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Research article

Enhancing physics problem-solving skills through guided discovery and scaffolding strategies: Evidence from Saudi technical colleges

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Abstract: Problem-solving skills empower students to deal with challenges efficiently, think critically, and craft effective solutions. This translates to their academic success and fosters their adaptability, resilience, and critical thinking, all required to thrive in the ever-changing professional world. This study investigates the effectiveness of guided discovery and scaffolding strategies in enhancing problem-solving skills among students in Physics courses in Saudi technical and vocational colleges. Those pedagogical strategies aim to create higher-order thinking skills required for problem-solving within technical and science education, as well as in the professional life that the students must live after leaving college. Correspondingly, we designed a quasi-experiment with a pre- and post-intervention assessment involving 104 students enrolled in a Physics course within a technical diploma program. The results indicated a significant difference in students' problem-solving skills between those instructed in the traditional teaching condition and those who received guided discovery and scaffolding strategies as major instructional components. The findings suggest that guided discovery and scaffolding improve students' problem-solving skills and promote their engagement and motivation to develop effective solutions. This study contributes to developing existing literature on successful teaching strategies in technical and science education. It also provides practical implications for educators seeking to establish problem-solving competencies among students.

Keywords: problem solving, scaffolding strategies, guided discovery, science education, technical education

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1 Introduction

In today's rapidly evolving technological landscape, the ability to solve complex problems is paramount for students in technical and vocational education. Problem-solving capabilities involving critical thinking, analytic reasoning, and application of knowledge to practical contexts are what will make them successful in technical fields. As highlighted by Jonassen (2011) and Snyder and Snyder (2008), these skills enable students to adapt effectively to real-world challenges and contribute meaningfully to their professional domains. Moreover, these skills encourage a questioning mindset and the ability to think critically among the students.

Technical education emphasizes preparing students to address complex, realistic problems within their disciplines. Problem-solving proficiency requires analyzing situations, devising alternatives, and implementing effective strategies. This not only fosters professional success but also drives technical innovation (Hmelo-Silver, 2004). Given the fact that technical fields are constantly evolving, problem-solving helps students think creatively and come up with innovative solutions to emerging challenges. However, developing these skills within educational settings remains challenging, particularly when traditional teaching methods fail to engage students or equip them with the tools to address real-world scenarios (Xu et al., 2023).

Physics, as a foundational discipline in technical education, plays a critical role in equipping students with these competencies. Physics not only provides theoretical knowledge but also underpins the practical applications crucial for technical industries, such as engineering, manufacturing, and energy systems. It fosters the ability to analyze systems, model real-world phenomena, and apply principles to solve complex problems (Garrett, 1987). For instance, understanding concepts such as force, energy, and motion is integral to troubleshooting machinery, designing efficient systems, and optimizing industrial processes. These skills are particularly relevant in the context of Saudi Arabia's Vision 2030, which emphasizes workforce development and economic diversification, requiring a technically proficient and adaptable workforce (Vision 2030, 2016).

Despite the centrality of Physics in technical education, traditional teaching methods often fail to engage students or equip them with the tools to address real-world scenarios. Conventional approaches focus on rote memorization of formulas and theoretical principles, limiting opportunities for active learning and critical thinking (Al-Harbi, 2011). This disconnect between pedagogy and practical application poses a significant challenge to developing problem-solving skills in Physics.

Guided discovery and scaffolding strategies have emerged as promising approaches to address this educational gap. Guided discovery learning involves providing students with opportunities to explore and construct knowledge actively, with guidance from instructors to facilitate the learning process (Mayer, 2004). Scaffolding, on the other hand, refers to the support provided by educators to help students achieve higher levels of understanding and skill acquisition than they would independently (Wood et al., 1976). Accordingly, these strategies have enhanced students' cognitive development and problem-solving abilities (Belland et al., 2017).

Saudi Arabia's technical colleges are uniquely positioned to benefit from these pedagogical approaches. With the country's emphasis on diversifying its economy and developing a skilled workforce, enhancing the problem-solving skills of students in technical education is crucial (Vision 2030, 2016). Moreover, previous studies have highlighted the need for innovative teaching methods to improve educational outcomes in the region (Al-Harbi, 2011; Al-Zahrani, 2015). However, there is a paucity of research specifically examining the impact of guided discovery and scaffolding in this context (Enijuni, 2022).

This study aims to fill this gap by investigating the effectiveness of guided discovery and scaffolding strategies in enhancing problem-solving skills among students in Saudi technical colleges. Therefore, by employing a quasi-experimental research design, this study seeks to provide a comprehensive understanding of how these pedagogical approaches influence students' cognitive abilities and overall learning experiences.

1.1 Guided discovery learning

Guided discovery learning has become an effective instructional strategy that balances student autonomy with instructor guidance. Guided discovery is the model of cognitive learning that develops the teaching of students under the teacher's guidance by preparing a situation that can make students actively discover their knowledge to solve complicated and abstract concepts. This learning model is related to inquiry-based, problem-based, and constructivist learning. It is useful for students of low learning outcomes levels to independently, systematically, critically, and logically build knowledge, attitudes, and skills (Muhali et al., 2021).

Guided discovery is also known as an inductive approach (Prince et al., 2006). At this stage, it is essential to distinguish between deductive and inductive reasoning. The learning method of guided exploration sits somewhere on the continuum between learning focused on the students and education centered on the instructor (Villanueva, 1976). Students are presented with introductory challenges, issues, or subjects to investigate in their respective areas (Ormrod et al., 2023). Correspondingly, students comprehend the material via experiential learning, logical deliberation, and self-reflection. Notably, the primary responsibility of instructors is to provide students with foundational knowledge and work resources. Another essential component is for instructors to engage in questioning, advice, and encouragement while providing feedback (Rowe, 2004).

According to Mayer (2004), guided discovery allows students to interact with the content and explore the concepts, enabling the construction of knowledge. Nevertheless, at the same time, it provides significant support to prevent cognitive load. This is in contrast to pure discovery learning, which lacks structure and has the potential for information overload (Kirschner et al., 2006). Several studies indicate that guided discovery can be an effective means of developing problem-solving abilities. For example, Alfieri et al. (2011) discovered in a meta-analysis of the literature that individuals can learn much more with the help of guided discovery than through direct instruction with its reliance on some form of lecture-type teaching or through unguided discovery alone. Moreover, an additional fact is that guided discovery leads to a better understanding and retention of knowledge since students are actively involved in the learning process (Hmelo-Silver et al., 2007; Ramadhaniyati et al., 2023). In the following subsections, we first explain the concepts of guided discovery approach and scaffolding strategies. Consequently, we discussed the importance of problem-solving skills in the Saudi technical context and the theoretical foundations of this study that assisted us in formulating our research questions and hypotheses.

1.2 Scaffolding approach in science and technical education

During the past two decades, scaffolding has been dubbed one of the most promising approaches to learning and teaching (Davis, 2015). The term has also been used interchangeably with any supportive instruction. The term "scaffolding" originated in construction. Scaffolding is a temporary structure in the construction industry that workers use to build or renovate buildings. Furthermore, scaffolding is one of the numerous components of successful education and can serve as the basic framework for acquiring scientific knowledge. The concept of scaffolding, introduced by Wood et al. (1976), involves providing temporary support to students to help them achieve tasks they cannot complete independently. This support is gradually withdrawn as students become more proficient, promoting autonomous learning and skill acquisition. Moreover, scaffolding has been widely recognized for facilitating cognitive development and enhancing problem-solving abilities (Belland et al., 2017).

A teacher typically works with a large class; all classes have students with various learning tendencies, abilities, and weaknesses. It is thus impractical for one teacher to directly oversee and tailor support to every scholar in a diverse group of learners when each one of these students has an independently different multidimensional Zone of Proximal Development (ZPD) (Roth & Radford, 2010). This is one of the major arguments used by advocates of direct instruction to demonstrate that whole-class teaching, with teacher exposition, is superior to learning-through-discovery approaches (Kirschner et al., 2006).

Subsequently, research has proven that scaffolding happens in several ways: through hints, prompts, modeling, and feedback (Puntambekar & Hubscher, 2005; van Geert & Steenbeek, 2005). For example, Reiser (2018) argued that scaffolding helps students manage complex tasks by breaking them into more straightforward tasks. In addition, scaffolding fosters an extensive learning and critical thinking process since students are guided to remain curious about the entire problem-solving process to ensure they can convincingly answer questions relating to the principle used to solve a problem (van de Pol et al., 2010).

Physics, a cornerstone of technical education, involves complex and often counterintuitive concepts such as forces, energy transformations, and motion dynamics. These concepts require not only rote memorization but also deep comprehension and the ability to apply theoretical principles to real-world scenarios. Scaffolding addresses these challenges by enabling students to:

- Visualize abstract concepts through guided demonstrations.
- Break down multi-step problems into manageable components.
- Reflect on their thought processes with structured feedback.

Scaffolding in Physics education aligns with the practical goals of technical training by connecting abstract principles to their applications in industries such as engineering, manufacturing, and renewable energy systems. For example, scaffolding helps students design experiments to calculate energy efficiency in systems or troubleshoot mechanical failures by systematically analyzing forces and energy transfers. This relevance fosters engagement and prepares students for problem-solving challenges in their professional lives.

1.3 Problem-solving skills in saudi technical education

Problem-solving skills are the bedrock of technical and science education (Garrett, 1987; Kiong et al., 2020). These fields focused on memorizing facts and understanding and applying knowledge to navigate challenges. From designing experiments in science to troubleshooting complex machinery in engineering, the ability to break down problems, analyze information, and develop effective solutions is paramount. Hence, by nurturing strong problem-solving skills, technical and scientific education empowers individuals to think critically, innovate, and become successful contributors in a world driven by constant change and discovery. Notably, the development of problem-solving skills is particularly relevant in Saudi Arabia's technical education, given the country's focus on economic diversification and workforce development as outlined in Vision 2030 (2016). Despite the recognized significance of these skills, traditional teaching methods in Saudi technical colleges have often been criticized for their emphasis on rote learning and lack of engagement (Al-Harbi, 2011).

Recent studies have urged the implementation of innovative pedagogical strategies to solve such challenges. For instance, Al-Zahrani (2015) observed that active learning methods, including the flipped classroom approach, helped improve students' creative thinking and problem-solving skills. Similarly, Alharthi and Alsufyani (2020) verified a need to further improve results in Saudi technical education by incorporating student-based learning centered on problem learning.

1.4 Theoretical background underlying scaffolding and guided discovery approaches

The theoretical basis for this study is constructivist learning theories that posit knowledge as actively constructed by learners through interaction with the environment (Vygotsky & Cole, 1978). Guided discovery and scaffolding form part of constructivist principles, whereby active engagement and support to achieve understanding are allowed. Moreover, the two also align under the cognitive apprenticeship model, whereby the role of social interaction and guided practice in skill development is underlined (Collins, 2013).

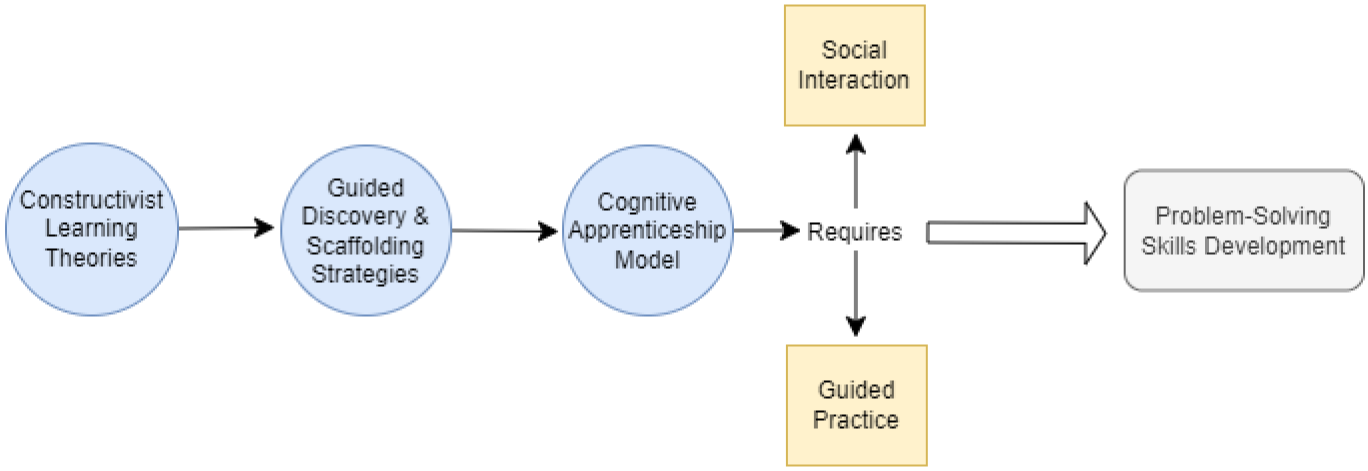
Technical education in Saudi Arabia prepares students for contemporary workforce needs. However, the current educational practices are highly focused on rote learning and memorization at the cost of significant cognitive competencies development, including problem-solving, critical thinking, and analytical reasoning. This approach has, unfortunately, created a gap between the competencies of graduates and the expectations of employers, who have started to increasingly value higher-order thinking skills and the ability to tackle complex real-world problems (Al-Harbi, 2011). Despite several forms of educational reforms, the traditional pedagogical methods in Saudi technical colleges have continued to grapple with the challenge of engaging students effectively within the discourse that will lead to developing such critical skills. One challenge is the conventional teacher-centeredness or focus on rote memorization instead of critical thinking and student engagement. This can stifle creativity and hamper the development of some vital skills required in the modern world. Therefore, there is an urgent need for teaching strategies that can bridge such gaps in technical education.

Two instructional methods that hold the most promise in promoting active learning and cognitive development are guided discovery and scaffolding. Guided discovery refers to a type of problem-solving that is structured in a manner that enables students to explore and construct knowledge, albeit under an instructor's guidance. In contrast, scaffolding refers to the instructional approach where targeted support is provided in a manner that will enable them to negotiate any challenging task ahead of them—challenging but far beyond what a person's present level of functioning would be until they become self-sufficient (Alfieri et al., 2011; Wood et al., 1976). The effectiveness of all these strategies is yet to be explored in Saudi technical education.

The integration of scaffolding and guided discovery reflects the intersection of cognitive and constructivist learning theories. While guided discovery allows learners to take ownership of their learning, scaffolding provides the necessary support to navigate complex tasks. Together, these strategies create an optimal learning environment that fosters deep understanding, critical thinking, and problem-solving skills (Belland et al., 2017).

In the context of Saudi technical education, these theoretical principles were applied to address the challenges posed by traditional teaching methods, such as rote learning and lack of engagement. Figure 1 illustrates the theoretical framework underpinning this study, highlighting the dynamic interplay between scaffolding, guided discovery, and their shared basis in social interaction theory. Specifically, the figure shows how these strategies contribute to learners' cognitive apprenticeship model to foster problem-solving skills.

Figure 1: Theoretical foundations of scaffolding and guided discovery learning



1.5 Research aim

This study aims to examine the effectiveness of guided discovery and scaffolding strategies in enhancing problem-solving skills among students in Saudi technical colleges. By implementing these instructional approaches, the study aims to determine whether they can significantly improve students' cognitive abilities, engagement, and overall learning outcomes in technical education settings. This research seeks to provide empirical evidence to support adopting these pedagogical methods and offer practical insights for educators and policymakers to enhance the quality of technical education in Saudi Arabia.

In specific terms, the study is guided by a single question, which is provided below. This question makes a prime objective in measuring the improvement in students' problem-solving ability after the intervention of guided discovery and scaffolding strategies.

- What is the impact of guided discovery and scaffolding strategies on the problem-solving skills of students in Physics courses at Saudi technical and vocational colleges?

Both null and alternative hypotheses are included to ensure a rigorous statistical framework for testing the research question. The null hypothesis (Ho) represents the baseline assumption that guided discovery and scaffolding strategies do not significantly affect problem-solving skills, while the alternative hypothesis (Ha) posits that these strategies have a positive impact. Including both hypotheses allows for an unbiased evaluation of the intervention's effectiveness, ensuring the reliability and validity of the conclusions drawn from the statistical analysis.

- H_o: Guided discovery and scaffolding strategies do not significantly impact the problem-solving skills of students in Physics courses at Saudi technical and vocational colleges.
- H_a: Guided discovery and scaffolding strategies significantly improve the problem-solving skills of students in Physics courses at Saudi technical and vocational colleges.

2 Research methodology

2.1 General background

A study's research design is critical since it offers a structure for ensuring the investigation is conducted successfully and economically (Asenahabi, 2019). This study employs a quasi-experimental design to investigate the effectiveness of guided discovery and scaffolding strategies in enhancing problem-solving skills among students in Saudi technical colleges. Specifically, the research design included pre- and post-intervention assessments. A quasi-experimental research design is one in which the researchers study the impact of a treatment or intervention on a group of participants without randomly allocating the group into Experimental Group (EG) and Control Group (CG) (Reichardt, 2009). In addition, the quasi-experimental design was based on the effectiveness of the instructional module, which mainly used guided discovery and scaffolding techniques as core teaching components. Both EG and CG had measures prior to and immediately following the intervention in accordance with the pre-test and post-test experimental design. Correspondingly, the pre-and post-test results were compared to observe if the instructional intervention had a noteworthy impact on the participants' problem-solving skills. A brief synopsis of the research design used for this study is summarized in Table 1.

Table 1. Quasi-experimental design for the study

Groups	Pre-test	Treatment	Post-test
Experimental group (EG)	PPSI survey	Instruction with guided discovery and scaffolding strategies	PPSI survey
Control group (CG)	PPSI survey	Conventional instruction	PPSI survey

PPSI: Personal problem-solving inventory

2.2 Study context and participants

The study was conducted at Riyadh College of Technology, a technical and vocational institution in Saudi Arabia that provides diploma programs in a range of trades. It is one of the largest government training institutions in the country. It is located in Saudi Arabia's capital, Riyadh. Technical and Vocational Training Corporation (TVTC) has administrative jurisdiction over the college. In the first semester of the 2023–2024 academic year, there are now about 1750 students studying Physics in 50 classrooms.

The college was selected for the study purposefully since it is situated in a suitable geographical area that enables the researchers to control the non-EG by preventing them from mixing with their counterparts in the EG. Note that the selected college works under the administrative control of TVTC, a government agency responsible for technical and vocational training in the country. Hence, the college is well equipped with the necessary infrastructure and resources to implement this experimental study, i.e., a well-equipped Physics laboratory, a modern computer lab, and classrooms, to name a few.

Four sections of Physics 101 were employed as the sample for this investigation, consisting of 104 students. In this study, half of the students—two classes (52 students)—formed the EG, and the other half—also two classes (52 students) formed the CG. The course comprised 06 credit hours, with 02 hours dedicated to practical work and 04 hours to theory. The experiment was conducted specifically with the course's second unit, which addresses the concepts of "Motion, Force, Work, and Energy." In five weeks, the unit requires about 30 teaching hours to complete. Both the EG and CG covered the same course materials.

Ensuring the ethical integrity of research is paramount, particularly in studies involving human participants. Prior to the commencement of data collection for the current study, we followed several procedures to address ethical concerns and safeguard the rights and well-being of the participants involved in this study. These procedures included institutional review board approval, informed consent from the Physics students for their volunteer participation, and confidentiality and anonymity of research data.

2.3 Study intervention

The intervention consisted of guided discovery and scaffolding strategies integrated into the existing curriculum of the Physics course. The guided discovery approach involved structured problem-solving activities where students were encouraged to explore and construct knowledge with the guidance of their instructors. Scaffolding techniques included providing hints, prompts, and feedback to support students' learning processes and gradually reducing assistance as students became more proficient (Wood et al., 1976). The intervention was implemented with students attending Physics 101, a 6-credit hour course in the first semester of academic session 2023-24. Other than that, each session focused on specific problem-solving tasks relevant to the course syllabus, designed to challenge their cognitive skills and promote critical thinking and problem-solving. An example of instructional activity that involved scaffolding technique is given below: Students were given a hands-on activity titled as “My Home to School Roadmap”. The activity aimed to explore the difference between distance and displacement. In this activity, they were in drawing a roadmap from home to school, label roads, landmarks, and calculate distances using a scale. It inherently focused on understanding spatial relationships, interpreting data, and applying scale to real-world problems. More examples of the activities are listed in Table 2. These problem assignments and scaffolding strategies were carefully tailored to align with the technical training objectives in Saudi colleges. By incorporating real-world scenarios such as workshop machinery and energy efficiency, the assignments connected theoretical Physics to practical applications, fostering both engagement and skill development in alignment with Vision 2030 goals for workforce readiness.

Table 2. Problem-solving activities for experimental group

Activity	Objective	Materials	Procedure	Problem-solving focus
My home to school roadmap	Explore the differences between distance and displacement.	Ruler, bond paper, pencil, colored pen	Draw a roadmap from home to school, label roads, landmarks, and calculate distances using a scale.	Spatial reasoning, interpreting data, and applying real-world problem-solving skills.
Velocity and acceleration	Solve problems on velocity and acceleration.	Bond paper, calculator, pen	Solve assigned problems, show solutions, and box final answers.	Applying formulas, analyzing motion, and interpreting results.
Motion with constant acceleration	Calculate acceleration of moving objects.	Pen, paper	Complete missing quantities in a table, show solutions, and answer questions.	Analyzing data, applying kinematic equations, and interpreting motion scenarios.
Inertia	Explain The Effects Of Inertia On Motion When Forces Are Applied.	Coin, Paper, Table, Water, Glass, Tumblers, Tablecloth	Perform Experiments (E.G., Pulling Paper Under A Coin, Pulling A Tablecloth Under Tumblers).	Observing And Explaining Physical Phenomena, Drawing Conclusions From Experiments.
Force, mass, and acceleration	Determine the relationship between force, mass, and acceleration.	Bond paper, tape, straw, coin, scissors	Create a paper box, blow it with/without a coin, and observe changes in motion.	Experimenting with variables, analyzing relationships, and applying newton's second law.
Rocket balloon	Compare forces of two interacting objects.	Balloon, straw, string, tape, chairs	Set up a string and straw system, attach a balloon, and observe its motion.	Designing experiments, analyzing forces, and interpreting results.
Work or no work?	Determine whether work is done in given situations.	Pen, paper	Analyze pictures, fill in a table, and discuss answers with a partner.	Analyzing scenarios, applying the concept of work, and interpreting results.
Who is the most powerful?	Compare the power of group members.	Stair, timer, meterstick	Measure stair height, time group members walking/running upstairs, calculate work and power.	Collecting data, applying formulas, and comparing results.
Mechanical energy	Solve problems related to potential and kinetic energy.	Pen, paper	Solve problems on mechanical energy, potential energy, and kinetic energy.	Applying conservation laws, analyzing energy transformations, and solving equations.
Law of conservation of energy	Analyze energy transformations and solve related problems.	Pen, paper	Solve problems on mechanical energy, potential energy, and kinetic energy.	Applying conservation laws, analyzing energy transformations, and solving equations.

On the other hand, the students within control group (CG) participated in the study under conditions designed to mirror typical classroom activities without the intervention being tested. The activities for the CG included: traditional instruction with existing learning materials for the same topics taught to experimental group, and similar assessment activities as done with the students in experimental group.

In order to maintain the threats to internal and external validity of the current study, we made efforts to control for potential confounding variables, such as students' prior knowledge, their socio-economic status, and Physics teacher effectiveness. Moreover, both groups were subjected to the same testing conditions, including the environment, timing, and instructions, to ensure that these factors did not influence the results. Additionally, the study was conducted in a natural classroom setting rather than a laboratory, enhancing the ecological validity and ensuring that the results are applicable to real-world educational environments.

2.4 Data instrument

Students' problem-solving skills were the main construct of the current study as this study attempts to determine whether and what the impact of the intervention instruction (guided discovery and scaffolding strategies) on students' problem-solving skills is. The instrument that measures study participants' problem-solving skills was adapted from the Personal Problem-Solving Inventory (PPSI). The PPSI was developed by Heppner and Petersen (1982), and it is a tool designed to assess an individual's problem-solving abilities. Furthermore, it is a self-report questionnaire that measures a person's perceptions of their problem-solving skills and the effectiveness of their problem-solving strategies. This inventory comprises 32 items and three factors. The first of these factors is Problem-Solving Confidence (PSC), which consists of 11 items; the second is Approach Avoidance Style (AAS), which consists of 16 items. Meanwhile, the third factor is Personal Control (PC), which consists of 05 items. The PPSI is a 6-point Likert-type scale comprising 32 items, assessing adolescents' and adults' self-perception of problem-solving skills. Notably, the scale was also adapted into Turkish, where Cronbach's alpha coefficient was determined to be .88.

Although the PPSI had already been discovered to be valid and reliable in several studies, its feasibility for use in the current study was assessed by several measures. Firstly, we sought local experts' opinions regarding the item's feasibility for the potential participants of the current study. After making any revisions based on the feedback received from the expert, the instrument was pilot-tested with a small group of potential study participants (n = 30). The pilot study aimed to refine the scale, identify potential issues or ambiguities, and ensure its effectiveness in measuring students' problem-solving skills, specifically within the domain of Physics in the context of technical and vocational colleges in Saudi Arabia. Additionally, a Principal Component Analysis (PCA) with varimax rotation was applied to the collected data to confirm the three sub-constructs within the PPSI scale (Soomro et al., 2018). Consequently, a minimum item loading of 0.4

was specified in this step. A three-component solution confirmed the existing sub-constructs within the PPSI scale, i.e., PSC, AAS, and PC (see Table 3).

Table 3. Factor loadings of PPSI scale

Item no.	**Factor loading**
Problem-solving confidence	Cumulative extraction = 52.243%
PSC1	.842
PSC2	.826
PSC3	.835
PSC4	.809
PSC5	.892
PSC6	.823
PSC7	.777
PSC8	.689
PSC9	.729
PSC10	.718
PSC11	.772
Approach avoidance scale	Cumulative extraction = 44.372%
AAS1	.765
AAS2	.657
AAS3	.800
AAS4	.766
AAS5	.632
AAS6	.675
AAS7	.706
AAS8	.732
AAS9	.683
AAS10	.814
AAS11	.841
AAS12	.838
AAS13	.849
AAS14	.817
AAS15	.845
AAS16	.847
Personal control	Cumulative extraction = 49.238%
PC1	.784
PC2	.743
PC3	.689
PC4	.729
PC5	.818

Given the use of survey data, which often exhibit non-normal distributions such as left-skewness, the normality of the PPSI pre-test and post-test scores was rigorously evaluated using statistical and visual methods. The Shapiro-Wilk test was applied to the PPSI scores. Results showed $p>0.05$, indicating no significant departure from normality. Moreover, Visual inspection of Q-Q plots indicated that data points closely followed the diagonal line, supporting the assumption of normality.

Cronbach's alpha coefficient was computed to assess the internal consistency reliability of the PPSI scale. This coefficient indicates the extent to which all items in the scale measure the same underlying construct of problem-solving skills. A high Cronbach's alpha value (typically above 0.70) suggests that the items are highly correlated with each other and reliably measure the intended construct (Soomro et al., 2024). Accordingly, Cronbach's alpha coefficient of 0.82 indicates that the items on the PPSI scale are internally consistent and reliable (Field, 2013).

2.5 Data analysis

The quantitative data were analyzed using statistical methods to determine the effectiveness of the intervention (Field, 2013). Various statistical techniques were used to assess all the data gathered. Version 26 of Statistical Package for Social Sciences (SPSS) was employed for all data analysis. Correspondingly, descriptive and inferential statistical tests were used in the data analysis. Factor scores and demographic analysis were conducted using descriptive statistics, including mean, frequency distribution, and standard deviation. Moreover, inferential statistics such as independent sample T-test, Analysis of Covariance (ANCOVA), and Multivariate Analysis of Variance (MANOVA) were used to answer specific hypotheses for the current study. Subsequently, effect sizes were calculated to assess the magnitude of the intervention's impact (Field, 2013).

3 Research results

Prior to conducting the actual data analysis to answer the question of interest, we took care of the statistical assumptions inherent to our selected statistical tests, particularly the inferential statistical test, to examine the study hypothesis. Particularly, we examined the assumptions of normality, linearity, homoscedasticity, and independence. Results indicated that the required assumptions were met. Consequently, we calculated descriptive statistics, including mean and standard deviation of the main continuous variables involved in the study: PPSI_PreTest and PPSI_PostTest (and their respective sub-scales, i.e., PSC, AAS, and PC). The variable PPSI_PreTest was used to measure and record the score for participants' problem-solving skills prior to the intervention. Similarly, the PPSI_PostTest indicates the participant's score after the intervention. These statistics offer a snapshot of the data's distribution and variability, providing a context for the deeper analyses that followed. Table 4 provides basic descriptive statistics of the two main variables and their sub-scales (sub-constructs).

Table 4. Descriptive statistics of pre-test and post-test for PPSI

Name of the variable	N	Mean	Standard deviation
PPSI_pretest	104	4.13	.517
PPSI_PSC_pretest	104	4.504	.597
PPSI_AAS_pretest	104	4.030	.482
PPSI_PC_pretest	104	3.863	1.151
PPSI_posttest	104	4.25	.562
PPSI_PSC_posttest	104	4.455	.634
PPSI_AAS_posttest	104	4.216	.504
PPSI_PC_posttest	104	4.084	1.114

An independent sample T-test was conducted to assess if the students in the CG and EG were significantly different with respect to their problem-solving skills at the pre-test phase of this study. In this analysis, the dependent variable was PPSI_PreTest (containing students' scores on the PPSI questionnaire before the intervention), whereas the independent variable was grouped with two levels: CG and EG.

Prior to conducting the independent sample T-test, Levene's test for equality of variances was performed to assess the assumption of homogeneity of variance. The results of Levene's test were not significant (F = 1.318, p = .254), suggesting that the variances for the two groups were equal. Given this, equal variances were assumed for the subsequent independent sample T-test. The results of the independent sample T-test revealed that there was no significant difference in students' scores on PPSI between the CG and EG; t (102) = -1.457, p > .05 (see Table 5 for details).

Although the descriptive statistics revealed that the EG had a higher mean (M = 4.205, SD = .556) compared to the CG (M = 4.058, SD = .468) (see Table 6), the independent sample T-test revealed that these differences were insignificant. These results suggest that both groups of students, the ones in the CG and those assigned to the EG, were almost the same regarding their problem-solving skills before the intervention started.

Table 5. Results of independent sample T-test for variables PPSI_pretest

t	***df***	***Sig.* (2-tailed)**	**Mean difference**	**Std. error difference**	**95% confidence interval of the difference**	
					Lower	**Upper**
-1.457	102	.148	-.14692	.10085	-.34696	.05311

Table 6. Summary statistics for PPSI_pretest scores (N =104)

DV	**Group**	***N***	***Mean***	***Std. deviation***
PPSI_pretest	Control	52	4.05	.469
	Experimental	52	4.20	.556

To examine the effect of guided discovery and scaffolding strategies on Physics students' problem-solving skills (PPSI), an independent sample T-test was conducted. In this analysis, the dependent variable was PPSI_PostTest (containing students' scores on the problem-solving questionnaire after the intervention), whereas the independent variable was grouped into two levels: CG and EG.

Prior to conducting the independent sample T-test, Levene's test for equality of variances was performed to assess the assumption of homogeneity of variance. The results of Levene's test were insignificant (F = .2.381, p = .126), suggesting that the variances for the two groups were equal. Given this, equal variances were assumed for the subsequent independent sample T-test. The results of the independent sample T-test indicated that there was a significant difference in students' problem-solving skills scores between the CG and EG; t (102) = -3.852, p < .01 (see Table 7 for details). Thus, the null was rejected, and the alternative hypothesis was accepted. Specifically, the EG had a higher mean (M = 4.450, SD = .472) compared to the CG (M = 4.052, SD = .575); see Table 8. The mean difference was -.397, with a 95% confidence interval ranging from -.602 to -.192. These results suggest that the guided discovery and scaffolding strategies significantly positively affected students' problem-solving skills, i.e., the students who were taught using the guided discovery and scaffolding strategies scored higher on their problem-solving skills than those taught using the conventional approach.

Table 7. Results of independent sample T-test for variables PPSI_posttest

t	*df*	*Sig.* (2-tailed)	Mean difference	Std. error difference	95% confidence interval of the difference	
					Lower	Upper
-3.852	102	.000	-.39769	.10323	-.60245	-.19294

Table 8. Results of independent sample T-test for variables PPSI_pretest

DV	Group	*N*	*Mean*	*Std. deviation*	*Std. error mean*
PPSI_posttest	Control	52	4.0527	.57520	.07977
	Experimental	52	4.4504	.47253	.06553

In addition to the independent sample T-test, the ANCOVA was conducted to evaluate the impact of the guided discovery and scaffolding strategies on students' problem-solving skills (PPSI), controlling for their initial problem-solving skills as indicated by pre-test scores. For this analysis, the dependent variable was the PPSI_PostTest score, and the independent variable was the students' group (Control or Experiment). The covariate in our analysis was the pre-test PPSI scores. Prior to conducting the ANCOVA, the assumptions of the test were verified. Meanwhile, the relationship between the covariate (PPSI_PreTest scores) and the dependent variable (PPSI_PostTest scores) was determined to be linear. The assumption of homogeneity of regression slopes was satisfied, indicating that the effect of the covariate on the dependent variable was consistent across all levels of the independent variable. Additionally, the normality of residuals and homogeneity of variances were also confirmed (see Table 9).

Table 9. Levene's test of equality of error variances (DV: PPSI_posttest)

F	*df1*	*df2*	*Sig.*
2.458	1	102	.120

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.
a. Design: Intercept + PPSI_PreTest + Group

The adjusted means for the final PPSI scores, after controlling for pre-test scores, were calculated for each group. The ANCOVA revealed a significant effect of the guided discovery and scaffolding strategies on final PPSI scores after adjusting for pre-test scores, $F(1, 101) = 14.683$, $p < .01$ (see Table 10 for details). The effect size, measured using partial eta squared, was .127, suggesting a small effect of the guided discovery and scaffolding strategies on students' problem-solving scores.

Table 10. ANCOVA results for between-subjects effect on the PPSI_posttest: P< 0.05

Source	Type III sum of squares	*df*	Mean square	*F*	*Sig.*	Partial eta squared
Corrected model	4.130a	2	2.065	7.385	.001	.128
Intercept	29.567	1	29.567	105.735	.000	.511
PPSI_pretest	.018	1	.018	.065	.799	.001
Group	4.106	1	4.106	14.683	.000	.127
Error	28.243	101	.280			
Total	1912.233	104				
Corrected total	32.373	103				

a. R Squared = .128 (Adjusted R Squared = .110)

Additionally, MANOVA was conducted to observe if significant differences exist between participants' scores on PPSI (problem-solving skills) across its subscales between CG and EG. Although the differences in the performance of the two groups (CG and EG) were revealed to be significantly different in terms of overall PPSI score, it would have been interesting to observe if both groups performed significantly differently on each of the three levels of PPSI scale: PSC, AAS, and PC at the post-test stage.

MANOVA extends the Analysis of Variance (ANOVA) to cases where there are multiple dependent variables (Field, 2013), like the three dependent variables in this study, PPSI_PSC, PPSI_AAS, and PPSI_PC. The PPSI_PSC, PPSI_AAS, and PPSI_PC subscales of the PPSI scale at the post-test stage were the subjects of a MANOVA (2x3) in this study, with the groups of the independent variables (having two levels: the EG and CG). The summary statistics for PPSI subscales (PSC, AAS, and PC) post-test scores are provided in Table 11.

Table 11. Summary statistics for PPSI subscale post-test scores (N = 104)

Variable		Mean	SD
Problem-solving confidence	Control	4.2987	.61009
	Experimental	4.6121	.62541
Approach avoidance style	Control	4.1263	.57754
	Experimental	4.3067	.40394
Personal control	Control	3.7346	1.23968
	Experimental	4.4346	.84919

The homogeneity of the variance-covariance assumption underlying MANOVA was examined using the Box's Test of Equality of Covariance Matrices. The result reveals that the homogeneity of variance-covariance is met, as provided in Table 12. The outcome demonstrates that the post-test (Box's M = 18.534, F = 2.990 p = .116 > 0.05) achieved homogeneity of variance.

Table 12. Results of the homogeneity test for the PPSI subscales

Variable	F-value	df1	df2	Sig
PPSI subscales	2.990	6	75379.925	.116

The study compared the differences between the EG and CG in the PPSI subscales at the post-test stage. The results were revealed to be significant at two sub-scales: PPSI_PSC (Mean Square = 2.555, F = 6.693, p = .011 < 0.05) and PPSI_PC (Mean Square = 12.740, F = 11.285, p = .001 < 0.05). However, the results for PPSI_AAS were determined to be non-significant (Mean Square = .846, F = 3.406, p = .068 > 0.05). Please refer to Table 13 for details. In addition, the mean total score in the dependent variables post-test for the EG was significantly higher than that of the CG for specific sub-scales.

Table 13. Results of MANOVA for between-subjects effect of the research variables: P < .05

Source	Dependent variable	Type III sum of squares	df	Mean square	F	Sig.	Partial eta squared
Corrected model	PPSI_PSC	2.555	1	2.555	6.693	.011	.062
	PPSI_AAS	.846	1	.846	3.406	.068	.032
	PPSI_PC	12.740	1	12.740	11.285	.001	.100
Intercept	PPSI_PSC	2064.447	1	2064.447	5408.910	.000	.981
	PPSI_AAS	1849.036	1	1849.036	7445.035	.000	.986
	PPSI_PC	1735.145	1	1735.145	1536.921	.000	.938
Group	PPSI_PSC	2.555	1	2.555	6.693	.011	.062
	PPSI_AAS	.846	1	.846	3.406	.068	.032
	PPSI_PC	12.740	1	12.740	11.285	.001	.100
Error	PPSI_PSC	38.931	102	.382			
	PPSI_AAS	25.333	102	.248			
	PPSI_PC	115.155	102	1.129			
Total	PPSI_PSC	2105.933	104				
	PPSI_AAS	1875.215	104				
	PPSI_PC	1863.040	104				
Corrected total	PPSI_PSC	41.486	103				
	PPSI_AAS	26.179	103				
	PPSI_PC	127.895	103				

R Squared = .062 (Adjusted R Squared = .052)
R Squared = .032 (Adjusted R Squared = .023)
R Squared = .100 (Adjusted R Squared = .091)

From the test results, it can be concluded that a significant difference exists in the mean score in the PSC and PC subscales. However, not for the AAS at the post-test stage between the two groups, where students in the EG reported higher PSC mean scores (M = 4.612, SD = .625) compared to their counterparts (M = 4.298, SD = .610) in the CG. Students in the EG reported a higher PC mean score (M = 4.435, SD = .849) than their counterparts (M = 3.735, SD = 1.24) in the CG. Nevertheless, the differences in the scores for AAS between the two groups were not discovered to be significant with mean score of

4.306 (Standard Deviation= .404) for EG and 4.126 for CG (Standard Deviation= .577). At the same time, it is crucial to recognize that participants in both groups had significant differences in their scores for their overall problem-solving skills.

4 Discussion

This study explored the impact of guided discovery and scaffolding strategies on enhancing problem-solving skills among students in Saudi technical colleges. The results indicate that these pedagogical approaches significantly improve students' cognitive abilities and engagement. The EG, which received the intervention, exhibited substantial gains in problem-solving assessment scores compared to the CG.

The significant improvement in problem-solving skills among students in the EG aligns with previous research on guided discovery and scaffolding strategies. Guided discovery represents a balance between student autonomy and instructor support aimed at active engagement toward an in-depth understanding of concepts and enhanced student learning outcomes (Alfieri et al., 2011; Mayer, 2004). Furthermore, guided discovery activities facilitated a better, more meaningful, and retained understanding of technical concepts, as the results of this study present (Akinbobola & Afolabi, 2010).

Likewise, the scaffolding allowed by the teachers supported the students' cognitive development. Scaffolding manages the complexity of problem-solving tasks by breaking them into manageable parts and slowly withdrawing support as the student's competency level improves (Wood et al., 1976). This is similar to other results that suggest that scaffolding positively influences and enhances learning, as it supports achieving tasks that the students may not perform on their own (Belland et al., 2017).

The findings of this study have significant implications for the learning of Physics among technical students. Physics, being a foundational subject in many technical fields, requires a deep understanding of theoretical concepts and their practical applications. The integration of innovative instructional methods and technologies can greatly enhance the learning experiences and outcomes for these students. Technical students, who often face rigorous and demanding curricula, can greatly benefit from these innovative educational tools. The ability to customize learning experiences to meet individual needs ensures that all students, regardless of their starting point, can achieve mastery of essential concepts.

The findings of this study also have implications for technical education, particularly in the context of Saudi Arabia's Vision 2030, which emphasizes workforce development and economic diversification (Vision 2030, 2016). Note that traditional teaching methods in Saudi technical colleges have often been criticized for emphasizing rote learning and lack of engagement (Al-Harbi, 2011; Al-Seghayer, 2021). This study demonstrates that incorporating guided discovery and scaffolding strategies can address these challenges by fostering higher-order thinking skills and creating a more engaging learning environment.

Despite the promising results, this study also encountered several challenges and limitations. One of these limitations is the short period of the intervention provided during the results, which is only a few weeks in period. A lengthier period might assert with more weight the evidence of how the effect of guided discovery and scaffolding on problem-solving skills endures. In further investigations, longitudinal research should be considered on the influence of these pedagogical strategies. Studies about long-term effects were proposed by Hortigüela et al. (2016). Another challenge is ensuring that the guided discovery and scaffolding are consistently applied by the different instructors and technical colleges. A variation in one's teaching style and the variation in the context of the institution may be factors that affect the success of the intervention. Hence, future studies may use more detailed instructor training and standardize the procedures for implementing the interventions.

The results derived from this research provide several avenues for future research. An exciting field could be exploring what exact components of guided discovery and scaffolding may most effectively foster problem-solving skills development. It could help define the critical elements of these strategies and pave the way for educators to implement their instructions in a more fine-tuned, optimal way. Furthermore, other cognitive and affective outcomes, such as critical thinking, creativity, and self-efficacy, need to be studied for their effects on guided discovery and scaffolding. He needs to have a broader perspective on these pedagogical approaches to channel further implications and adaptations to other educational settings.

This study provides strong evidence for the effectiveness of guided discovery and scaffolding strategies in enhancing problem-solving skills among students in Saudi technical colleges. The improvement in assessment scores and perceptions of students, together with the observed behaviors in the classroom, suggests these pedagogical methods have promise in transforming technical education. Notably, the strategy of guided discovery and scaffolding, which will assist students in developing higher-order thinking skills, will make the learning environment more attractive in terms of better preparation for life in the labor market in the new age and better achievement of the goals of Vision 2030 in Saudi Arabia.

While the study proves the effectiveness of scaffolding and guided discovery in improving technical students' problem solving skills, several challenges must be addressed for successful implementation by educators. These challenges encompass technical, pedagogical, and ethical dimensions, each of which requires careful consideration and strategic planning.

Conclusions and implications

This study examined the impact of guided discovery and scaffolding strategies on enhancing problem-solving skills among students at technical colleges in Saudi Arabia. The findings demonstrate significant improvements in students' problem-solving skills as a result of these pedagogical interventions. An independent sample T-test showed that the experimental group (EG) scored significantly higher on the post-test (Mean = 4.45, SD = 0.47) compared to the control group (CG) (Mean = 4.05, SD = 0.57), with a mean difference of 0.40, $t(102) = -3.85, p < 0.01$. This supports the rejection of the null hypothesis (H0), affirming the positive impact of guided discovery and scaffolding strategies on problem-solving skills. Thus, integrating guided discovery and scaffolding strategies in technical education is instrumental in solving several years of problems posed by the Saudi educational system. There is excessive rote learning and little student-centeredness and interaction in teaching. Hence, they are encouraged to strengthen active engagement and better understanding, which are some of the best practices worldwide and aspirations akin to those of Saudi Arabia's Vision 2030, aimed at developing a skilled and more competent workforce. Although the results anticipated from this are promising, several limitations exist for this study, including a relatively brief period of intervention and a small sample size selected from only one college in Saudi Arabia. Future research will have to delve deeper into the longitudinal impacts and differentiate the most effective components of guided discovery and scaffolding, as well as their other cognitive and affective benefits. For the time being, the results of this study proved very useful for educators and policymakers in striving to improve the quality of technical education and reach the nation's economic and educational goals.

Research ethics

Author contributions

AAA: Writing original draft; methodology, software, graphical representation,
KO: Writing – Review & Editing, Supervision,
LH: Writing – Review & Editing.

Informed consent statement

Informed consent was obtained from all research participants.

Data availability statement

Data is unavailable due to privacy or ethical restrictions.

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Conflicts of interest

The authors declare no conflicts of interest.

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