
2nd week	The activity and presentation titled "The Meeting with Two Engineers" were conducted to provide an explanation of the "Engineering Profession" and the "Engineering Design Process." Furthermore, the administration of EDBI, which is based on the objectives of Solar System concepts, was initiated for the class.	Design the New World Lesson Plan
3rd week	1) Describe a problem, 2) Finding possible solutions, and 3) Choosing the best solution 4) Building the prototype; planning prototype activity, planning design activity step of EDP was administered.	Design the New World Lesson Plan
4th week	5) Test the prototype step; evaluation and presentation of each group of EDP step were administered. Also, the project evaluation and self-evaluation sections were administered.	Design the New World Lesson Plan
5th week	EDBI based on the topic of "Solar System" was administered to the class.	Design the Spacecraft Lesson Plan
6th week	1) Describe a problem, 2) Finding possible solutions, and 3) Choosing the best solution 4) Building the prototype; planning prototype activity, planning design activity step of EDP was administered.	Design the Spacecraft Lesson Plan
7th week	5) Test the prototype step; evaluation and presentation of each group of EDP step and, the assessment and self-evaluation sections were administered.	Design the Spacecraft Lesson Plan
8th week	Two distinct assessment tools were administered as a post-test to assess students' understanding of astronomy concepts.	Data collection Instruments

engineering design process. Students met with engineers and learned how they apply the engineering design process to their projects shared by guest speakers. To pique the students' interest, the second lesson began with the question, "Do you want to be an engineer for your future career?" and then moved on to "What type of engineering have you heard of?" The researcher presented the concepts of "Nature of Engineering" and "Engineering Design Process" to the students. The researcher facilitated discussions among students regarding the engineering profession, including the different types of engineers and their key characteristics. The second aspect of the presentation was the Engineering Design Process (EDP), which was presented as a diagram to assist students in visualizing and understanding the circle of process. After thoroughly reviewing each step of the EDP with the students, the researcher asked them to relate their experiences to those mentioned by the guest engineers. The presentation ended with the question, "If there were no engineers, what would happen to the world?"

Design the New World. During the subsequent two lesson hours, the participants were provided with engineering design-based science instruction on the topic of the "Solar System" The lesson began by assessing the students' prior knowledge of the solar system gained in previous academic years. They were asked the following questions: "What is our celestial body called?" "Does the Earth possess any natural or artificial objects orbiting around it?” and “Can you name any celestial bodies that orbit the Sun in our solar system?” After background information was gathered, students were introduced to the lesson topic through a video presentation. Furthermore, the researcher taught students about the solar system, encompassing topics such as the Sun, planets, orbits, and asteroids.

The third week of class started with the engineering design process activity titled “Design a New World.” The researchers prepared the activity by following the steps in the engineering design process. In addition, “The Handbook of Engineers Team Activity Sheet” was developed serving as a valuable resource for both students and the researcher to manage the lesson more effectively. At the beginning of the lesson, students were divided into small groups of three or four and each group received a copy of the activity sheet. They were told to act like engineers throughout the activity and follow EDP steps. The researcher initiated the activity by presenting the scenario while displaying it on the smart board. Following the scenario, the lesson covered three EDP steps: 1) describing a problem, 2) identifying potential solutions, and 3) choosing the best EDP option. To ensure students followed the EDP steps during the activity, the researcher projected the engineering design process steps onto the smart board. Students collaborated as a team to identify issues in a given scenario.

After identifying the problem, students were expected to investigate potential solutions by analyzing previous solutions or brainstorming new ideas. While researching possible solutions, students determined where humans could live in the solar system and built a living space. The students used their knowledge of the solar system’s planets, stars, asteroids, and satellites to locate an appropriate living space. They identified the properties of these celestial bodies, such as temperature (hot or cold), terrestrial or Jovian planets, physical features (mountains, caves), and suitability for human use. The student groups evaluated their potential solutions and then conducted research using computers and scientific magazines to explore the advantages and disadvantages of each option. After conducting research, brainstorming, and group discussions, the groups determined the best solution to the scenario’s problem. After completing the first three steps, students moved on to the next phase of EDP, which involved building and testing prototypes over the next two lesson hours of the third week. Student groups created model drafts that incorporated details such as the materials utilized and brief descriptions introducing the systems or components of living spaces. As a result, the choice of materials used was determined based on these detailed drawings. Then, each group developed a prototype of the best solution identified in the previous step. In the first two lessons of the fourth week, students tested their prototypes using the activity criteria. The evaluation criteria rubric provided in the activity sheet was used to evaluate each group’s prototype. Subsequently, students were asked to answer conceptual questions in the "Project Evaluation" and "Self-Evaluation" sections of the worksheet. These sections asked questions about the design process, potential redesign concepts, and engineering design process steps.

Design a Spacecraft. During the fifth week of treatment, Students were actively engaged in the engineering design process activity titled 'Design a Spacecraft' for two hours. Initially, the researcher used the questioning method to gather students' prior knowledge. After receiving the students' responses, the researcher reviewed each question in detail. The simulation was used to answer questions and visualize concepts about the solar system. Finally, the researcher explained how a planet's distance from the Sun affects its properties. Afterwards, the "Handbook of Engineers for Space Mission" activity sheets were distributed to student groups. Students were expected to act like engineers during the activity and complete each step in groups, as they had done in the previous activity. In the classroom, the researcher introduced a scenario about the solar system, emphasizing an engineering team's experience with a failed space mission. While the procedures for the previous and current activities were identical, the "Design a Spacecraft" task required students to select which EDP steps to begin with based on their proposed solutions. The student groups debated the issue in the given scenario. After describing the problem, the activity led them to identify the most fitting step of the Engineering Design Process (EDP) for their solution. Each group justified their choice of EDP step by providing reasons. One group decided to start by "finding possible solutions," which included researching new solutions to the problem on the Internet and in scientific magazines, as well as analyzing existing solutions to ensure that they met the requirements of the problem. Meanwhile, another group decided to start with "choosing the best solution"; analyzing the given possible solutions in the scenario, and then replacing the best solution with another one from within the possible ones. Each group continued the activity during the next two lesson hours by developing an EDP prototype step. Student groups created detailed model drafts that included mentioning the materials used as well as briefly introducing the spacecraft's parts and components; as a result, the materials to be used were determined by their drawings. Finally, the groups created prototypes using their best solutions from the previous step. In the first two lessons of the seventh week, students tested their models using the activity's criteria. The evaluation criteria rubric presented in the activity sheet was used to evaluate each group's prototype. In addition, one group member gave a brief presentation to the class about their models.

Data Analysis

Given that the study employed a one-group experimental pre-test post-test design, the data from The SUACS was analyzed using the paired sample t-test. The SUACS was a questionnaire that allowed for open-ended responses. The data collected from the SUACS was organized and analyzed using a rubric developed by Ekiz and Akbas (2005), who categorized students' understanding levels into five categories: sound understanding, partial understanding, no understanding, specific misconceptions, and no response. The interrater agreement method was employed to classify students' responses based on the provided scale. The researcher compared their analysis with that of another researcher who possesses both a master's degree in science education and is an active science teacher. Cohen's Kappa statistics were utilized to determine the level of concordance among researchers. The study found that the interrater reliability among the researchers was measured at Kappa = 0.64, indicating a "substantial agreement" level of agreement. To transform the students' responses on the provided scale into numerical data, the researchers categorized the levels of understanding and assigned these categories a numerical value— "No Response", "Specific Misconceptions," and "No Understanding" levels were grouped and assigned as "0 (zero)" point while "Partial Understanding" was assigned as "1 (one)" point. Lastly, the understanding level of "Sound Understanding" was given as a score of "2 (two) points" on the scale.

The normal distribution of the data gathered through the SUACS was assessed using the Shapiro-Wilk test due to a sample size smaller than 50 participants. Results indicated that the data followed a normal distribution, as the obtained value ($p = 0.302$) was greater than the alpha value (0.05) (Pallant, 2010). Consequently, the assumption was not violated, parametric test was appropriate for the SUACS due to the normal distribution of the collected data. The paired sample t-test was employed to analyze the data.

Findings

This section presents the major findings of the descriptive and inferential statistical analyses of the data obtained after administering the SUACS, measuring the effect of the EDBI on students' understanding of astronomy concepts.

Effects of EDBI on Students' Understanding of Astronomy Concepts

Table 2. Descriptive Statistics of Experimental Group.

	N	$\bar{x}_{pre}$	$\bar{x}_{post}$
Study Group	37	4.63	8.67

Table 3. Paired Sample Statistics of Astronomy Understanding.

	Test	*N*	*M*	*SS*
SUACS	Pre-test	37	4.63	2.643
	Post-test	37	8,67	3.333

Table 4. Paired Samples Test of Astronomy Understanding.

	M	*SD*	*t(36)*	*p*	Cohen's *d*
SUACS	4.036	2.872	+8.550	0.000	11.586

Descriptive statistics for the pretest and posttest results for the astronomy understanding are displayed in **Table 2** which presents the statistical summary of the study group.

Upon examination of **Table 2**, it was determined that the mean score of the pre-test was $\bar{x} = 4.63$, while the mean score of the post-test was $\bar{x} = 8.67$. As observed, the students' average scores increased after the instructional intervention.

The paired sample t-test was used to determine if there was a statistically significant difference between the mean values of the pre-test and post-test. The mean scores of the students' comprehension of astronomy concepts before and after EDBI were analyzed. **Table 3** presents the statistical data for the paired samples on students' understanding of astronomy concepts.

Table 4 indicates that the p-value for the test is less than the significance level ($p < 0.05$), so there was a significant mean difference in students' astronomy understanding between the pre-test and post-test, t (36) = 8.550, $p < 0.05$ with a large Cohen's d value of 11.586. The results indicated that the post-test results (M = 8.67, SD = 3.333) was significantly higher than pre-test results (M = 4.63, SD = 2.643), t(36) = 8.550, p = < 0.05. This result indicated that students' comprehension of astronomy improved after introducing engineering design-based science instruction. The Cohen's d test was also calculated to find the effect size of the study which was found to be large according to Cohen’s (1988) criteria, as the calculated d value exceeded 0.8, indicating a large effect size.

The five concepts on the scale (universe, solar system, stars, planets, and orbit) were comprehensively examined. Frequency distribution tables of pre-test and post-test values with percentages are displayed below. Additionally, responses indicating “no understanding,” “specific misconception,” or “no response” were grouped into a category labeled “no understanding level” within the tables. These tables also present student responses on both the pre-test and post-test, frequency distributions.

Universe

The first two questions centered on the concept of “universe” in astronomy. A statistical analysis was conducted to compare the students’ comprehension levels before and after introducing EDBI focused on the concept of the universe. The data on students’ comprehension of the concept of the universe is displayed in **Table 5**.

The statistical analysis showed an increase in students’ partial understanding level and a decrease in students’ no understanding level after the EDBI. Students’ inadequate and illogical understanding of the concept of the universe decreased after EDBI. **Table 6** displays the sample responses of students before and after the implementation.

Solar System

Questions three to five were designed to assess students’ understanding of the solar system concept. **Table 7** displays the statistics regarding students’ comprehension of the concept of the solar system.

The statistical analysis showed an increase in students’ partial understanding and sound level frequency, indicating that students gained a better understanding of solar system components following EDBI. Moreover, there was a decrease in the frequency of students exhibiting no understanding after the implementation of EDBI. **Table 8** provides examples of the students’ responses to the solar system concepts before and after the implementation.

Stars and Planets Concepts

Questions six to eight of the questionnaire were specifically designed to assess students’ understanding of concepts related to stars and planets. **Table 9** displays the statistics regarding students’ comprehension of concepts related to stars and planets.

Table 5. Frequency and Percentage Values for Universe Concept.

	No understanding				Partial Understanding				Sound Understanding			
	f_{pre}	%	f_{post}	%	f_{pre}	%	f_{post}	%	f_{pre}	%	f_{post}	%
Q1	36	97.3	25	67.5	1	2.7	12	32.4	0	0	0	0
Q2	28	75	26	70	9	24.3	11	29.7	0	0	0	0

Table 6. Example Responses of Students to Universe Concept.

Test Type	No Understanding	Partial Understanding	Sound Understanding
Pre	The universe is our environment. The trees and animals constitute the Universe.	The Earth, the Sun, and the Moon are parts of the Universe.	
Post	The Earth where humans are living on is the Universe.	The Solar System is part of the Universe.	

Table 7. Frequency and Percentage Values for Solar System Concept.

	No understanding				Partial Understanding				Sound Understanding			
	f_{pre}	%	f_{post}	%	f_{pre}	%	f_{post}	%	f_{pre}	%	f_{post}	%
Q3	30	81.1	14	37.8	6	16.2	17	45.9	1	2.7	6	16.2
Q4	35	94.6	23	62.2	2	5.4	12	32.4	0	0	2	5.4
Q5	8	21.6	2	5.4	7	18.9	1	2.7	22	59.5	34	91.6

Table 8. Example Responses of Students to Solar System Concept.

Test type	No understanding	Partial Understanding	Sound Understanding
Pre	The sky, stars, the Sun, the Moon, the Earth, and the universe are made up of the Solar System. In order to formation of one day.	The Sun is at the center, and eight planets and Pluto, and maybe meteorite are made up the Solar System. The Earth has a path around the Sun, and it has to follow this path.	The solar system consists of eight planets moving around the Sun, their satellites, and asteroids.
Post	All stars and all planets in space come together, and they form the solar system When the Earth revolves around the Sun, the night and day occur.	The solar system has the Sun and eight planets inside of it. The Earth has a rotational path, and it always follows this path without stopping.	The system in which the Sun is at the center and eight planets and their satellites revolve around the sun is called the solar system… The Earth has an orbit around the Sun and follows this orbit periodically.

Table 9. Frequency and Percentage Values for Stars and Planets Concept.

	No understanding				Partial Understanding				Sound Understanding			
	fpre	*%*	*fpost*	*%*	*fpre*	*%*	*fpost*	*%*	*fpre*	*%*	*fpost*	*%*
Q6	21	56.8	17	45.9	16	43.2	17	45.9	0	0	3	8.1
Q7	29	78.4	13	35.1	7	18.9	21	56.7	1	2.7	3	8.1
Q8	17	45.9	8	21.6	20	54.1	25	67.5	0	0	4	10.8

Table 10. Example Responses of Students to Stars and Planets Concept.

Test type	No understanding	Partial Understanding	Sound Understanding
Pre	Jupiter is the biggest planet. The satellites are white, but planets can be different colors. No. Because the stars are only seen at night.	The stars are natural light sources while the planets are not the light source. The planets revolve around the stars, for example, the Earth and the Sun. Yes. Because the Sun sends its light to the Earth like other stars.	The biggest difference between them is that the satellite revolves around the planet, and the planet revolves around a star. For example, solar system.
Post	The planet rotates on its own axis, but stars are motionless The satellites consist of asteroids, but planets are not. No. Because the Sun is bigger than stars.	A planet may have a satellite, but a star does not have a satellite. A satellite revolves around a planet; that is the difference. Yes. The stars and the Sun are shining, and they are natural sources of light.	The stars are a light source, but planets are not. They are hotter and bigger than planets. Planet: revolves around the star (like the Sun). Satellite revolves around the planet (like Earth) Yes. All stars give heat and light to their surroundings. The Sun is the heat and light source of our Earth, so the Sun is a star.

Table 11. Frequency and Percentage Values for Orbit Concept.

	No understanding				Partial Understanding				Sound Understanding			
	fpre	*%*	*fpost*	*%*	*fpre*	*%*	*fpost*	*%*	*fpre*	*%*	*fpost*	*%*
Q9	21	56.8	10	27.0	15	40.5	23	62.1	1	2.7	4	10.8
Q10	17	45.9	8	21.6	15	40.5	23	62.1	2	5.4	6	16.2

Table 12. Example Responses of Students to Orbit Concept.

Test type	No understanding	Partial Understanding	Sound Understanding
Pre	It means around the Earth in the Space. Maybe all meteorites would fall to the Earth.	The path the Earth revolves is called by the orbit. I think the planets collide with each other.	The path is drawn by the body in space around other celestial bodies like a star. The moon hits the Earth first, and then the Earth hits the Sun; it could even burn. I think it would be like this.
Post	There is an orbit between the Sun and the Earth. There would be no planets.	The path where planets constantly travel through space, for example, the orbit of the Earth. The Earth and its twin Venus would collide because their orbits are close together.	The Orbit is the path that a celestial body makes around another celestial body while it is revolving. All the asteroids in the asteroid belt would scatter into space. The planets collide with those asteroids.

The statistical analysis revealed an increase in students' partial understanding and sound level frequency after receiving EDBI. The students distinguished planets from other celestial bodies (stars and satellites) more logically. The incidence of students' comprehension difficulties decreased following EDBI. **Table 10** provides illustrative examples of students' responses to the concepts of stars and planets.

Orbit Concept

The last two questions in the questionnaire focused on assessing comprehension of the orbit concept. **Table 11** displays the statistics regarding students' comprehension of the orbit concept.

The statistical analysis revealed an increase in students' partial understanding level and a decrease in students' no understanding level after the EDBI. After EDBI was implemented, the students gained a comprehension of the components of the orbit concept. **Table 12** displays the students' sample responses regarding the concept of stars and planets.

Discussion

This study investigated the impact of engineering design-based science education on 6th-grade students' understanding of astronomy concepts. According to the findings of this study, students' mean scores after receiving EDBI were higher than before treatment. Furthermore, the mean difference between students' pre-test and post-test scores was significant. In the current study, students were taught through instruction on engineering design process activities based on astronomy topics. These students created prototypes to solve astronomy problems by following the steps of the engineering design process. This experience may improve students' understanding of astronomy after the treatment. In this regard, Wendell and Rougers (2013) reported findings consistent with those of the current study, concluding that engineering education led to an increase students' average science course scores. Students performed better in science classes when engineering design process steps were included (Yıldırım & Altun, 2015), and students who received science education based on engineering design had a better grasp of the material (Guzey et al., 2016). A study that combined engineering education with the aerospace and space fields revealed that this field was a good fit for engineering design-based education. Students also used the engineering design process to develop appropriate problem solutions (English et al., 2013). Based on these findings, it is possible to conclude that the engineering design steps positively impacted the students' success and understanding of the science course. In contrast to the findings of the present study, it was stated that engineering education made a significant difference in the success of only high-achieving students (Doppelt et al., 2008). The lack of consensus among these studies may be attributed to the different measurement tools used in these studies. Unlike the current study, this study collected data using a standardized knowledge test. According to the researchers of the aforementioned study, knowledge tests may not accurately measure students' success because, when the designs of the students were examined qualitatively, it was discovered that students with a low level of achievement had lower test scores than high-level students. In contrast, their designed products could be as suitable for the problem as the other high-level achievement students.

This study discovered that after implementing engineering design-based education, students provided more robust scientific explanations for their answers. For example, in the pre-test, students answered that the sun is a star because it is bright, whereas in the post-test, they explained that the sun provides heat and light. While explaining the difference between a planet and a satellite, the pre-test results only included examples of Earth and the moon. In contrast, after receiving engineering design instruction, the students demonstrated the differences between the planet and the satellite using their movements. Similarly, Purzer et al. (2015) found that engineering design-based education improves students' understanding of science content and promotes more meaningful science learning. According to the study, design-based activities helped students provide better scientific explanations. Furthermore, engineering design-based education has improved students' decision-making and critical thinking skills while also developing conceptual understandings of science topics (Fan & Yu, 2015). Guzey et al. (2019) conducted a study to determine the impact of participation time in engineering design-based science education on knowledge development. They found that engineering activities were critical in developing students' knowledge. Another study found that design-based activities effectively structured scientific knowledge and that these designs serve as a bridge for science education (Fortus et al., 2004). Similarly, the current study found that students provided better scientific explanations after receiving engineering design process activities. The current study included activities that followed the engineering design process steps, and it was discovered that implementing these activities improved students' understanding of astronomy.

The activities in this study required students to perform analyses to identify problems. As a result of the analysis, the students researched the concepts they believed they did not fully understand to build a scientific foundation. Furthermore, students compared various concepts to determine a possible solution. For example, they compared stars, satellites, and planets to determine which celestial body can support life based on features like atmosphere, landforms, and temperature. The engineering design process may have provided students with a scientific understanding of astronomical concepts. Furthermore, English and King (2015) emphasized the importance of each stage of the engineering design process, particularly the redesign phase, in developing disciplinary knowledge. Similarly, the presented study focused on the EDP redesign step and required all working groups to explain "what they would change if they wanted to make changes in their models." As a result, students may be able to reflect on their mistakes and identify areas for improvement.

Adams and Slatter (2000) discovered that students struggled to understand the solar system and its components and had numerous misconceptions when it came to astronomy. Although the pre-test of the current study yielded similar results, the post-test results revealed that the frequency of students explaining all correct components of responses increased. In contrast, students with misconceptions and illogical responses to the solar system concept decreased. Students stated that before EDBI, there were many stars in the solar system, the largest of which was the sun. According to the post-test responses, the students believe that the solar system contains only one star, which is known as the Sun. The studies conducted with sixth-grade students and measuring students' understanding of astronomy concepts revealed that students had difficulties in understanding the concepts of orbit and universe in particular and misconceptions about these concepts (Ekiz & Akbaş, 2005; Keçeci, 2012). The pre-test results of the current study were similar to those of previous studies, indicating that students had misconceptions, particularly about orbits. However, when examining the post-test results, it is clear that the students' understanding of the orbit concept has improved because the frequency of students with no understanding has decreased following EDBI. Students' understanding of the orbit concept and overcoming misconceptions may have been aided by the EDBI they received, as one of the problems assigned to them was related to the concept of “orbit.” The students conducted extensive research, group discussions, and brainstorming on the orbit concept while attempting to define a problem and find potential solutions. In this way, students may have gained a conceptual understanding of orbit. The study found that students’ understanding of astronomy topics improved after receiving EDBI. The students better understood astronomical concepts like the universe, solar system, planets, stars, and orbit, and they could provide more logical and scientific explanations. This could be because engineering design-based education was appropriate for teaching astronomy subjects; it encouraged students to think at a higher level, such as decision-making and critical thinking, resulting in more meaningful learning (Arslan & Koparan, 2018; Lin et. al., 2015; Purzer et al., 2015). As a result, the current study can conclude that integrating astronomy-based activities into the engineering design process improved students’ understanding of astronomy topics.

Engineering plays a vital role in the developing world, so engineering education should be integrated into primary school science lessons to produce more skilled individuals (Banks-Hunt et al., 2016). Engineering design-based science education, which includes engineering design process activities, is how the engineering field is introduced into the science curriculum. These engineering design process activities improve students’ performance in science lessons (Fortus et al., 2004), and they gain a better understanding of science concepts and overcome misconceptions (English & King, 2015; Purzer et al., 2015). In the same vein, the present study showed that students’ understanding of astronomy concepts improved positively after receiving EDBI based on astronomy topics, as the mean of students’ scores on the post-test was higher than the mean scores on the pre-test. Furthermore, the pre-and post-test mean scores differed significantly. After EDBI, students gained a better scientific understanding of the universe, solar system, stars, planets, and orbits. According to the current study’s findings, while the frequency of students responding to logical and scientific answers increased, the frequency of students who could not explain their answers or responded to illogical answers decreased in the post-test. Engineering design process activities should be provided to students as often as possible in order for them to overcome misconceptions and develop concepts (Guzey et al., 2019). Thus, it can be concluded that engineering design-based science education improved students’ comprehension of astronomy concepts.

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ORIGINAL ARTICLE

A Comparison of Labor Competence of College Students in Different Educational Tracks: A Study Based on a Survey in Guangxi University of Foreign Languages

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Abstract*: This article is a case study of students' labor competence in two different educational tracks from the Guangxi University of Foreign Languages. According to research findings, there was no significant difference in the overall level of labor competence between ordinary undergraduates and vocational students, and there were disparities in labor competence in specific dimensions, including labor consciousness, labor knowledge, labor qualities, and labor creativity, between the two groups. Ordinary undergraduates significantly outperformed vocational college students in the dimension of labor consciousness, whereas the latter scored higher in the dimension of labor knowledge. Both groups scored poorly in terms of labor creativity. Also discussed is the importance of cultivating innovation ability, building labor knowledge, shaping labor values, and improving off-campus labor education participation among college students.*

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Keywords*: Labor Competence, Educational Track, Labor Consciousness, Labor Knowledge, Labor Qualities, Labor Creativity*

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AI Declaration*: The authors affirm that artificial intelligence did not contribute to the process of preparing the work.*

IN MARCH 2020, the State Council of China (2020) issued the "Opinions on Comprehensively Strengthening Labor Education in Tertiary, Secondary, and Primary Schools in the New Era," emphasizing that labor education is an integral part of the Chinese education system, which places equal value on moral, intellectual, physical, aesthetic, and labor education, and putting forward fresh requirements for labor education at all education levels in the new era. Labor education is not only an essential component of the national education system, but it also supports other components in that it helps cultivate morality, promote intellectual development, boost physical well-being, and nurture aesthetic perceptions in students. In labor education, students develop labor awareness, skills, and resilience, as well as establishing appropriate values and outlooks on life. In China, official labor education as compulsory in the school curriculum is still in its early stages, and the issue of its effective implementation is pending further research.

There are significant distinctions in training objectives, knowledge structures, teaching substances, instructional methods, and practical curriculum between ordinary undergraduate education and tertiary vocational education (Guo, 2017), resulting in variations in labor competence between college students in the two different streams. A thorough examination of the variations in their labor competence is beneficial for improving labor education curricula in tertiary education institutions. The Guangxi University of Foreign Languages provides both ordinary undergraduate and tertiary vocational education. This study investigates the current state of labor competence among students in the two tracks at the university and makes an empirical comparison. Based on its research findings, it discusses the differential labor education needs of the two groups and proposes relevant education pathways.

Research Subjects and Methodology

Research Subjects

The sample of this study includes ordinary undergraduates and vocational students from Guangxi University of Foreign Languages. A total of 2,803 questionnaires were distributed and collected, with 2,720 being valid (a 97.04% validity rate). Among the respondents, 1,234 were vocational students and 1,486 ordinary undergraduates.

Research Methodology

Our survey questionnaire is an adaptation of the College Student Labor Competence Scale (Yuan, 2023), including four dimensions: labor

Table 1. A Description of the College Student Labor Competence Questionnaire.

Dimensions	Sub-Dimensions	Chief Content	Question Items
Labor consciousness	Perceptions of the value of labor	Understanding of the purpose of labor	1, 2, 3, 4, 5
	Attitudes towards labor	Attitudes to labor and working people	6, 7, 8, 9
	Labor ethics	Moral and rational judgments on labor activities; subjective satisfaction from labor	10, 11, 12, 13
Labor knowledge	Theoretical knowledge of labor	Essential knowledge for labor enactment	14, 15, 16, 17, 18
	Labor skills	Basic labor skills for everyday life	19, 20, 21, 22, 23
Labor qualities	Labor resilience	Dedication to labor responsibilities and readiness of taking on labor burdens	24, 25, 26, 27, 28
	Labor habits	Active participation in labor activity	29, 30, 31, 32, 33
Labor creativity	Innovation in daily-life labor	Innovation of labor processes and tools in everyday life	34, 35, 36
	Innovation in production labor	Outcomes of labor practice, such as patents and research papers	37, 38, 39, 40
	Innovation in voluntary service labor	Content design and organization of voluntary services	41, 42, 43

Table 2. Validity Test Results.

KMO measure of sampling adequacy		0.977
Bartlett’s test of sphericity	Approximate Chi-squared value	96281.31
	df	903
	Sig.	0

Table 3. Differences in Labor Competence in Four Dimensions between the Two Groups.

	Labor Consciousness	Labor Knowledge	Labor Qualities	Labor Creativity	Labor Competence
Ordinary Undergraduates	4.28±0.54	3.89±0.69	4.05±0.64	3.67±0.82	3.97±0.59
Vocational college students	4.19±0.61	3.96±0.71	4.03±0.69	3.74±0.86	3.98±0.65
T-value	4.09	2.57	0.58	1.95	0.27
p-value	< 0.001	0.01	0.56	0.51	0.784

consciousness, labor knowledge, labor qualities, and labor creativity (**Table 1**). “Labor consciousness” contains 13 question items in three sub-dimensions: “perceptions of the value of labor,” “attitudes towards labor," and labor ethics.” “Labor knowledge” has 10 items in the two sub-dimensions of “theoretical knowledge of labor” and “labor skills.” “Labor qualities” contain 10 items in the two sub-dimensions of “labor resilience” and “labor habits.” “Labor creativity” has 10 items in three sub-dimensions: “innovation in daily-life labor,” “innovation in production labor,” and “innovation in voluntary service labor." Each item in the questionnaire is scored from 1 to 5, with 1 denoting “absolutely disagree,” 2 “fairly disagree,” 3 “agree,” 4 “considerably agree,” and 5 “absolutely agree.” The average score of all items included in a dimension or sub-dimension was calculated as the score of each dimension or sub-dimension. Data were analyzed with SPSS 22.0 for further discussion of research findings.

Reliability and Validity of the Questionnaire

According to the analysis results via SPSS22.0, the Cronbach’s coefficient alpha was 0.970 for the questionnaire, signaling good reliability; the KMO value is 0.977 (above 0.7), indicating that the scale had good construct validity (**Table 2**).

Research Findings

Overall Levels of Labor Competence of Ordinary Undergraduates and Vocational College Students

As shown by the analysis results (**Table 3**), there was no significant difference in the overall level of labor competence between the two groups. Ordinary undergraduates and vocational students scored highest in “labor consciousness” with 4.28 and 4.19, respectively, and scored lowest in “labor creativity” with 3.67 and 3.74, respectively. In addition, ordinary undergraduates scored significantly higher than vocational students in “labor consciousness” ($p < 0.05$). Inversely, vocational students scored significantly higher than ordinary undergraduates in “labor knowledge” ($p < 0.05$).

Differences in the Sub-Dimensions of Labor Consciousness between the Two Groups

The differences in “labor consciousness” between the two groups of college students were mainly exhibited in “perceptions of the value of labor” and “labor ethics” as sub-dimensions. Ordinary undergraduates scored higher in

Table 4. Differences in the Sub-Dimensions of Labor Consciousness between the Two Groups of College Students.

Sub-Dimensions	Vocational Students	Ordinary Undergraduates	T	p
Perceptions of the value of labor	4.16±0.67	4.26±0.61	-4.175	< 0.001
Attitudes towards labor	4.05±0.75	4.09±0.73	-1.534	0.125
Labor ethics	4.37±0.65	4.49±0.55	-5.384	< 0.001

Table 5. Differences in the Sub-Dimensions of Labor Knowledge between the Two Groups of College Students.

Sub-Dimensions	Vocational Students	Ordinary Undergraduates	T	p
Theoretical knowledge of labor	4.00±0.74	3.94±0.75	2.145	0.032
Labor skills	3.92±0.75	3.84±0.73	2.707	0.007

Table 6. Differences in the Sub-Dimensions of Labor Qualities between the Two Groups of College Students.

Sub-Dimensions	Vocational Students	Ordinary Undergraduates	T	p
Labor resilience	4.07±0.71	4.1015±0.66	-1.11	0.267
Labor habits	3.99±0.74	3.9962±0.69	-0.092	0.926

Table 7. Differences in the Sub-Dimensions of Labor Creativity between the Two Groups of College Students.

Sub-Dimensions	Vocational Students	Ordinary Undergraduates	T	p
Innovation in daily-life labor	3.88±0.83	3.86±0.80	0.625	0.532
Innovation in production labor	3.58±0.99	3.46±0.97	3.175	0.002
Innovation in voluntary service labor	3.80±0.88	3.77±0.84	0.908	0.364

Table 8. Off-Campus Labor Activity Participation among Students at the Two Educational Levels.

	Yes		No	
	Vocational Students	Ordinary Undergraduates	Vocational Students	Ordinary Undergraduates
Participation in practical education like placement	43.68%	35.26%	56.32%	64.74%
Participation in voluntary service activity	50.32%	50.54%	49.68%	49.46%

these two sub-dimensions than vocational students ($p < 0.05$), but there was no significant difference in “attitudes towards labor” between the two groups (**Table 4**).

Differences in the Sub-Dimensions of Labor Knowledge between the Two Groups

Vocational students scored higher than ordinary undergraduates in both sub-dimensions: “theoretical knowledge of labor” and “labor skills” (**Table 5**).

Differences in the Sub-Dimensions of Labor Qualities between the Two Groups

There was no significant score difference in “labor resilience” and “labor habits” as sub-dimensions between the two student groups (**Table 6**).

Differences in the Sub-Dimensions of Labor Creativity between the Two Groups

Both groups scored lowest in “Innovation in production labor.” Despite the absence of significant differences in the overall level of labor creativity between the two groups, vocational students scored noticeably higher than ordinary undergraduates in “Innovation in production labor” (**Table 7**).

The Rates of Off-Campus Labor Activity Participation among the Two Groups of Students

The participation rate of placement among vocational students was 43.68%, higher than the 35.26% among ordinary undergraduates. The participation rates of voluntary service activity in the two groups are almost the same (**Table 8**).

Discussion

Data show no significant disparities in the overall level of labor competence between vocational college students and ordinary undergraduates. Students in both tracks exhibited acceptable levels of labor competence. For both groups, labor education is an integral part of the curriculum. The state places equal weight on labor education in the two tracks, and it is incorporated into the curricular programs to foster the labor competence of all tertiary students.

Students' scores on the labor competence scale suggest that labor education has been equally valued in the two different streams.

Nevertheless, both vocational college students and ordinary undergraduates perform low in "labor creativity." Their weakness in "labor creativity" is particularly evidenced by their poor performance in the sub-dimension of "innovation in production labor," which includes raising original ideas, conducting scientific research projects, initiating business projects, and achieving places in professional competitions, among others (Huang et al., 2022).

Ordinary undergraduates outperform vocational college students in "labor consciousness," with the gap mainly due to the disparities in "perceptions of the value of labor" and "labor ethics," i.e., the differences in the comprehension of the purpose of labor as well as moral experience and subjective satisfaction from labor, between the two groups. The gap is likely associated with the difference in their educational focuses. Vocational education places higher emphasis on practice than theoretical knowledge, resulting in the proficiency in hands-on skills but a lack of deep understanding of the meaning of labor in vocational students, who may have difficulty keeping their motivation level high in an enduring process of labor. Contrarily, ordinary undergraduate education underscores the delivery of content knowledge as well as liberal education, which is conducive to their development of an in-depth understanding of the purpose of labor. Also, undergraduates receive more education on the value of labor, largely boosting their performance in "labor consciousness." All these factors help ensure the maintenance of a positive mentality in long-term labor, contributing to their persistent inquiry in the study.

On the other hand, vocational students develop better labor knowledge than ordinary undergraduates in their college life due to vocational education's focus on cultivation of practical skills. The vocational education curriculum provides students more opportunities for hands-on manipulation training, bringing them richer labor knowledge and experience. They can improve their labor skills by participating in the practical production process as part of their training program. As a result, they can adapt more quickly to labor settings. Compared with this group, ordinary undergraduates have longer years of education, which focuses more on the training of basic content knowledge. They receive inadequate training in practical labor skills, such as software operation and equipment manipulation, resulting in their lower performance in labor scenarios than their peers in the vocational track.

Currently, off-campus labor activity for college students primarily comprises practical education programs like placement and voluntary services. Placement helps students enhance labor consciousness, improve labor skills, and foster labor qualities by experiencing the authentic labor process through on-site engagement. In the meantime, participating in volunteer activities allows students the chance to serve the community, improve their problem-solving skills, and develop competences through practice. Moreover, it helps foster upbeat attitudes, the public spirit, and sound values in students, which is the paramount role of labor education. Nevertheless, our investigation results show that almost half of ordinary undergraduates and vocational college students sampled have never participated in these two forms of off-campus labor activity, indicating inadequate participation in practical labor education and insufficient experience of labor practice among college students. Ordinary undergraduates have even lower awareness in this regard than vocational students.

Suggestions

Heightening the Weight of Innovation Capacity Development in Labor Education

Labor education is instrumental in developing students' creativity and innovation capacity. The "Guidelines for Labor Education in Tertiary, Secondary, and Primary Schools (Trial)," released by the Ministry of Education of China (2020), emphasize that labor education must encourage creation and innovation in students, the major actors in the process, and motivate them to experiment with new methods and explore new technologies based on prior experiences and techniques of others. In recent years, Chinese universities have paid more attention to developing students' innovation capacity in labor education. Specifically, they offer innovation and entrepreneurship education courses and relevant competitions; students who successfully complete these courses or win places in the competition are awarded credits (Jing, 2023). However, this arrangement has not worked as effectively as expected, because students have participated for the sake of credits, and their creations are mostly imitations of winners of previous competitions.

Therefore, it is necessary to note that labor creativity education is not a matter of form but rather a process requiring substantive enactment. Peer influence and teacher support are the two vital factors for its successful implementation. Labor creativity education requires students' use of initiative, which, to some extent, comes from peer influence (Wang, 2016). Peer influence is helpful in stimulating the competitive mentality in students, who might be spurred to actively engage in innovation activity by the role model effect of peers or by their desire to gain recognition from peers. Thus, it is important to increase inter-student interactions in labor creativity education. Furthermore, teacher support plays an essential role in fostering students’ innovation ability. When students encounter challenges in innovation activities and feel reluctant to go ahead because of their lack of experience and knowledge, the teacher should provide extra directions.

Improving Ordinary Undergraduates’ Labor Knowledge through Labor Education

First off, it is imperative to increase students’ opportunities to practice in order to enhance their labor literacy. According to the “Opinions of the Ministry of Education and Other Six Departments on Further Strengthening the Practical Education Work in Universities,” higher education institutions should increase class hours for practical education to ensure its thorough implementation, and more training opportunities ought to be provided for students to experience the value of labor in a real labor setting via collaboration with industry (Ministry of Education of China, 2012). More diverse forms of practical education should be experimented with, including online and offline blended practice and the “seminar + on-site placement” pattern, to meet the individual needs of students. Also, it is imperative to establish more effective feedback and evaluation mechanisms for continuous improvement of the quality of practical education.

Equally important is to improve instructional methods in labor education. Aside from the separate labor curriculum, ordinary undergraduates' labor education is typically concerned with the practical components of their specialties (Guo, 2017). Often, the teachers focus on delivering specific labor goals and certain labor methods, leading to students relying on rote-learning in the process of labor knowledge acquisition but failing to develop problem-solving skills. Yet, in practice, labor activity could take place in a diverse range of scenarios, and the challenges arising in the process of labor are unpredictable. Labor knowledge education should not limit itself to the instruction of certain manipulation methods but instead seek to foster students' ability to solve problems. Therefore, crucial to student labor knowledge acquisition are diversifying labor education methods and propelling students to solve real-world problems by various means.

Additionally, legitimate evaluation criteria for labor skills should include examinations of both students’ theoretical expertise and hands-on manipulations. Currently, general tertiary education in China puts content knowledge education and corresponding examinations first, paying little regard to the training of practical manipulation, resulting in students’ inability to apply knowledge in actual situations (Guo, 2017). Despite practical components having been increased in certain courses, students tend to prioritize theoretical over practical training due to the oversimplistic and biased assessment mechanisms. Thus, it is imperative to modify the assessment criteria to direct ordinary undergraduates and their teachers to pay more attention to labor skill training.

Strengthening the Education on the Value of Labor in Vocational College Students

Vocational education aims to enhance students' skills and techniques, but it should also foster a correct understanding of the value of labor. As per the State Council of China’s “Opinions on Promoting High-Quality Development of Modern Vocational Education,” it is of vital importance to propagate exemplary stories of successful frontline technical and skilled workers among vocational college students, creating a labor-, practical skill-, and creation-valued education climate (Wang, 2022).

Our investigation suggests that vocational college students have a lower level of “labor consciousness” than ordinary undergraduates, which is mainly reflected by the variations in the two sub-dimensions, “perceptions of the value of labor” and “labor ethics.” These variations are the result of the varied focuses of the two educational tracks. Vocational education focuses more on cultivating applied talents and thus gives less emphasis on liberal education or value education. Moreover, in the context of the surging influence of consumerism, utilitarianism, and other Internet-related popular thoughts, unitary vocational education is likely to exacerbate the students’ tendencies to materialize labor, reduce emotional and moral connections with it, and regard it merely as a commercial means for earning money (Huang et al., 2022). That is why education on the value of labor and its relevant moral aspects needs to be incorporated into vocational education.

An appropriate campus climate can realize labor-related values and morality (Fang, 2019). To cultivate a labor-valued campus culture, the school can use various means, such as posters, radio, internet-based media, and school events, to increase students’ exposure to excellent practices of skilled working forces. In the meantime, the teachers can select high-performing students as role models to enhance vocational students’ identification with technical careers through the peer effect.

Increasing Students’ Participation in Off-Campus Labor Education Activities

Participating in off-campus labor education activities, such as placement and volunteer services, is also a valuable avenue for boosting college students’ labor competence. Nevertheless, our survey results indicate that the participation rates in these activities among both ordinary and vocational college students remain low. Increasing students' participation in non-school-based labor education activities has become an outstanding issue that current tertiary education institutions must address.

Students' involvement in volunteer services is beneficial for enhancing their overall level of labor competence, including bolstering their labor skills and sharpening their conception of the value of labor as well as their labor qualities. Establishing a legitimate evaluation and feedback mechanism for volunteer activities can be effective in raising students' participation levels. In recent years, state-level advocacy and schools' efforts have resulted in the rise of volunteer activities among college students. With it, however, come the challenges, such as the superficiality of the volunteer activities and the illegitimacy of students' motives (Zhou et al., 2017). Since a certain amount of volunteer service provision means some credits in most universities, a portion of students participate in volunteer activities merely for the purpose of earning credit, which is against the spirit of volunteer activities, i.e., dedication to public interests. A sound evaluation and feedback mechanism can help identify volunteer activities that inspire students' sense of meaning and screen out those that are unproductive in terms of social significance. It will also contribute to developing volunteer activities that support students' study of their specialties. Additionally, participants can receive feedback on the outcomes and impacts of their volunteer services through internet-based media platforms.

Off-campus practical education programs, such as placement, give college students the opportunity to apply and improve their knowledge in practice and develop a comprehensive understanding of all aspects of labor. The school can boost students' participation in off-campus labor activity by strengthening school-industry cooperation and expanding channels of placement provision. Currently, placement arrangements for college students primarily occur in the final semester, leaving a significant gap that hinders the development of student labor competence. Summer internships might be valuable practices. Some college students have voluntarily made attempts at summer internships but failed to reach desired outcomes due to a lack of information support and protective guarantees (Wang et al., 2019). Therefore, it is advisable for the school to sponsor students' summer internships that align with their specialties to increase the participation rate of off-campus labor activity in them while also circumventing the risks of uninformed decisions on summer internships.

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REVIEW

The Effect of Artificial Intelligence-Assisted Personalized Learning on Student Learning Outcomes: A Meta-Analysis Based on 31 Empirical Research Papers

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Abstract: *The application of artificial intelligence in education has garnered more attention in academia, and its role in promoting student personalized learning has sparked a lot of discussion. Many researchers have emphasized the positive effect of intelligent technology in supporting student personalized learning; however, there is a lack of systematic data evidence in this regard. This article seeks to evaluate the effects of artificial intelligence-assisted personalized learning on student learning outcomes based on a meta-analysis of 36 experimental and quasi-experimental studies from 31 published papers. The analysis results show that artificial intelligence-assisted personalized learning has moderately positive effects on student learning outcomes in terms of knowledge, competence, and emotional development. Variables such as the type of Edutech applications, learning scenario, and duration of application can moderate the relationship between artificial intelligence-assisted personalized learning and student learning outcomes, whereas the education phase and disciplinary domain do not exhibit significant moderating effects on this relationship. The purpose of this study is to provide implications and references for further research and practical explorations of artificial intelligence application in education.*

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Introduction

TODAY, artificial intelligence (AI), one of the most popular terms among the public, has become the driver of the advances in many sectors. In the field of education, AI is also leveraged to create fresh solutions to teaching and learning challenges (Pedro et al., 2019). As a major branch of computer science, AI has multiple sub-areas such as machine learning, natural language processing, machine vision, and robotics. Technologies like these can be integrated into the processes of teaching, learning, and educational administration to enhance the experience of teachers and students (Chen et al., 2020). Specifically, they are employed to support personalized learning, improve instructional evaluation and assessment, analyze educational data, develop virtual learning environments, build smart campuses, and more (Chen et al., 2020; Huang et al., 2021). Recent years have witnessed an accelerated growth in the application of AI in instruction, with a focus on intelligent learning analytics, mechanisms for developing and sharing teaching resources, the construction of smart platforms for teaching management and evaluation, and the technical upgrading of learning environments (Hu & Wang, 2022). According to research, AI has the potential to assist with personalized learning because it enables students to learn at their own pace and in their own styles, resulting in improved learning outcomes (Harry & Sayudin, 2023).

To reveal AI’s role and prospects in individualized education, some researchers have used the qualitative method to analyze existing research findings on AI’s effects on personalized learning (Zhang et al., 2023). Nevertheless, there is a lack of quantitative analyses of the actual outcomes of AI-assisted personalized learning in the literature. To bridge this gap, we drew on relevant experimental and quasi-experimental research results to evaluate the effects of AI-assisted personalized learning on student learning outcomes, using the meta-analysis techniques.

Literature Review

Personalized learning is viewed as an inclusive, student-centered approach to learning that is aimed at meeting the needs of all students, especially those who struggle with learning (Zhang, 2023). The approach’s centerpiece is its emphasis on adjusting teaching content, progression, and evaluation methods to the specific needs of each individual student as opposed to the traditional “one-size-fits-all” modality. With its principles of flexibility, adaptability, and respect for the students’ agency, it can help create a vibrant educational environment (Ayeni et al., 2024). In certain studies, terms like adaptive learning, customized learning, and individualized teaching are also used to represent the concept of personalized learning (Shemshack & Spector, 2020).

A plurality of research findings has demonstrated that personalized learning has its advantage over conventional instructional methods in boosting student academic performance (Zhang et al., 2020). In the past, it was nearly impossible to realize personalized learning, especially across-the-board personalized learning, due to the limits of the teaching force and educational resources (van der Vorst & Jellic, 2019). Nowadays, the ever-increasing infusion of technology into education has provided avenues for reaching efficacious personalized learning (Shemshack & Spector, 2020). Particularly, AI applications in education can play a significant role in creating personalized learning experiences. Murtaza et al. (2022) argued that an effective system of personalized learning should contain certain core capabilities, including delivering knowledge suiting the learner's academic level, recommending and presenting teaching content according to their needs, and making ongoing evaluations of their performance. AI technology helps deliver these functions because AI algorithms can achieve adaptive content delivery by collecting and analyzing colossal amounts of data (including student academic performance, learning preferences, and learning processes), customizing educational experiences, and dynamically adjusting the levels of difficulty of teaching materials (Ayeni et al., 2024). In addition, AI facilitates personalized learning by providing real-time feedback to evaluate students' everyday assignment completion in a timely and targeted manner.

Currently, educational researchers have made a lot of efforts to leverage AI to support personalized learning. Among all educational technology (Edutech) applications for this end, the most used are the intelligent feedback mechanism, learning path recommendation, and personalized scaffolding. The intelligent feedback mechanism is different from the conventional one in that it automatically generates feedback through learning analytics while also dynamically adjusting feedback strategies in response to varying teaching scenarios and student behaviors, whereas the latter simply uses pre-set feedback strategies according to the type of error detected without the ability to handle instances beyond the predicted ones (Gutierrez & Atkinson, 2011; Chen et al., 2021). A learning path is a combination of purposeful education activities and resources aimed at facilitating the learner's acquisition of knowledge and skills in a certain subject area (Kong et al., 2020). The technology of learning path recommendation utilizes algorithms to select the most suitable path for the learner based on their distinctive characteristics and needs (Niknam & Thulasiraman, 2020). Scaffolding is an instructional strategy that aids students in internalizing knowledge and developing autonomous learning competences (Lim et al., 2023). The personalized scaffold dynamically modifies supporting strategies based on the monitoring of the student's learning progress, assisting the student in judging whether the current learning content is suitable for them (Su, 2020).

Furthermore, technologies like the adaptive learning system, intelligent tutoring system, smart education platform, and educational robot are integrated applications of AI-based Edutech, including the aforementioned three ones. An adaptive learning system typically concerns a complete cycle, including collecting data from the learner, using the data to estimate their learning progress, instantly recommending pertinent study activities for the learner, and providing targeted feedback. Following the learner's adaptation of their learning strategies based on the feedback, the system collects fresh data and initiates a new cycle (Wang et al., 2020). The adaptive system's algorithms typically make decisions by referring to a domain model of the knowledge to be learned, a student model of learners' background characteristics, and a task model that specifies features of the learning activities (Lee & Park, 2008). The intelligent tutoring system uses AI algorithms to mimic the methods of human teachers, offering customized guidance and support to students. It serves as additional teacher resources by offering students personalized feedback and directions according to their individually different learning styles (Ayeni et al., 2024). Some researchers noted that the intelligent tutoring system draws on the zone of proximal development theory and can enhance students' understanding by posing moderately challenging questions as human teachers do (Beal et al. 2010). Aside from the above two applications specializing in personalized services for students, the smart education platform, as a more comprehensive system, provides intelligent support services for both teachers and students using a wide range of AI technologies. It assists teachers in managing educational resources and organizing teaching and evaluation processes for more precise instruction, while also supplying students with interactive tools and learning resources that meet their needs based on the identification of their characteristics and automatically recording their learning process and assessing their learning outcomes (Luo, 2023; Deng & Wang, 2024). In this study, educational robots are not simply physical robots but also include software-based virtual ones, which were referred to as intelligent agents or assistants by some researchers (Wang et al., 2022). These educational robots can simulate human conversations through natural language processing, perceive student learning needs through interactive Q&A, and provide tailored teaching intervention and support accordingly (Zhang et al., 2023).

In addition, the researchers have also tried to combine AI with other technologies to strengthen the implementation of personalized learning. For instance, the integration of AI with virtual reality technology has the potential to create more diverse learning scenarios to meet the distinct needs of individuals (Zhang & Aslan, 2021). In some studies, the AI-enabled virtual-reality learning system is treated as a type of visual interactive system

(Zhang & Aslan, 2021; Zhang et al., 2023). Also, it must be emphasized that learning analytics is the technology underpinning all AI-based Edutech applications, albeit it is not separately discussed here.

To sum up, AI has been applied to a variety of applications that assist personalized learning. Many experimental and quasi-experimental studies have been conducted to explore the outcomes of AI-assisted personalized learning. A thorough understanding of its effectiveness and the optimization of its implementation necessitate more in-depth analysis of prior research findings. Multiple factors, such as the type of AI-based Edutech applications, application scenario, duration of application, disciplinary domain, and educational phase, can all influence the outcomes of AI-assisted personalized learning in students, which deserves further research.

Research Questions

We analyzed 36 relevant experimental and quasi-experimental studies using meta-analytic techniques to address the following questions:

1. Compared with traditional learning methods, can AI-assisted personalized learning significantly improve student learning outcomes?
2. What are the effects of a variety of AI-based Edutech applications on personalized learning outcomes?
3. How do the application scenario, application duration, disciplinary domain, and educational phase influence the effects of AI-assisted personalized learning on student learning outcomes?

Research Methodology

Literature Search and Screening

This study sourced relevant literature in Chinese from the China National Knowledge Infrastructure (CNKI) and publications in English from Web of Science and EBSCO, using search words “artificial intelligence,” “AI,” “personalized learning,” “adaptive learning,” “customized learning,” and “individualized instruction.” As of July 2024, 372 articles in Chinese and 1282 in English were retrieved. Moreover, the method of snowballing was adopted to conduct a secondary search in the literature retrieved and reference lists of certain systematic reviews to find additional 19 articles. Altogether, 1673 articles were obtained.

For literature screening, we set inclusion criteria as follows: (i) research topics concerned with AI-based educational technology and personalized learning; (ii) research design being experimental or quasi-experimental with the use of the experimental group (adopting AI-assisted personalized learning) and control group (using traditional learning methods);

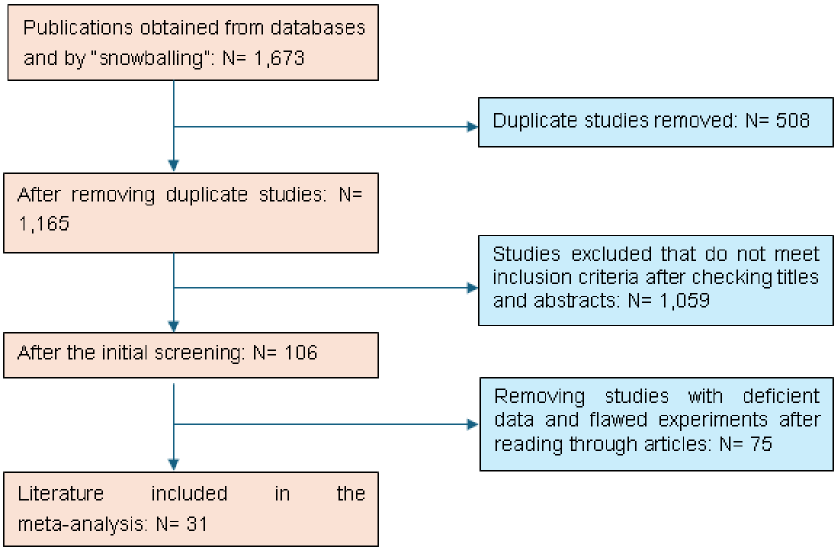

Figure 1. Literature Search and Screening Procedure.

(iii) Complete data including means (MD) and standard deviations (SD) for the computation of the mean and combined effect sizes. According to these criteria, 31 articles were selected and included in our meta-analysis, with six in Chinese and 25 in English. Five of them contain two independent studies; hence, the total number of experimental and quasi-experimental studies amounts to 36. **Figure 1** shows the literature search and screening processes of this study.

Literature Coding and Effect Size Estimation

For systematic analysis, we coded the characteristic values of the included 36 studies and extracted the following details: the first author, publication year, sample size, duration of experiment, educational phase, discipline domain, type of Edutech applications, application scenario, and student learning outcomes (**Table 1**). Disciplines involved in the studies were classified into science (e.g., mathematics, physics, and computer science) and non-science domains (e.g., language, arts, and management). Types of AI-based Edutech applications include the smart education platform, adaptive learning system, intelligent tutoring system, educational robot, intelligent feedback mechanism, learning path recommendation, personalized scaffolding, and virtual reality-based learning. Application scenarios included the offline classroom, digital platform, mobile platform, and virtual-reality learning environment. Student learning outcomes were

Table 1. Coding of the 37 Studies Included in the Meta-Analysis.

The First Author/Publication Year	Learning Outcomes	Types of Application	Application Scenarios	Educational Phases	Disciplinary Domains	Sample Sizes	Experiment Durations (months)
Ma(2023)	Knowledge	Smart education platform	Offline classroom	Primary	Science	103	3 - 6
Dai(2021)	Knowledge	Adaptive learning system	Offline classroom	Secondary	Science	98	3 - 6
Wang(2022)	Knowledge Emotion	Intelligent feedback mechanism	Offline classroom	Primary	Non-science	42	< 1
Kong(2020)	Knowledge Emotion	Learning path recommendation	Digital platform	Tertiary	Science	59	3 - 6
Yan(2020)	Knowledge	Intelligent tutoring system	Offline classroom	Secondary	Science	124	1 - 3
Luo(2023)	Knowledge Competence	Smart education platform	Offline classroom	Secondary	Science	94	1 - 3
Wang (2020)-1	Knowledge	Adaptive learning system	Offline classroom	Secondary	Science	155	< 1
Wang (2020)-2	Knowledge	Adaptive learning system	Offline classroom	Secondary	Science	84	< 1
Bahçeci (2016)	Knowledge	Intelligent tutoring system	Digital platform	Tertiary	Science	56	1 - 3
Beal (2010)	Knowledge	Intelligent tutoring system	Offline classroom	Secondary	Science	25	1 - 3
Chen (2009)	Knowledge	Learning path recommendation	Digital platform	Tertiary	Science	86	< 1
Deng (2023)	Knowledge	Smart education platform	Digital platform	Tertiary	Non-science	90	3 - 6
Divekar (2024)	Knowledge	Virtual reality-based learning	Virtual-reality learning environment	Tertiary	Non-science	20	1 - 3
Dolenc (2015)	Knowledge	Adaptive learning system	Digital platform	Secondary	Science	117	< 1
Hooshyar (2016)	Knowledge	Intelligent tutoring system	Digital platform	Tertiary	Science	58	1 - 3
Hwang (2020)	Knowledge Emotion	Adaptive learning system	Mobile platform	Primary	Science	109	< 1
Lang (2023)-1	Knowledge	Intelligent feedback mechanism	Mobile platform	Tertiary	Non-science	65	Not indicated
Lang (2023)-2	Knowledge	Intelligent feedback mechanism	Mobile platform	Primary	Non-science	593	Not indicated
Li (2017)	Knowledge	Intelligent feedback mechanism	Offline classroom	Secondary	Non-science	63	> 6
Lim (2024)	Knowledge	Personalized scaffolding	Digital platform	Tertiary	Science	59	< 1
Niknam (2020)	Knowledge	Learning path	Mobile platform	Tertiary	Science	50	1 - 3

		recommendation					
Su (2020)	Knowledge	Personalized scaffolding	Digital platform	Tertiary	Science	80	1 - 3
Wei (2023)	Knowledge	Intelligent tutoring system	Mobile platform	Tertiary	Non-science	60	1 - 3
	Emotion						
	Competence						
Wijekumar (2012)-1	Knowledge	Intelligent tutoring system	Digital platform	Primary	Non-science	130	3 - 6
Wijekumar (2012)-2	Competence	Intelligent tutoring system	Digital platform	Primary	Non-science	109	3 - 6
Xu (2014)	Knowledge	Intelligent tutoring system	Virtual-reality learning environment	Tertiary	Non-science	183	< 1
	Emotion						
Qianjing & Lin (2021)	Knowledge	Adaptive learning system	Digital platform	Tertiary	Non-science	60	Not indicated
Julia (2016)	Competence	Educational robot	Offline classroom	Primary	Science	21	1 - 3
Goda (2014)-1	Emotion	Educational robot	Digital platform	Tertiary	Non-science	63	< 1
	Competence						
Goda (2014)-2	Competence	Educational robot	Digital platform	Tertiary	Non-science	67	< 1
Serrano (2018)-1	Knowledge	Intelligent tutoring system	Digital platform	Secondary	Non-science	47	< 1
Serrano (2018)-2	Knowledge	Intelligent tutoring system	Digital platform	Primary	Non-science	68	< 1
Nugent (2010)	Emotion	Educational robot	Offline classroom	Primary	Science	269	< 1
Alfieri (2015)	Knowledge	Educational robot	Virtual-reality learning environment	Secondary	Science	104	< 1
	Emotion						
	Competence						
Zafar (2015)	Knowledge	Adaptive learning system	Digital platform	Tertiary	Science	57	< 1
Zhou (2023)	Knowledge	Smart education platform	Digital platform	Tertiary	Science	350	>6
					Non-science		

presented in three dimensions: knowledge development (measured by test results, academic progress, etc.), competence development (including the growth in critical thinking, problem-solving, and more), and emotional development (reflected by the improvements of learning motivation, self-efficacy, etc.). The coding was carried out by two researchers to ensure its accuracy. The Kappa value of the coding is 0.89, indicating a high level of agreement.

This study adopted Comprehensive Meta Analysis (CMA) 3.0 as the tool for data analysis. In a meta-analytic study, the effect size is estimated by Cohen’s d or Hedges’ g, which value to use depends on the sample size of the prior studies included. Cohen’s d is applicable to all sample sizes, whereas Hedges’ g is often opted for when the sample size is less than 20 because it is multiplied by a correction factor for small samples (Glass, 1976; Borenstein et al., 2021). Our literature coding shows that the sample sizes of the studies included in this meta-analysis are all above 20. Therefore, we used Cohen’s d to estimate the effect sizes. In practical research, Cohen’s d is commonly represented as SMD; in the software of CMA, “std diff in means” is the term for this value. Some of the studies included have more than one effect size because they evaluate student learning outcomes in various dimensions or disciplines. As a result, we extracted 54 effect sizes from the 36 studies.

Publication Bias Analysis

Publication bias is encountered when the significance and direction of research results bias the decision to publish on the part of researchers, reviewers, or editors (Ma & Liu, 2019). To evaluate the possibility of publication bias in the studies included in our meta-analysis, we conducted a comprehensive assessment using the funnel plot, fail-safe N, and Egger's regression analysis. As **Figure 2** shows, the majority of the 54 effect sizes are relatively evenly and symmetrically distributed on both sides of the average effect size; however, a small number of them fall outside the two sides of the funnel, indicating the possible presence of heterogeneity between studies. The fail-safe N is another indicator for evaluating the presence of publication bias. When the meta-analysis results show statistical significance, the larger the fail-safe N value, the lower the possibility of the meta-analytic conclusions being refuted, that is, the lower the possibility of publication bias (Hu & Wang, 2022). Using Rosenthal’s (1979) computation method, we obtained a fail-safe N = 5312 (far greater than 5K+10=280, where K represents the number of effect sizes; in this study, it is 54), signaling a low possibility of publication bias in this study. The Egger’s regression analysis results showed a t-value of 1.27 and a p-value of 0.209 > 0.05, also indicating that there was no significant publication bias in the literature included (Higgins et al., 2003). These analytic results suggest that the findings of our meta-analysis are reliable.

Heterogeneity Analysis

The purpose of heterogeneity analysis is to evaluate the combinability of research results from various studies for the generation of a combined effect

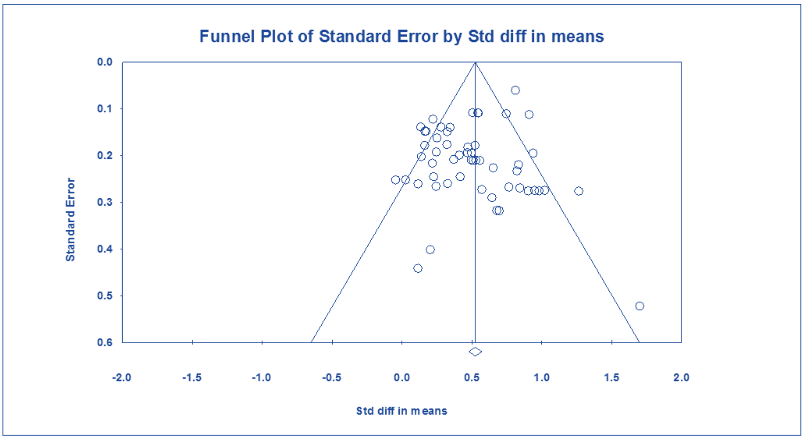

Figure 2. The Funnel Plot for Publication Bias Analysis.

Table 2. Results of Heterogeneity Analysis and the Estimation of Overall Effect Size.

		Effect Sizes & 95% Confidence Intervals			Heterogeneity Tests			
Effects Models	Nos of Effect Sizes	SMD	Standard Error	95% Confidence Intervals	Q Value	df	p Value	I^2
Fixed effects model	54	0.523	0.023	(0.477, 0.569)	138.194	53	0.000	61.648
Random effects model	54	0.490	0.041	(0.409, 0.571)				

size. Also, due to the presence of differences in the intervention, sample size, estimate results, and more between different studies, the results of heterogeneity analysis are crucial for the selection of the meta-analysis model. The commonly used statistical measures in heterogeneity analysis are the Cochran’s Q and I^2 tests. The p-value is the primary indicator in the Cochran’s Q test. A greater-than-0.1 p-value means the absence of heterogeneity, while a less-than-0.1 p-value indicates the presence of heterogeneity. According to Higgins et al. (2003), the I^2 values of 25%, 50%, and 75% represent low, medium, and high levels of heterogeneity, respectively. As **Table 2** shows, the overall effect size of this study has a Q value of 138.194 ($p < 0.001$) and an I^2 value of 61.648%, exhibiting statistically significant and medium-level heterogeneity between the studies included. Hence, a random effects model is employed for further analysis. Furthermore, these results of heterogeneity analysis indicate the presence of

Table 3. Differential Effects of AI-assisted Personalized Learning on Various Dimensions of Student Learning Outcomes.

		Effect Sizes			Two-Sided Tests		
Dimensions	Nos of Effect Sizes	SMD	Standard Error	95% Confidence Intervals	Z Value	p Value	Between-Group Effect
Knowledge	35	0.557	0.046	(0.467, 0.647)	12.121	0.000	Q=12.075 p=0.002
Emotion	9	0.268	0.070	(0.131, 0.405)	3.837	0.000	
Competence	10	0.436	0.106	(0.228, 0.643)	4.120	0.000	

Table 4. The Moderating Effect of the Type of Edutech Applications.

		Effect Sizes			Two-Sided Tests		
Types of Edutech Application	Nos of Effect Sizes	SMD	Standard Error	95% Confidence Intervals	Z value	p value	Between-Group Effect
Virtual reality-based learning	1	1.701	0.522	(0.678, 2.724)	3.260	0.001	Q=41.357 p=0.000
Personalized scaffolding	2	0.479	0.354	(-0.214, 1.172)	1.355	0.176	
Learning path recommendation	4	0.673	0.195	(0.291, 1.055)	3.455	0.001	
Intelligent feedback mechanism	4	0.776	0.055	(0.668, 0.885)	13.997	0.000	
Adaptive learning system	8	0.482	0.115	(0.255, 0.708)	4.172	0.000	
Educational robot	9	0.272	0.093	(0.089, 0.455)	2.918	0.004	
Smart education platform	11	0.610	0.053	(0.506, 0.713)	11.553	0.000	
Intelligent tutoring system	15	0.381	0.056	(0.271, 0.492)	6.784	0.000	

Table 5. The Moderating Effect of the Application Scenario.

		Effect Sizes			Two-Sided Tests		
Application Scenarios	Nos of Effect Sizes	SMD	Standard Error	95% Confidence Intervals	Z Value	p Value	Between-Group Effect
Virtual-reality learning environment	7	0.267	0.077	(0.116, 0.417)	3.447	0.001	Q=15.818 P=0.001
Mobile platform	8	0.599	0.093	(0.417, 0.781)	6.449	0.000	
Offline classroom	15	0.364	0.053	(0.269, 0.468)	6.886	0.000	
Digital platform	24	0.585	0.061	(0.466, 0.704)	9.639	0.000	

moderating variables that affect the effects of AI-assisted personalized learning on student learning outcomes. Thereby, we need to conduct moderation effect tests following the overall effect size estimation.

Research Results

The Overall Effect Size

According to Cohen (2013), the effect sizes of 0.8, 0.5, and 0.2 are large, medium, and minor, respectively. As shown in **Table 2**, the combined effect size in this study is 0.490, approximating 0.5, and the p-value is less than 0.001, indicating that AI-assisted personalized learning has a moderately positive effect on student learning outcomes.

We further delve into the effects of AI-assisted personalized learning on student knowledge, competence, and emotional development. The effect sizes are 0.557 ($p < 0.001$), 0.436 ($p < 0.001$), and 0.268 ($p < 0.001$) for the dimensions of knowledge, competence, and emotional development, respectively (**Table 3**). This reveals that AI-assisted personalized learning has moderately positive effects on students' knowledge and competence development, with a more significant impact on their knowledge development. Nevertheless, its impact on students' emotional development is much weaker. Moreover, the between-group effect size was 12.075 ($p < 0.005$), also displaying significant differences in the effects of AI-assisted personalized learning on various dimensions of student learning outcomes.

Moderating Variables

The Type of Edutech Applications

Table 4 shows the impact of the type of AI-based Edutech applications on the outcomes of personalized learning. The between-group effect size is 41.357 ($p < 0.001$), indicating heterogenous effects of distinct types of Edutech applications. Among the aforementioned applications, virtual reality-based learning produces the strongest effect (SMD = 1.701, $p < 0.005$). Nonetheless, there is only one effect size under this category; the results of this single study are not representative enough to evidence that personalized learning based on this application can generate the best learning outcomes. Except for personalized scaffolding (SMD = 0.479, $p > 0.005$), the rest of the Edutech applications all have positive effects on the outcomes of personalized learning ($p < 0.005$). Among them, the intelligent feedback mechanism shows the largest effect size (SMD = 0.776, $p<0.001$), followed by learning path recommendation (SMD = 0.673, $p<0.005$), the smart education platform (SMD = 0.610, p < 0.001), the adaptive learning system (SMD = 0.482, p < 0.001), the intelligent tutoring system (SMD = 0.381, p < 0.001), and the educational robot (SMD = 0.272, p < 0.005). According to the analysis results, personalized scaffolding does not exhibit a statistically significant effect on the outcomes of personalized learning. This may not be an accurate reflection of the actual impact of this application, as the estimation is based on a very small number of effect sizes (N = 2).

The Application Scenario

We also looked into the heterogenous effects of AI-assisted personalized learning on student learning outcomes in differential learning scenarios. The between-group effect size (15.818, p < 0.005) in **Table 5** exhibits significant heterogeneity in the impact of the learning setting on the outcomes of AI-assisted personalized learning. The mobile platform (SMD = 0.599, p < 0.001) and the digital platform (SMD = 0.585, p < 0.001) had more significantly positive impacts than the offline classroom (SMD = 0.364, p < 0.001) and the virtual-reality learning environment (SMD = 0.267, p < 0.005).

The Educational Phase and Disciplinary Domains

As displayed in **Table 6**, there are modest differences between the effects of AI-assisted personalized learning on learning outcomes of tertiary education students (SMD = 0.573, p < 0.001), primary education students (SMD = 0.437, p < 0.001), and secondary education students (SMD = 0.385, p < 0.001). Yet, the impact of age is not significant, as indicated by the between-group effect size (5.069, p > 0.05).

Table 7 shows that AI-assisted personalized learning has moderately positive effects on student learning outcomes in both science (SMD = 0.481, p < 0.001) and non-science (SMD = 0.502, p < 0.001) disciplines. The disciplinary differences had no significant impact on the outcomes of AI-assisted personalized learning, as supported by the between-group effect size (0.065, p = 0.798 > 0.05).

The Duration of Experiment

Table 8 presents the moderating effects of varied durations of experiments. Three of the studies are excluded from the effect size test on this moderating variable because they do not specify the durations of their intervention. The between-group effect size (Q = 11.200, p < 0.05) produced by this test indicates statistically significant heterogeneity in the impact of the application duration on the outcomes of AI-assisted personalized learning.

Table 6. The Moderating Effect of the Educational Phase.

Educational Phases	Nos of Effect Sizes	Effect Sizes SMD	Standard Error	95% Confidence Intervals	Two-Sided Tests Z Value	p Value	Between-Group Effect
Primary	12	0.437	0.094	(0.254, 0.621)	4.674	0.000	Q=5.069 p=0.079
Secondary	15	0.385	0.057	(0.274, 0.496)	6.776	0.000	
Tertiary	27	0.573	0.062	(0.451, 0.695)	9.193	0.000	

Table 7. The Moderating Effect of the Disciplinary Domain.

Disciplinary Domains	Nos of Effect Sizes	Effect Sizes SMD	Standard Error	95% Confidence Intervals	Two-Sided Tests Z Value	p Value	Between-Group Effect
Science	29	0.481	0.055	(0.373, 0.589)	8.706	0.000	Q=0.065 p=0.798
Non-science	25	0.502	0.063	(0.379, 0.625)	8.018	0.000	

Table 8. The Moderating Effect of the Duration of Experiment.

Experiment Durations (months)	Nos of Effect Sizes	Effect Sizes SMD	Standard Error	95% Confidence Intervals	Two-Sided Tests Z Value	P Value	Between-Group Effect
<1	23	0.339	0.053	(0.236，0.443)	6.410	0.000	Q=11.200 P= 0.011
1 - 3	15	0.579	0.065	(0.452，0.707)	8.892	0.000	
3 - 6	7	0.545	0.117	(0.315，0.775)	4.642	0.000	
> 6	6	0.590	0.088	(0.419，0.762)	6.739	0.000	

Experiments lasting 1-3 months (SMD = 0.579, $p < 0.001$), 3-6 months (SMD = 0.545, $p < 0.001$), and more than 6 months (SMD = 0.590, $p < 0.001$) have moderately positive impacts, as opposed to the modestly positive impacts of the experiments shorter than one month (SMD = 0.339, $p < 0.001$).

Discussion

According to our statistical analysis results, AI-assisted personalized learning can improve the overall learning outcomes of the student, which is supported by the findings of previous studies on this topic (Hu & Wang, 2022; Zhang et al., 2023). The successful integration of AI technology into personalized learning can provide students with a more individualized learning experience, meeting the individually different needs and preferences among them. Our research finding justifies the broad implementation of personalized learning in the context of the widespread application of AI technology.

The meta-analytic results demonstrate that AI-assisted personalized learning has positive effects on knowledge, competence, and emotional development of the student. Specifically, its effect is the most prominent on student knowledge development but the weakest on student emotional development. One possible reason for this gap is that the design and development of educational AI applications are more targeted at facilitating student knowledge acquisition and academic success, resulting in the ongoing optimization of the roles of these applications in enhancing the students' learning outcomes in the dimension of content knowledge development. Another reason may be that current research tends to adopt the self-report questionnaire survey in gathering information for the evaluation of student emotional development. The information is subject to the subjective biases and memory failures of the respondents as well as the influence of social expectations, leading to inaccurate or incomplete research results in this regard. On the contrary, the evaluation of student knowledge development can be conducted by quantitative methods like the standardized test, which has helped increase researchers' interest in this area. In addition, although a few of the studies included in the meta-analysis established emotional variables, such as learning motivation, self-efficacy, and learning satisfaction, for the examination of student emotional development, only one of them (Nugent et al., 2010) made this dimension a focal point of its research. This may be emblematic of the neglect in academia of the effect of AI-assisted personalized learning on student emotional development.

This study also finds that factors, such as the type of Edutech applications, application scenario, and duration of application, can impact the outcomes of AI-assisted personalized learning. This suggests that the improvement of student learning outcomes in personalized study is contingent on a combination of multiple factors. Our meta-analysis shows that the effect sizes of apps that only use one technology, like learning path recommendation and the intelligent feedback mechanism, are slightly bigger than those that use more than one technology, like the adaptive learning system, smart education platform, and intelligent tutoring system. This finding implies that Edutech applications based on integrated technologies may encounter more challenges in data integration, which considerably compromises their overall effectiveness, and that their effects are more likely to be affected by other factors like students' preferences of technology use and teacher engagement, as opposed to the better reception of single-technology-based applications among students because of their easy use and specific focuses. Furthermore, this study finds that the intelligent feedback mechanism is the most effective in boosting the outcomes of personalized learning among all the single technology-based applications. It highlights the significance of instant, individualized feedback for student academic progress, which deserves more in-depth research. Among integrated technology-based applications, the smart education platform has the most prominent positive effect on the outcomes of personalized learning. As stated earlier in the study, the smart education platform helps the teacher administer precision instruction. Hence, teacher engagement may be the primary factor for the outstanding performance of this application. More research efforts are needed to explore the roles of teacher engagement in AI-assisted personalized learning. It is also found that the educational robot has a minor positive impact on the outcomes of personalized learning. Some researchers pointed out that this may be due to the insufficient sensitivity of the data analysis method, leading to the inability to spot the variations between the experimental and control groups (Gode et al., 2014), or due to the inordinately short durations of intervention (Nugent et al., 2010). We suggest that the researchers and educators should extend the time of interaction between the student and educational robot when introducing the latter into personalized learning.

Among the four learning scenarios, the offline classroom has less influence on the outcomes of AI-assisted personalized learning compared with the digital platform and mobile platform. This is because the student enjoys less freedom in learning (e.g., the time limit and susceptibility to disruptions from peers) in the traditional classroom environment, resulting in the constrained effects of the technological intervention on student learning (Beal et al., 2010). In contrast, the student has more autonomy in learning on the digital platform and mobile platform, where they can experience more private and flexible learning patterns. The analysis results show that the virtual-reality learning environment has the least influence on the outcomes of AI-assisted personalized learning, which can be linked to overly short periods of the experiments (most of them only lasted for one week). With such a condition, it is almost impossible to determine the genuine impact of the virtual-reality learning environment on students' long-term learning behavior and outcomes (Divekar et al., 2024). In examining the impact of the duration of the experiment as a moderating variable, we also discovered that duration of less than one month has the smallest effect on the outcomes of AI-assisted personalized learning. Therefore, it is important that educators prescribe adequate lengths of application when using AI technology in student personalized learning to ensure its outcomes.

On the other hand, the meta-analysis results demonstrate that the educational phase and disciplinary domain have little impact on the outcomes of AI-assisted personalized learning. This finding indicates that the role of AI-assisted educational technology in promoting personalized learning is stable and generalizable. It provides justifications for increasing AI application in all disciplines at all educational levels to further enhance instructional quality and student achievements.

Conclusion

This study analyzed the research results of 36 studies in 31 publications using meta-analytic techniques. The research findings show that AI-assisted personalized learning has positive effects on the overall learning outcomes of the student, particularly in the dimension of knowledge development, and those factors, such as the type of AI-based Edutech applications, application scenario, and duration of application, can also impact the outcomes of personalized learning. An important implication of this study is that educators need to pay regard to multi-faceted factors when introducing and implementing AI-assisted personalized learning to reach optimal results. First, they should adopt the type of Edutech application pertinent to the specific needs of the student and characteristics of the discipline to make best use of the application's benefits. Second, it is important to remove disruptive factors in certain learning scenarios in order to improve the outcomes of personalized learning. Third, the application duration of technologies deserves serious consideration; an appropriate length of application is beneficial for the thorough evaluation of the long-term effect of the technology on student learning outcomes.

It is noteworthy that AI-based Edutech applications adopted in personalized learning are far more than these mentioned in our study, but empirical research in this area is inadequate, warranting more attention from academia. Also, the roles of AI-assisted personalized learning in interdisciplinary instruction, which were not addressed in this study, deserve thorough exploration. Furthermore, for more effective application of AI technologies in personalized learning and their deeper integration into the field of education across the board, it is imperative for the researchers to investigate the issues of privacy, security, and digital divides. Equally important is to encourage continuous practical explorations among teachers to improve the implementation tactics for AI-assisted personalized learning to promote the cognitive and non-cognitive development of the student.

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REVIEW

Using the Mixed-Meta Method to Assess Portfolios in Science Teaching

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Abstract*: The purpose of this research is to assess portfolio studies in science education in Turkey. The mixed-meta method, which comprises meta-analysis and meta-thematic analysis methods, was used to assess quantitative and qualitative data through document analysis. Studies retrieved from certain databases within the scope of specific criteria were examined with the CMA and MetaWin tools for meta-analysis, and the effect size was found to be as great as g = 1.005 among the 17 studies included in the analysis. It was concluded that the usage of portfolios in science teaching has a good effect. 13 studies based on document analysis within the framework of the determined criteria were assessed with the Maxqda program using content analysis in the meta-thematic analysis. Themes were created, and certain codes were obtained according to these themes. These are the following themes: the effect of portfolios on academic achievement, classroom environment, and 21st-century skills; negative aspects of using portfolios; and recommendations for using portfolios in science education. It has been concluded that the research findings are consistent, and the usage of portfolios in science education has a favorable impact in a variety of ways.*

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Introduction

THE CONCEPT of learning in the twenty-first century is updated with an understanding that develops and alters on a daily basis. A learning process that overlaps with lifelong learning is deemed vital in the new education paradigm (Tunca et al., 2015). Its goal is to assist students become individuals who can conduct independent research, question, and assess what they have learned from a critical standpoint. In this sense, both teachers and the evaluation system must be revised (Somoncuoğlu & Yıldırım 1998). Traditional assessment takes a result-oriented approach that attempts to quantify how much knowledge is maintained in memory. It looks to be still popular today due to its practical benefits (time, money, and effort). These assessment methods include fill-in-the-blank questions, short-answer questions, true or false questions, matching questions, open-ended questions, and multiple-choice questions (Demirören et al., 2009). In traditional assessment, students are requested to write down all of their knowledge and skills on a test paper in a certain amount of time while under the supervision of at least one instructor (Şahinkarakaş, 1998). This type of assessment has several drawbacks in that it cannot measure high-level skills. This assessment primarily provides for the examination of lower-level skills, which are tested using achievement assessments. The success scores acquired from these assessments cannot indicate the learners' true learning skills, i.e. their experiential dimension (Öncü, 2009). Furthermore, the danger of students learning exam-oriented subjects solely for the sake of the exam and guiding their learning style toward measurement should not be overlooked (Özen, 2011). These drawbacks of traditional assessment have highlighted the necessity for contemporary evaluation. This resulted in the shift from "test logic" to "evaluation logic." In the evaluation logic, there is an assessment in which both the process and the result are considered together. This procedure assures that the student accepts responsibility for his or her own evaluation, that he or she is active, dynamic, self-critical, and cooperative (Tatar & Ören, 2009).

Unlike traditional assessment and evaluation, alternative measurement and evaluation methodologies have acquired traction in contemporary assessment and evaluation. A portfolio is one of these (Demirören, et al., 2009). A portfolio is an evaluation technique that displays students' work and demonstrates their progress throughout the learning process in relation to the targeted goals. It is the collection and organization of student work into a file. This compilation, on the other hand, includes investigations conducted in accordance with established strategies and criteria (Baki & Bilgin, 2004). In other words, students organize their life experiences and reflect them in the form of a collection (Kaptan & Korkmaz, 2000). Portfolios, as opposed to assignments, reinforce themes taught, reflect them in the form of posters or activities, file them, and provide feedback to students (Kutlu, et al., 2008). This is substantially different from previous techniques of attaching files. Because the portfolio exposes all aspects of what the students have done, from the first piece of work to the correction paper, it reflects the learner's own style (Öncü, 2009). In this respect, a portfolio is an achievement bank that reflects students' worksheets, activities they carried out within the scope of the subjects, experiments, project reports, performance notes, evaluation reflective diaries, and other learning skills they acquired during the learning process (Şenol & Güzeller, 2007; Turan & Sakız, 2014). Furthermore, it contains video recordings, images, personal drawings, written notes, audio tapes, and stunning audio-visual materials (Turan & Sakız, 2014). Thus, the portfolio enables both the teacher and the student to track their own progress through the educational process. It not only allows students to review their work with honesty and demonstrate how it can reflect their own beliefs, but it also allows their classmates to examine these files and see alternative perspectives (MoNE [Minister of National Education], 2006). With samples from their work, the portfolio illustrates what pupils know and how they know it. This supports the premise that students should approach their education with a creative and critical mindset in order to promote their future learning. Portfolios boost self-esteem by empowering students to take charge of their own education (Betty, 2012). Furthermore, the portfolio fosters and documents high-level cognitive skills. Based on this, it might help to make critical decisions by establishing which areas the student is talented in through the studies he or she submits (Turan & Sakız, 2014).

Duschl and Gitomer (1997) investigated the impact of portfolios on science education in their project. They studied how portfolios may be constructed and used in science classes for secondary school students in their project termed Project SEPIA (Science Education through Portfolio Instruction and Assessment). During this process, they came to the conclusion that "the teacher's activities and decisions" are the most essential factors in establishing quality and success in teaching. Feedback is an essential component of portfolio-based teaching in science education. According to Oğan-Bekiroğlu (2004) providing feedback on the material learnt is more crucial than repeating and comprehending it. Because it is assumed that information is organized in this manner. Therefore, a portfolio technique without feedback is nothing more than a collection of files containing completed work (Kutlu et al., 2008). Portfolios must be evaluated and monitored at regular intervals within the framework of a specific plan. Again, the teacher should notify the students of their progress in the portfolios they are following because the mutual interaction between teacher and student is essential in this method. Correct and effective feedback helps the student see her or his shortcomings, mistakes, and weaknesses, as well as her or his strengths (Turgut & Baykul, 2011).

The portfolio contains a wide range of research. Portfolios, according to a Deniz-Kan (2007) study, allow students to make self-criticism, which in turn allows them to develop self-esteem, self-confidence, and self-evaluation. Thus, it was determined that a preschool child’s individual achievement improves. Birgin (2008) used a portfolio, an alternative evaluation approach, to assess pupils in the seventh grade of primary school in mathematics courses. It was determined that the students provided positive comments as a result of the portfolio application. Simultaneously, it was determined that the student offered thorough information to herself or himself and her or his teacher, as well as establishing dynamic communication between teacher and student. Gülbahar-Güven and Köse (2006) explored the effects of adopting electronic portfolios in the evaluation of education for prospective teachers in their study. An e-portfolio was employed in a project-based teaching style course for teacher candidates. The candidates’ comments were gathered, and it was found that this technique had numerous advantages. Bahçeci and Kuru (2008) studied the impact of portfolio application on undergraduate students’ self-efficacy and life skills. In this study, contemporary and conventional assessment methods were contrasted. As a result, it was determined that the portfolio technique used in the human anatomy course is beneficial for teaching. İzgi and Güçlüm (2012) employed a quasi-experimental technique on 66 eighth grade primary school pupils in their study. They sought to look into the impact of portfolio assessment in science education on exam anxiety and learning retention. According to the study’s findings, there is a statistically significant association between the persistence of learning and test anxiety in the experimental group *v.s.* the control group to whom the portfolio was applied. Looking at all of these researches, it is clear that the impact of portfolios on science education cannot be overlooked.

The Importance of the Research

The conditions demanded by the new era include not only having information and abilities, but also transferring and applying these knowledge and skills in one’s life. Therefore, in today’s educational paradigm, ideas like communication skills, technological literacy, argumentation, and so on come to the fore. These new ideas prompted the development of new programs, methodologies, and, as a result, a new measurement-evaluation functions. Different evaluation procedures, i.e., alternate measurement and evaluation, were required in this case (Ünal, 2019). A portfolio is one of these different assessments. Portfolios have evolved and changed throughout time. While it was once merely one of several alternative measuring and assessment procedures, it has gradually evolved into an instructive method. Instead of relying solely on the assessment of the student, this method considers the student's activity in the educational environment as well as the quality of instruction (Challis, 2001). This alteration in the portfolio has also received attention in the sphere of science education. According to Duschl and Gitomer (1997) with the recent acceleration of change in the field of science education, it is critical that students acquire high-level abilities and that education emphasizes this. It was stressed in this regard that present teaching methods should be examined, and portfolios should be used for this purpose. As a result, presenting the current situation of the studies in the portfolio will allow us to see the advantages and disadvantages in their entirety. In this approach, it is hoped that future research will be more qualified and will contribute to instructional evaluation efforts.

Purpose of the Research

The purpose of this research is to assess portfolio studies in science education in Turkey. For this purpose, answers were sought to the following questions.

(1) In the research included in the meta-analysis, what is the effect of portfolio applications in science education on students' academic success?

(2) According to the participants' views on PBL uses in science education, what are:

- The effect of portfolios on academic achievement?
- The effect of portfolios on the classroom environment?
- The effect of portfolios on 21st-century skills?
- Negative aspects of the portfolio?
- The recommendations for the portfolio?

Method

A mixed-meta method with two stages was employed in this research to investigate the effectiveness of portfolio use in science education. It was used to determine the effectiveness of portfolio application in science education, with meta-thematic in the qualitative dimension and meta-analysis in the quantitative dimension. The mixed-meta method is one that employs both verbal and numerical data. In other words, it is a method that combines the quantitative method with numerical data with the qualitative method with verbal data (Alkan et al., 2019). In the mixed-meta method, quantitative data is analyzed using CMA/MetaWin tools, and qualitative data is analysed using Nvivo/Maxqda programs. It provides the opportunity to combine and examine the products obtained from the programs (Batdı, 2020, p.3). The mixed-meta method is a combination of meta-analysis and meta-thematic methods based on document analysis (Batdı, 2021, p.1218). The analysis approach in this research, which used the mixed-meta method, is divided into two categories: meta-analysis and meta-thematic analysis.

Meta-Analysis Process

Meta-analysis is used to create the same and similar research in addition to performing a thorough literature review. As a result, it is possible to integrate various study data and synthesize them using an objective manner (Göçmen, 2013).

Data Collection Process

In this research, the Higher Education Council (HEC) and Google Scholar databases in English and Turkish were searched using keywords such as “portfolio use in science education, the effect of portfolio use on success in science education” to find studies on the use of portfolios in science education in the literature. Certain inclusion criteria were taken into account in the screenings. In this context, it was critical that the research be published at the national level to investigate the influence of portfolio use in science education and on learners’ academic achievement. In addition to these criteria, the arithmetic mean, number of samples, and standard deviation (x, n, SD) values required for meta-analysis were carefully considered. Those who did not match these requirements were excluded from the study. As a result of taking specific criteria into account, a total of 42 studies—24 theses and 18 articles—were reached, and 13 out of 24 theses and 4 out of 18 articles—a total of 17 studies—were included in the meta-analysis. The process of including these studies in the analysis is presented in the PRISMA flow diagram in **Figure 1**, together with the studies included in the meta-thematic analysis.

Several researches on the use of portfolios in science teaching were discovered when scanning various databases. A total of 42 studies were identified for meta-analysis, with 30 studies for meta-thematic analysis. Meta-thematic analysis took into account the databases, year range, and study publication status that were considered in the context of meta-analyses. However, in the meta-thematic analysis, qualitative studies based on participant opinions regarding the use of portfolios in science education were included in the analysis.

Due to duplication, 25 of the studies accessed were excluded from the meta-analyses. The remaining 17 studies were analyzed. For meta-thematic analysis, 17 papers were removed because their topics were irrelevant, whereas 13 studies were included. The remaining studies were

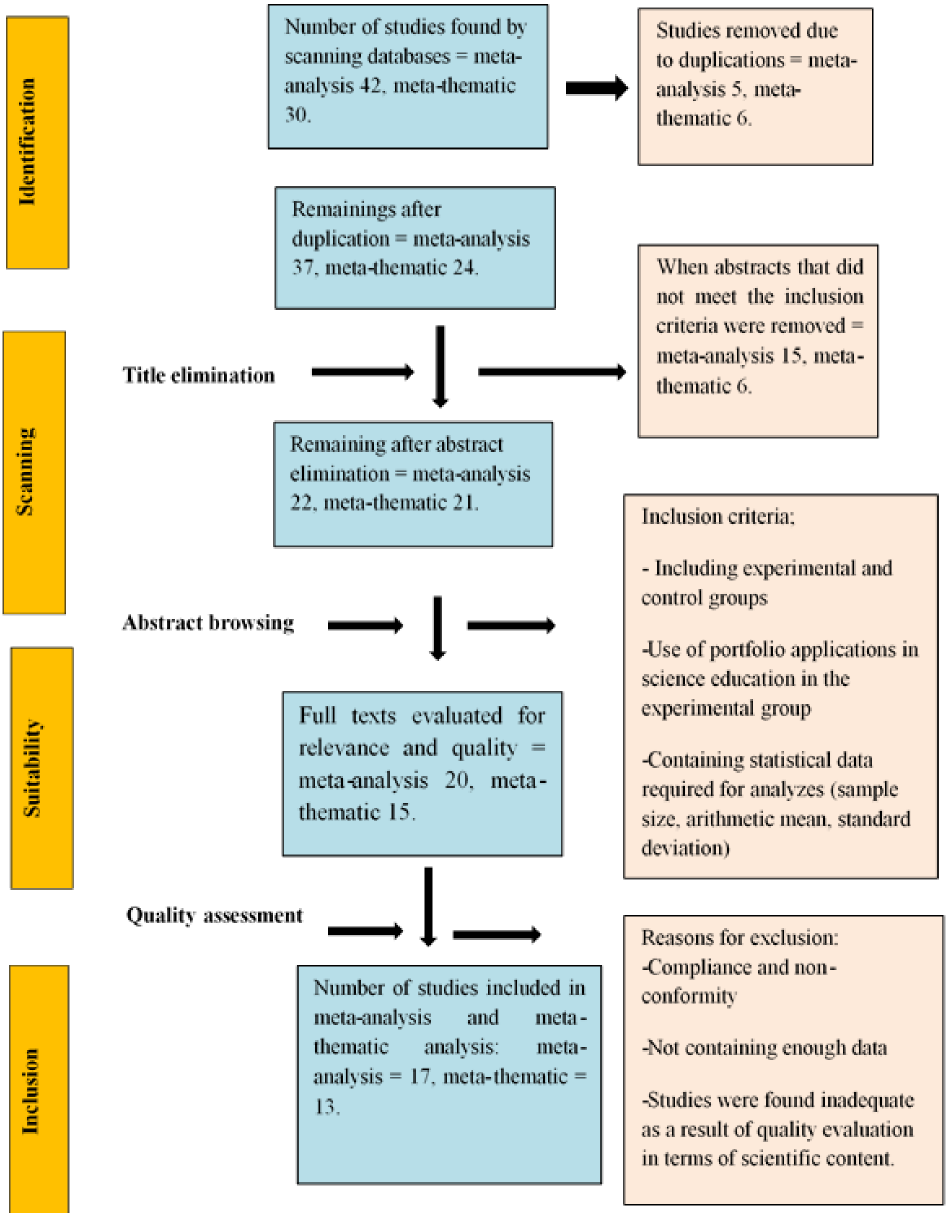

Figure 1. The Process of Studies Included in the Analysis.

chosen based on a variety of study criteria, including suitability, sufficient data content and scientific quality, as shown in **Figure 1**, using meta-analysis and meta-thematic analysis. At this stage, it is necessary to evaluate the quality of the studies and check their compliance with the level of scientific competence in order to achieve quality study results and make original and unique contributions to the field. In this regard, emphasis was placed on presenting the studies in an unbiased, systematic, and organized manner, as well as ensuring their relevance and originality. As a consequence of extensive reviews, studies appropriate for meta-analysis and meta-thematic analysis were included in the analytical process.

Data Analysis

The meta-analysis data were analyzed using MetaWin and the CMA 2.0 programs. The g value obtained was interpreted using Thalheimer and Cook's (2002, p.4-9) level classification. Thalheimer and Cook (2002, p. 3–9) defined the impact level as: -0.15 ≤ Cohen's d < 0.15 at a minor level; 0.15 ≤ Cohen's d < 0.40 at a small level; 0.40 ≤ Cohen's d < 0.75 at a moderate level; and 0.75 ≤ Cohen's d < 1.10 at a large level; 1.10 ≤ Cohen's d < 1.45 were classified as very large level, and 1.45 ≤ Cohen's d as excellent level. The effect size is important in meta-analysis since it helps determine the effect value of the independent variable on the dependent variable.

Meta-Thematic Analysis Process

In the second dimension of the research, it was aimed at obtaining rich data by combining the findings of qualitative research and performing meta-thematic analysis. Meta-thematic analysis takes place based on document analysis. In meta-thematic, coding created with specific criteria is summarized into specific categories, with the goal of generating holistic results by revealing specific themes (Büyüköztürk et al., 2018 p.259-260). As a result, the research conducted attempted to acquire comprehensive data about the study through meta-thematic and meta-analysis.

Data Collection and Analysis

Document analysis was used in this research to acquire data on the effectiveness of portfolio use in science education. Document review is defined as the process of reading, reviewing, querying, analyzing, and methodically carrying out the documents collected through a literature review of the primary and secondary sources that comprise the study's data set. Document review allows you to make sense of the data you've gathered, assess it, and synthesize it (Özkan, 2021 p.2). The contents of the studies that met the qualitative requirements were reviewed in the research, and their common points were discovered. When selecting common points, structural and semantic similarities in the data were taken into account. These common points were classified and reinterpreted. The meta-thematic analysis includes

13 studies. These studies were analyzed using the Mawqda-11 qualitative data analysis program.

Coding

The papers included in the research were examined in the meta-thematic analysis dimension, and themes were produced with the requisite coding. Coding is the process of categorizing information. The researcher selects his or her own categories in published papers and theses by focusing on his or her own study subject (Büyüköztürk et al., 2018, p.261-262). The codes obtained in this research were analysed with the Maxquda-11 program. As a result of the analysis, the coding was grouped into five themes. Models were created by grouping portfolios under five themes: "The effect of portfolios on academic achievement", "The effect of portfolios on the classroom environment", "The effect of portfolios on 21st-century skills", "Negative aspects of the portfolio" and "The recommendations for the portfolio". The research theses were coded by writing the thesis number and page number side by side (example: 123456, p.32).

Reliability in the Meta-Thematic Analysis Process

It is a well-known truth that capturing objects in qualitative research is challenging. Therefore, qualitative researchers use a range of strategies to increase the "credibility" of their findings (Merriam, 2013, p.205). One of these is triangulation, which is the comparison of the findings of two or more data gathering methods or two or more data sources (Başkale, 2016). In this research, two of the authors worked together from the beginning to the end of the research and exchanged ideas during the data collection, analysis, interpretation, and reporting processes.

Expert review is another view. It contributes to credibility when an expert who is knowledgeable about the subject of the research and methodology reviews the article and gives recommendations (Merriam, 2013, p210). Throughout the analysis, coding, and interpretation of the study, a second expert researcher provided constant opinions, and required arrangements were made within the framework of these opinions.

Results

The findings of the quantitative (meta-analysis) and qualitative (meta-thematic) analyses are reported under subheadings in this section of the research. First, the interpretation of meta-analysis data from studies on portfolio use in science education is addressed in this context. Following that,

Table 1. Meta-Analysis Findings.

			95% Confidence Interval		Heterogeneity		
Models	N	G	Lower	Upper	Q	P	I
SEM	17	1.086	0.957	1.214	389.971	0.000	95.897
REM	17	1.692	1.041	2.343			

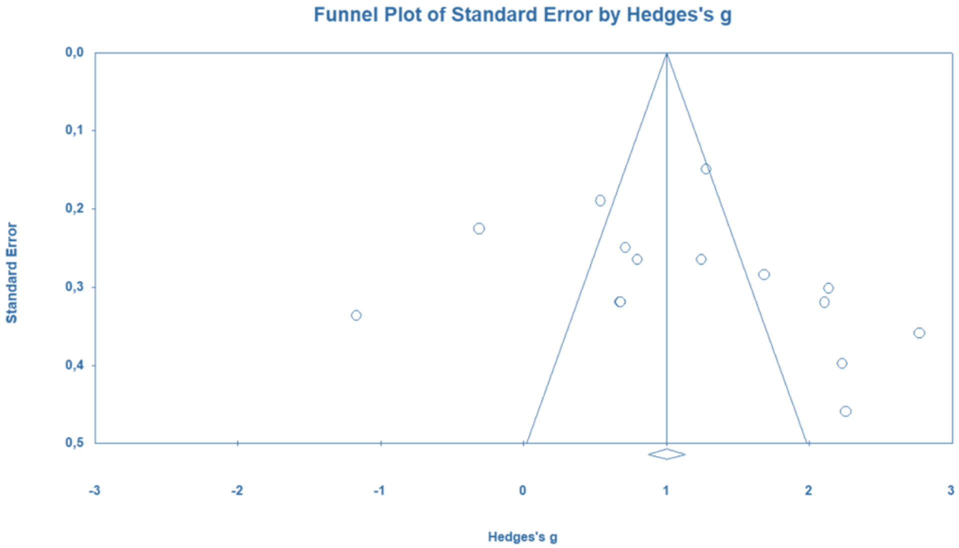

Figure 2. Funnel Plot Chart.

the findings and comments derived from the meta-thematic analysis of the study undertaken on the subject are included.

Meta-Analysis Results

Table 1 summarizes the findings, including meta-analysis data. The effect level according to REM was calculated as 1.692 [1.041; 2.343], and this effect level was assessed as 1.45 Cohen’s d according to Thalheimer and Cook’s (2002, p.3-9) classification in Table 1. This value obtained is at an excellent level, and it has been determined that the use of portfolios in science education has a positive effect on the academic achievement of students.

The graph in **Figure 2** is a summary of the meta-analysis data generated with the MetaWin and CMA data analysis programs, and it includes a funnel plot illustrating publication bias in addition to being

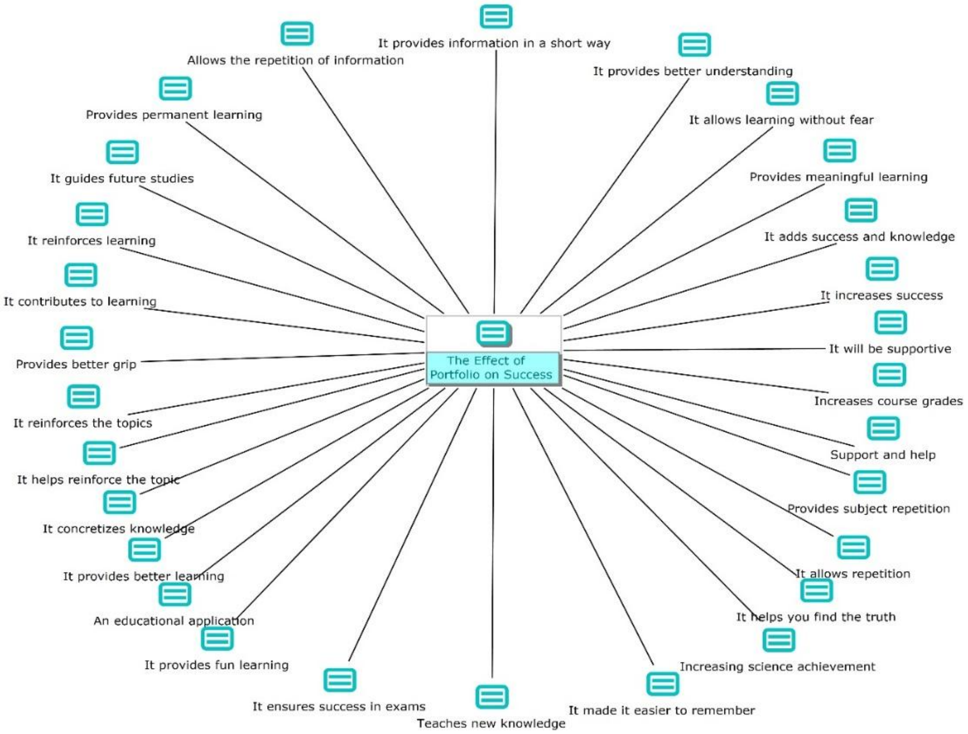

Figure 3. The Effect of Portfolios on Academic Achievement.

analyzed in a visual dimension (Cooper, et al., 2009, p428). Data gathered using the Meta Win and CMA analysis programs sometimes reveal scattering (Borenstein, et al., 2009). On the other hand, a funnel plot chart is given to show whether there is a publication bias. The 995 value obtained as a result of the calculations in the research indicates the error protection number used to reduce or eliminate the bias that occurs in the meta-analysis [Fail Safe (FSN)] (Rosendhal, 1979, p.638).

According to the study that revealed the number of FSNs, the influence of bias can be minimized by incorporating 995 additional papers in the scope of the meta-analysis. However, when the number of 995 obtained by calculating the number of studies included in the meta-analysis is evaluated, it is interpreted that the FSN value for the current study is a high value that cannot be achieved, and that the analysis is quite reliable, given that there is no publication bias (Cheung & Slavin, 2011, p.288).

Findings Regarding Meta-Thematic Analysis

Data from meta-thematic analysis are given in this section of the research. For the data, many codes and themes are provided. The investigation resulted in five themes for the use of portfolios in science education: *The effect of portfolios on academic achievement, the effect of portfolios on the classroom environment, the effect of portfolios on 21st-century skills, Negative aspects of using portfolios* and *Recommendations for using portfolios*. Models were created for these themes and codes. The models are presented, and they are backed up by quotes from the sources from which the codes are taken.

Figure 3 shows the codes associated with the theme of the effect of portfolios on academic achievement in scientific education. Under the theme of the impact of a portfolio on academic success, it provides such codes as *permanent learning, contributes to learning, provides better comprehension, provides mental visualization, reinforces subjects, provides the opportunity to apply what we have learned, is useful in understanding and interpreting information, ensures subject* reinforcement, concretizes knowledge, provides better learning, and provides meaningful learning, among others. In page 121 of the source code 442974, it says "*I think the portfolio is effective in reinforcing what we have learned; I think it is more permanent when we do it by applying it and adding things ourselves; I think it increases our creativity and skills.*" On page 192 of the source code for 373632, it states: *"First of all, I think it is useful; because our homework is not forgotten; we look at each other's with ease; I also find the process good"*. On page 119 of the source code 313929, it states: *"Yes, it is necessary; because it prevents him from forgetting the information he has learned; yes, children's education level improves faster"*. On page 96 of the source code 199552, it says: *"it had an impact on the exams; it had an impact on questions at school; with his influence, we entered many competitions, we organized competitions, we conducted experiments, we held a competition about static electricity, and thanks to this study, we learned the impact of electricity and technology on human life."* The usage of a portfolio, as demonstrated by the phrases, reinforces learning, ensures permanent learning, prevents material from being lost, raises the level of education, and ensures exam achievement. Other detailed codes regarding the effect of portfolios on academic achievement can be seen in the model in **Figure 3**.

Figure 4 shows the codes under the theme of the impact of portfolios on the classroom environment. Some of the codes belonging to this theme are listed as follows: It makes them enjoy the course; it has peer evaluation; it provides an exchange of ideas; it provides feedback; it provides feedback opportunities; it makes them love the science course; it enables them to be active in the lessons; and it enables the exchange of ideas. On page 121 of the source code 442974, it states: *"Portfolio evaluations are a suitable method to receive feedback; they enable students to review their portfolios themselves, see their shortcomings, mistakes, or areas where they did very well, and chart their own path in their next work"*. On page 118 of the

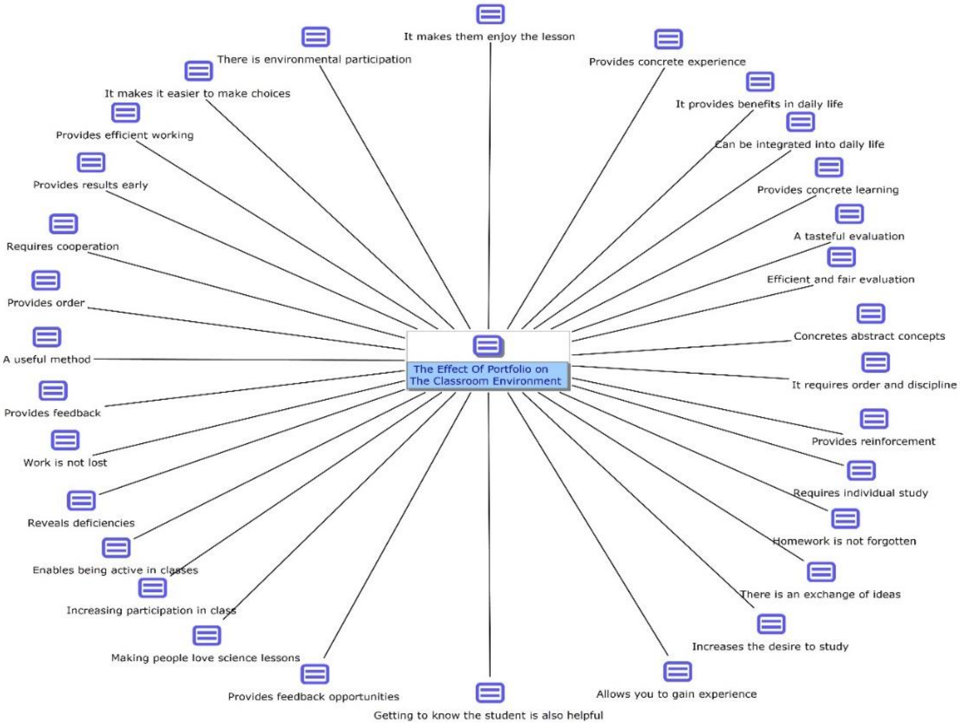

Figure 4. The Effect of Portfolio on the Classroom Environment.

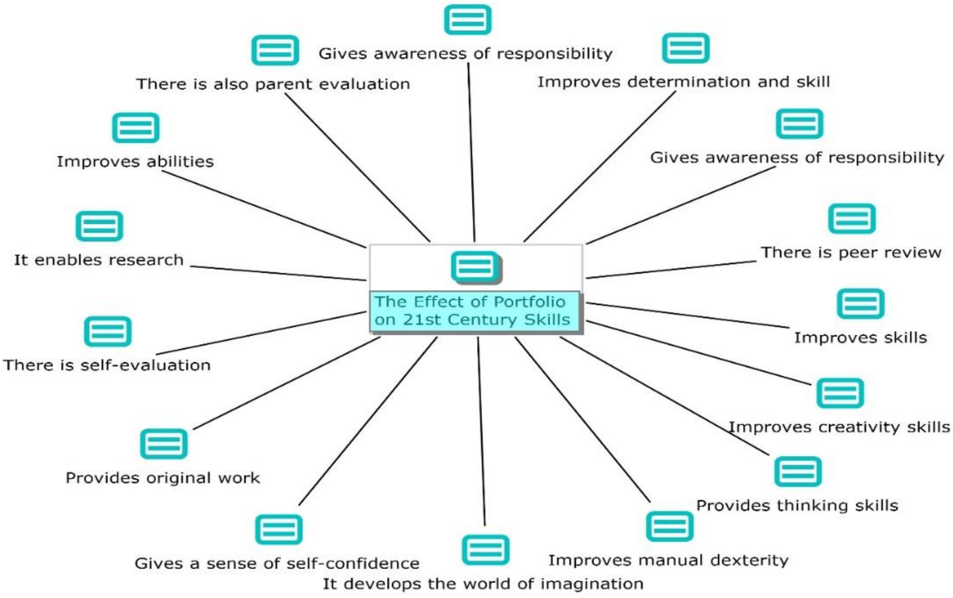

Figure 5. The Effect of Portfolios on 21st-Century Skills.

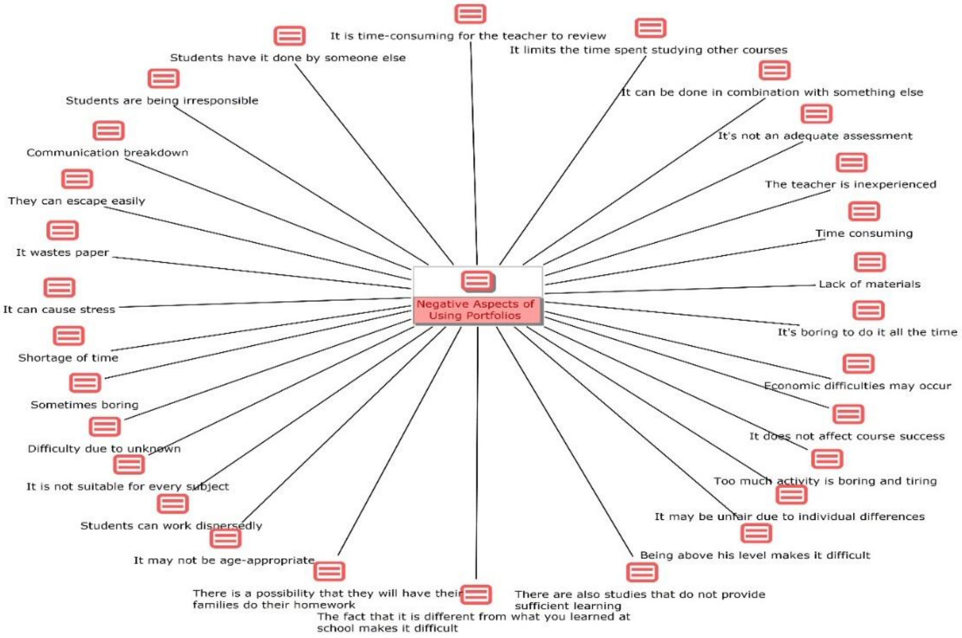

Figure 6. Negative Aspects of Using Portfolios.

source code 313929, it says *"I think it is necessary because having the skills together in a file is useful for me to learn what the student does annually and what stages he/she has gone through."* On page 96 of the 199552 source code, it states *"We can prepare the file at home and come and explain the topic in science class; its biggest contribution is that it helps people who do not like science to love it; we saw this in our class: if even a disorganized person like our friend named T. keeps a file, everyone else keeps a file."* As seen in the sample expressions, using a portfolio gives feedback, helps them understand their flaws, guides future studies, and can be said to make kids enjoy science lectures. **Figure 4** shows further codes from this theme in greater depth.

Figure 5 shows the codes related to the theme of the impact of portfolio use in science education on 21st-century skills. Some codes related to the theme of the effect of portfolio use on 21st-century skills are: *"It enables research; develops creativity skills; gives awareness of responsibility; develops manual dexterity; develops the world of imagination; develops determination and skill; there is self-evaluation; develops talents; provides thinking skills; self-esteem; it gives a sense of trust and awareness of responsibility."* In the source code 313929, page 118, it says, "I believe that our students develop their talents and thinking power better in this way, and yes, I think it is necessary; the student becomes responsible." In the

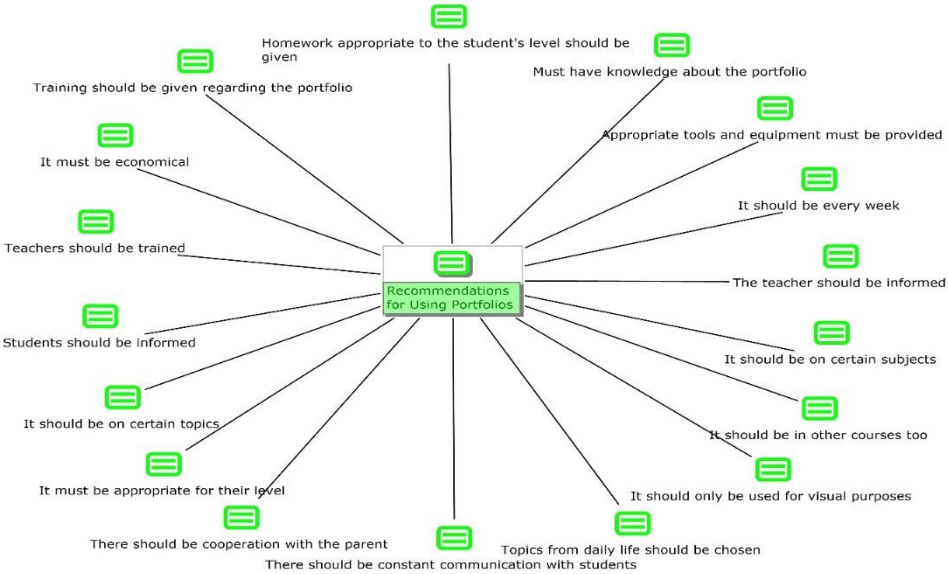

Figure 7. Recommendations for Using Portfolios.

source code 373632, page 200, it says, *"It is nice to evaluate and be evaluated; I can prepare myself accordingly."* In the source code for 442974, page 121 states, "I think the portfolio file is effective in reinforcing what we have learned; I think it is more permanent when we do it by applying it and adding something ourselves; I think it increases our creativity and skills." The sample expressions show that using a portfolio improves responsibility, develops creativity, increases abilities, and gives chances for self and peer evaluation. **Figure 5** depicts further codes from this theme in greater detail.

Figure 6 shows the codes related to the theme of negative aspects of using portfolios in science education. Codes that deal with the negative aspects of employing portfolios were as follows: *"Time-consuming; lack of materials; students being irresponsible; time-consuming for the teacher to review; lack of communication; students working in a disorganized manner; waste of paper; may not be age-appropriate; may cause stress; they can take it easy; economic difficulties may occur; and being above his level makes it difficult."* In the source code, page 121, it says *"I think portfolio evaluation is a really good exercise for some courses and applications; but I have come to the conclusion that there is a problem with doing this at very frequent intervals; I don't think it's right to have it at the end of every subject; because not every subject may be suitable for portfolio evaluation work."* The source coded 313929, p.133, states, *"Sometimes, when homework is given at a level that the student cannot do, the burden falls on us."* On page

86 of the source coded 330160, it says, *"Students acting lazy; not taking responsibility; the teacher does not care about this issue with the students."* As seen in the sample expressions, it can be said that the use of a portfolio may not be suitable for every subject, it may not be suitable for the student's level, and it has negative aspects such as the student not taking responsibility. **Figure 6** shows further codes from this theme in greater depth.

Figure 7 shows the codes related to the theme of suggestions for the use of portfolios in science education. Codes for recommendations for using portfolios are as follows: *"One should have information about the portfolio; training should be given about the portfolio; students should be informed; teachers should be trained; teachers should be informed; homework appropriate to the student's level should be given; appropriate tools and equipment should be provided; it should be on certain subjects; cooperation with the parents should be done; and there should be constant communication with students."* In the source coding 373632, p.202, it says *"In mathematics class... because I am not good at mathematics." I was successful in both social work and science. I also want to be successful in maths."* On page 80 of the source code for 330160, it states: *"First of all, we need to have very good knowledge about the portfolio; education for this is not provided at a sufficient level at the university; it is used in schools as much as we know, but in order to apply this effectively at school, we must first know what it is; collaborating with parents on issues by drawing students' attention and being in constant communication with students in this process."* On page 127 of the source code for 442974, it states *"The process was very good; but I think that if it were done not every week, but in the weeks when certain subjects are covered, the student would not get bored of doing it all the time and more creative things would come out."* Suggestions for using the portfolio are seen in the sample statements, such as: it should be used in other courses; one should have knowledge about the portfolio; and one should be familiar with certain subjects. **Figure 7** depicts further codes from this theme in greater detail.

Conclusion and Discussion

This study was conducted based on the mixed-meta method and is research that deals with the analysis of quantitative (meta-analysis) and qualitative (meta-thematic) data within the scope of document analysis. In the first part of the document analysis method in which the study was carried out, quantitative data were examined and presented with meta-analysis, and in the second part, qualitative data were examined and presented with meta-thematic analysis. The mixed-meta study enabled an attempt to comprehend the large picture, that is, a meaningful picture, of the issue. First, a meta-analysis of portfolio studies was performed in this study. Following that, the literature was used to examine and interpret the meta-thematic data collected under the themes of the effect of portfolios on academic achievement, classroom environment, 21st-century skills, negative effects of using portfolios, and recommendations for using portfolios. In this context, the meta-analysis comprised 17 papers, while the meta-thematic analysis included 13 researches.

When we examined the meta-analysis data, it was concluded that portfolio, which is one of the contemporary evaluation techniques in science education, has a positive effect on the learners (g = 1.005), considering the studies on academic achievement in learning. Based on this, it has been revealed that the evaluation technique applied to the experimental group was portfolio, which had a positive effect on academic success in science education when compared to the traditional evaluation technique applied to the control group. According to Thalheimer and Cook (2002, p.4-9)'s impact level classification, the impact value (g = 1.005) exhibits a positive and significant trend. When the findings of the meta-thematic analysis, which comprise the second part of this study, were investigated and evaluated, relevant codes and themes were developed by scanning the portfolio research, which is one of the evaluation approaches in scientific education. The analysis was modelled in accordance with these codes and topics. When the modelling is analysed in this context, it is discovered that the portfolio is an effective evaluation technique for learners' academic achievement. When we look at the literature, there are many studies (Turan & Sakız, 2014; Birgin, 2008; Okan, 2005; Bedir et al., 2009; Saylan et al., 2019) that show portfolios have a positive effect on the academic success of learners. It was discovered that the findings of this research support the literature and that the portfolio improves students' academic progress. When we examine the meta-thematic data, we see that codes like reinforce learning, provide permanent learning, provide better learning, boost success, and provide meaningful learning support the meta-analysis findings and relevant research or literature. This is because the portfolio encourages students to be creative and critical thinkers while also supporting their future learning with more qualified studies (Betty, 2012). These impacts are readily seen in the codes acquired from this research.

Ayaydın and Yıldız-Ayaydın (2016) conducted a secondary school study in which they investigated students' and parents' opinions on building a product (selection) portfolio in the social studies course. And they came to the conclusion that, based on the students' perceptions, the portfolio delivers meaningful learning, ensures permanent learning, reinforces what they have learned, and promotes success. Güven and Aydodu (2008) conducted a semi-experimental application of the portfolio evaluation technique on the sixth grade science and technology course's "systems in our body" unit. The portfolio approach was used to teach the course in the experimental group, while the traditional technique was used in the control group. According to the application results, the students' capacity to express themselves, confidence, responsibility, and cooperation abilities in the experimental group were more effective than in the control group. Portfolio evaluation methodologies are utilized to measure 21st century abilities (group work, communication, and leadership), according to a study conducted by Soland, Hamilton et al., (2013). Yalçın (2018) conducted a study with the goal of defining 21st-century talents and the methods used to measure them. For these purposes, the portfolio technique was examined, and according to this study, it was concluded that the portfolio technique developed the 21st-century skills of the students. Some of the codes in the data collected by meta-thematic analysis in this current research support these studies of relevant literature, such as enhancing creativity skills, improving thinking abilities, delivering original work, and gaining responsibility skills.

Ülker et al., (2021) conducted a study on science teacher candidates in which they were asked about the usability of the e-portfolio system, its positive and negative elements, and the application process. Accordingly, it was concluded that it has negative aspects such as being exhausting, making it difficult to access the internet, and not being face-to-face. The research conducted by Öncü (2009) mentions both the positive and negative elements of portfolios. Accordingly, it is found that the bulk of the works in the portfolio were done by the student herself, that the portfolio was economically costly, and that it was difficult to store spatially. Some of the codes in the data gathered from this current research support these literature-related findings, such as the potential of having their relatives do their homework, the fact that it is different from what they learned in school, and the lack of communication. Avan and Şahin (2020) conducted research on teachers' views on the usage of peer coaching and portfolio strategies in classroom supervision. In accordance with these viewpoints, it has been determined that portfolio methods can be used to address issues that teachers have in the classroom, that they can be utilized as a professional control and development tool, and that the employment of democratic approaches such as portfolios can be encouraged. Similar findings were achieved in this current research and related studies in the literature, implying that portfolio training should be provided, teachers should be taught, and they should be incorporated in other courses as well.

In conclusion, meta-analysis is utilized to design similar research in addition to doing a thorough literature review. In this way, it is possible to integrate various study data and synthesize them in an objective manner (Göçmen, 2013). Meta-thematic analysis is based on document analysis. Codings developed with certain criteria are summarized in specific categories, with the goal of achieving comprehensive findings by disclosing specific themes (Büyüköztürk et al., 2018, p.259-260). As a result, the current research was undertaken with the goal of acquiring holistic data about the subject through meta-thematic and meta-analysis. The mixed meta method allows the studies to present their broad aspects in a meaningful totality (Batdı, et al., 2021). Based on this, it is recommended that different assessment and evaluation methods and techniques, which have an important place in education, be carried out with the mixed-meta method. Only papers about the effect of portfolios, which is one of the assessment methodologies in scientific education in Turkey, were included in the review for this study. Therefore, it is recommended that the review contain various issues based on studies and sources completed in other countries. It is possible to establish which components of the portfolio have been investigated and analyzed from various perspectives by comparing studies and sources in Turkey and other countries. Furthermore, because the portfolio is a particularly effective evaluation approach, it is advised that both students and teachers receive training on how to use it more effectively. However, the teaching environment should be designed accordingly, without ignoring the limitations of the portfolio.

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