Comparison of the effectiveness of project-based 6E learning and problem-based quantum learning: Solomon four-group design

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Abstract

Purpose – Researchers have previously utilized the project-based 6E learning model and the problem-based quantum learning model in various courses, such as the instructional principles and methods course and the character and values education course. These models were evaluated for their impact on students in different subjects, including developing skills, values, democracy perceptions, attitudes towards cooperative learning, metacognitive thinking skills and teacher self-efficacy perceptions. In 2023, Ökmen, Sahin and Kiliç reported positive outcomes, while Sahin and Kiliç reported similar findings in 2023a, 2023b and 2023c. There has been no investigation into how the models affect students' critical thinking and academic literacy. This study seeks to determine the impact of both models on these skills, gain more insight into their effectiveness and determine which is more beneficial. The results will guide the decision-making process for the character and values education course and other courses in the future. Specifically, this research aims to compare the effects of the project-based 6E learning model and problem-based quantum learning model on critical thinking and academic literacy.

Design/methodology/approach – This research employed the Solomon four-group experimental design to assess the efficacy of the applications. Prior knowledge and experience of the participants were evaluated through pretests. However, it should be noted that pretests may impact posttest scores either positively or negatively. For instance, participants taking the test multiple times may become more interested or attentive to the subject matter. The Solomon four-group design was deemed appropriate to analyze the influence of pretesting. This design enables the investigation of the application effect, pretest effect and interactive effect of pretest and application (van Engelenburg, 1999).

Findings – It was concluded that the project-based 6E learning model was effective in developing critical thinking in students, but not significantly. It was concluded that the problem-based quantum learning model significantly improved students' critical thinking skills. It was concluded at the end of the study that the project-based 6E learning model notably enhanced students' academic literacy. It was concluded that the problem-based quantum learning model had a significant positive impact on students' academic literacy. According to research, it has been determined that the problem-based quantum learning model is superior in enhancing critical thinking abilities compared to the project-based 6E learning model. Nevertheless, there seems to be no detectable disparity in the academic literacy advancement of pupils between the problem-based quantum learning model and the project-based 6E learning model.

Originality/value – There has been no investigation into how the models affect students' critical thinking and academic literacy. This study seeks to determine the impact of both models on these skills, gain more insight into their effectiveness and determine which is more beneficial. The results will guide the decision-making process for the character and values education course and other courses in the future.

Keywords Academic literacy, Critical thinking, Problem based quantum learning model, Project based 6E learning model, Solomon four group design

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Introduction

In modern times, the approach to teaching has evolved and institutions that provide teacher training strive to include 21st-century skills in their programs. They also make necessary updates to ensure that qualified teachers are trained (Partnership for 21st Century Skills, 2010). The 21st-century skills consist of the knowledge, abilities and proficiency that students require to succeed in their daily lives and business ventures (Santos, 2017). These skills can be categorized into four main groups, which are: (1) methods of thinking (such as critical thinking, creativity, problem-solving, decision-making and metacognitive thinking), (2) Tools for work (such as information and communication technology literacy), (3) Methods of working (such as communication and collaboration) and (4) Ways of life (such as local and global citizenship, life and career, personal and social responsibility and cultural awareness) (Joynes *et al.*, 2019).

Critical thinking is a vital skill for the 21st century, involving using rational standards to analyze and evaluate information, thoughts and situations. It aims to create new knowledge, understandings, hypotheses and beliefs, equipping individuals to make informed decisions, solve problems effectively and achieve the correct results (Heard *et al.*, 2020). This skill encompasses a range of cognitive abilities, from processing information to identifying arguments, discovering biases and making reasonable decisions (Bassham *et al.*, 2011). Developing critical thinking skills can lead to academic and business success, broaden one's worldview and enhance the ability to make effective decisions and find direction in learning and life (Murawski, 2014). When thinking functions are not used correctly, emotions and desires can dominate thought, leading to personality degeneration into arrogance, injustice, bias, distrust, cowardice, selfishness and hypocrite. Therefore, critical thinking is an essential form of thinking that is necessary for one's mental health (Şenşekerci and Bilgin, 2008).

Academic literacy encompasses critical thinking, reading, writing and communication, as well as the ability to manage and produce information (Doru, 2018). In addition to writing skills, academic literacy includes accessing, interpreting and evaluating information and creating new texts. Critical thinking ability is closely linked to academic literacy (Klalare *et al.*, 2022). Developing advanced language skills and higher-order thinking is intricately tied to academic literacy. It is essential for knowledge creation and effective communication and is a critical component of language and cognitive growth. For this reason, academic literacy is widely recognized as a potent tool for promoting academic literacy development, facilitating knowledge production, driving communication and fostering transformation (Li, 2022). In the modern world, where vast information is at our fingertips, students must engage with texts effectively. They must approach these texts critically, carefully selecting those most valuable to their academic or research pursuits (Castillo-Martínez *et al.*, 2023).

Although critical thinking is universally recognized as an essential skill for students to acquire, many struggle in this area. Educators often find students' thoughts superficial (Willingham, 2020). In an academic setting, students face challenges comprehending text, identifying its main idea, establishing connections between different parts, relating it to their prior knowledge, drafting, producing and using language appropriately (Pinheiro *et al.*, 2016). The quality of education provided to students is crucial in developing critical thinking and academic literacy skills. The only way to enhance these competencies is to improve the quality of teaching (Kim *et al.*, 2019).

Mastering critical thinking is a multifaceted journey that cannot be accomplished through a single course. Educators must create opportunities for students to develop these skills in all aspects of their lives (Şenşekerci and Bilgin, 2008). Nurturing critical thinking requires students to take ownership of their education and engage in the learning process proactively (Murawski, 2014). This necessitates employing higher-order cognitive abilities, as critical thinking is a cognitive practice that necessitates introspection. Learning environments that promote critical thinking entail scrutinizing, amalgamating and assessing information to

solve problems and make decisions rather than simply committing facts to memory. To cultivate advanced thinking skills, teachers must employ pedagogical approaches that encourage reflection rather than methods that encourage rote learning. Lecturing and teaching techniques prioritizing memorization fail to adequately stimulate critical thinking, as they do not foster students' curiosity and analytical skills (Snyder and Snyder, 2008).

For students to cultivate sophisticated literacy skills, active engagement in purposeful and well-organized learning experiences that imbue meaning, values and emotion is imperative. Li's (2022) research corroborates this approach, emphasizing the need for educators to design activities that stimulate students' rational thinking, inference-making, problem-solving and conclusion-drawing abilities across all levels of academia, from preschool to higher education. Weideman and van Dyk (2014) underscore the significance of such activities.

In order to prepare students with indispensable abilities like critical thinking and scholarly competence in the modern era, it is imperative to implement educational frameworks. Two highly recommended frameworks are the project-based 6E learning model and the problem-based quantum learning model, which will be briefly introduced below. The methodology section will offer a comprehensive breakdown of their implementation.

Project based 6E learning model

The learning cycle is a highly effective method that engages students in a series of planned and sequential learning stages, empowering them to construct their knowledge. This approach offers numerous benefits, including comprehending complex concepts, fostering a positive attitude toward the subject matter and refining students' reasoning and critical thinking skills.

The project-based 6E learning model combines the strengths of project-based learning and the learning cycle, making it suitable for various disciplines. In this model, students engage in a cyclical process that involves problem identification, research, analysis, data collection, data analysis, developing strategies for problem-solving and producing products. The model is well-structured and integrated with lessons, with individual, group and classroom activities at each step. The aim is to help students develop high-level thinking skills (Şahin and Kılıç, 2023a).

In a study conducted by Şahin and Kılıç (2023a), it was discovered that the project-based 6E learning model significantly improved students' research skills, including problem identification, data collection, analysis, inference, reporting and presentation. Additionally, the model enhanced students' ability to work collaboratively, fostered positive attitudes toward group work and improved their self-control skills. Moreover, the students reported finding the learning model to be productive and effective, exciting and enjoyable.

Problem based quantum learning model

The Problem-Based Learning method is highly effective, aligns well with the constructivism theory, and equips students with crucial skills. Its benefits include improvements in problem-solving, creative and critical thinking, and overall academic performance. Meanwhile, the quantum learning model seeks to impart academic and life skills to students. This model encourages active participation in the learning process and instills a sense of responsibility in learners. Academic skills taught include quantum note-taking, memory, writing and reading techniques. Additionally, life skills taught include problem-solving, leadership, self-efficacy, responsibility and communication. By combining the steps of problem-based learning and the quantum learning cycle, the problem-based quantum learning model aims to develop students' problem-solving, creative thinking, critical thinking, academic and life skills (Ökmen *et al.*, 2023).

The problem-based quantum learning model positively impacted students' perception of their teachers' teaching abilities and their ability to learn the course material. The model's effectiveness was demonstrated through research, interdisciplinary connections and diligent effort on the part of the students, resulting in greater productivity and improved retention of information. In addition, the model was found to be engaging and increased students' motivation to learn, according to Ökmen *et al.* (2023).

Purpose of the research

The "project-based 6E learning model" is an innovative approach to learning that combines the best features of project-based and learning cycle models. It aims to help students in problem identification, research, investigation, data collection, data analysis, developing various strategies for solving the problem and producing products in a cyclical process. The steps are effectively structured and integrated with the course to ensure comprehensive learning. Additionally, the researchers combined the steps of the problem-based learning method with the quantum learning cycle to create a problem-based quantum learning model. This model effectively helps students in developing problem-solving, self-efficacy and thinking skills.

Researchers have previously utilized the project-based 6E learning model and the problem-based quantum learning model in various courses, such as the instructional principles and methods course and the character and values education course. These models were evaluated for their impact on students in different subjects, including developing skills, values, democracy perceptions, attitudes towards cooperative learning, metacognitive thinking skills and teacher self-efficacy perceptions. In 2023, Ökmen, Şahin and Kılıç reported positive outcomes, while Şahin and Kılıç reported similar findings in 2023a, 2023b and 2023c.

There has been no investigation into how the models affect students' critical thinking and academic literacy. This study seeks to determine the impact of both models on these skills, gain more insight into their effectiveness and determine which is more beneficial. The results will guide the decision-making process for the character and values education course and other courses in the future. Specifically, this research aims to compare the effects of the project-based 6E learning model and problem-based quantum learning model on critical thinking and academic literacy.

Method

Research design

This research employed the Solomon four-group experimental design to assess the efficacy of the applications. The prior knowledge and experience of the participants were evaluated through pretests. However, pretests can cause "pretest sensitivity," affecting posttest scores. Pretest sensitization is a phenomenon that occurs when a participant's performance on a posttest is influenced by taking a pretest, even if the participant has not been exposed to the experimental treatment or manipulation being examined. This can lead to incorrect conclusions about the effectiveness of an experiment and bias the results (Solomon, 1949). The Solomon four-group design was deemed appropriate to analyze the influence of pretesting. This design enables the investigation of the application effect, pretest effect and interactive effect of pretest and application (van Engelenburg, 1999). The study's experimental design is detailed in Table 1.

Based on the data presented in Table 1, there are four groups involved in the study – two experimental and two control groups. One experimental and one control group underwent a pretest while the other two did not. Specifically, the Mathematics and special education groups took the pretest, while the English and Turkish groups did not. End of the semester,

all groups took a posttest (O2, O4, O5, O6). Group 1 (Math) and Group 3 (English) used the project-based 6E learning model (X1), while Group 2 (Special Education) and Group 4 (Turkish) utilized the problem-based quantum learning model (X2).

The students in each department took the elective course "Character and Values Education." Due to the impossibility of randomly assigning individual students to different groups, groups were randomly assigned to the experimental and control groups.

Sample group

The research involved 173 students in the "Character and Values Education" course during the fall semester of 2022–2023 at a state university's education faculty. The number of students included in the sample is presented in Table 2.

The third-year students who are studying Mathematics, English and Turkish have all successfully completed the same educational science courses. Furthermore, the fourth-year students who are pursuing special education have performed equally well as their peers in the pretest with regards to academic literacy and critical thinking. Therefore, it is assumed that all groups are beginning the program with the same level of knowledge and skills.

Implementation process

The research ethics committee report was approved by the Scientific Research and Publication Ethics Committee of Duzce University on February 27, 2023, with the decision number E-78187535-050.06-268915.

The Character and Values Education course was a 14-week program that began with an introductory week where students were given an overview of the course and the pretests were conducted to assess the student's knowledge. The two models were then applied over the next 12 weeks, and in the program's final week, evaluations were carried out and final tests were administered to the students. Each group was led by the same faculty member throughout the entire course.

Groups		Pretest	Process	Posttest
Group-1	Mathematics	O1	X1	O2
Group-2	Special education	O3	X2	O4
Group-3	English		X1	O5
Group-4	Turkish		X2	O6

Note(s): X1: Project-Based 6E Learning, X2: Problem-Based Quantum Learning
Source(s): Table by authors

Table 1.
Solomon four group experimental design

	Gender		
Groups	Female	Male	Total
Mathematics	46	20	66
Special education	27	16	43
English	14	11	25
Turkish	30	9	39
Total	117	56	173

Source(s): Table by authors

Table 2.
Research sample

The study employed a collaborative approach, wherein 4 to 7 members were divided into experimental and control groups. Each group was assigned a leader to supervise the work for two weeks, and all members took turns in this role. To make it easier to keep track of files and assignments, all groups created a Google Classroom account using a shared email address.

During the semester, we covered six different topics, each lasting for two weeks. These topics included basic concepts, classification and formation of values, the historical process of values education, the interplay between family and values, the influence of environment on values, the role of curriculum in values education and approaches, models and methods for values education. The semester ended with a focus on the professional responsibilities of teachers.

Our weekly routine was divided into three parts: individual work, group work and class work. Each member completed their studies individually before coming together for the group study. The group study was conducted using a method agreed upon by the group, such as face-to-face meetings, Zoom calls or WhatsApp chats, at a predetermined time. Finally, the class study took place at specific times for each group. Group 1 had face-to-face meetings every Wednesday from 8:30–10:00, Group 2 met every Tuesday from 8:30–10:00, Group 3 met every Wednesday from 10:10–11:40 and Group 4 met every Thursday from 8:30–10:00.

The study implemented the project-based 6E learning model for the experimental groups in Math and English and the problem-based quantum learning model for the control groups in special education and Turkish. Details for both models are explained below.

Project-based 6E learning. 1st week. *Individual Studies:* The learning materials related to the subject were shared with the students via Google Classroom to grab their attention and assess their prior knowledge. The aim was to provide them with new information on the subject. Students were required to analyze the materials and answer two questions: "What did I learn about this topic?" and "What can I learn differently?". Based on the results of the analysis, they were expected to gather additional information from various sources and include it in their report.

Group studies: As a group, the students identified a common problem situation based on their studies. They then collected data by utilizing various data sources and data collection tools that matched the structure of the identified problem. The students analyzed the collected data as a group, drew various conclusions and generated ideas for solutions to reach a decision.

Classroom studies: During their presentation, the students shared their understanding and perspectives of the concepts, as well as their experiences in the problem-solving process. They also presented the solutions they came up with, the results they achieved and their recommendations for improvement. After each presentation, the students evaluated each group separately and sent their feedback to the group leader.

2nd week. *Individual studies:* Each student contributed new problems related to the first week's situation based on their experiences.

Group studies: The students provided individual suggestions to identify a common problem situation. The results from the previous problem analysis were applied to this new problem situation. The stages of collecting and analyzing new data were carried out for this new problem, which led to reaching conclusions and generating ideas for its solution. Finally, recommendations and mutual results for the first and second weeks were achieved and reported.

Classroom studies: During the learning process, the students shared their experiences, gained knowledge and perceptions about various concepts, and presented their results and solution proposals. They evaluated each other's presentations and sent their reviews to the group leader. At the end of the class, the lecturer gave feedback on the presentations and the reports were updated accordingly. Each group prepared a report every two weeks and

uploaded it to Google Classroom as a Word file. The head of the group was responsible for organizing and sending the file.

Problem-based quantum learning. 1st week. *Individual studies:* The students interpreted the given materials (scenario, situation, video, article, etc.) relating to their preliminary knowledge using the techniques outlined in the unit manual and then reported.

Group studies: The students worked together on materials that were individually interpreted. They identified problems and then determined the necessary information needed to solve them using techniques outlined in the unit manual, such as classification, writing slogans and mind mapping. After that, they reported their findings.

Classroom studies: The students presented their group report to the class and then completed the "They Have It, We Don't Have It" form while listening to other groups' presentations.

2nd week. *Individual studies:* The students collected the required data to resolve the issue. They then carried out a range of activities, including concept mapping, letter writing, memoir writing and summary writing using the Cornell technique, preparing a structured grid and creating a puzzle, as per the instructions given in the unit manual. Finally, they presented their findings on all of the activities they had accomplished.

Group studies: The students completed various activities in the unit manual based on their research. These activities included opposite panels, acrostic writing, fishbone preparation, story writing, circle technique, six hats thinking technique, article and curriculum review, snowball technique, work plan preparation, argumentation and drama writing. As a result, the students were able to come up with at least two solutions related to other disciplines using the information they gathered. They also reported on all of their completed work.

Classroom studies: The students presented their reports to the class, and completed a peer evaluation form while listening to other groups' presentations.

Data collection

For our data collection, we used two scales: the critical thinking tendency scale and the academic literacy scale. The critical thinking tendency scale, developed by Semerci (2016), has a total of 49 items and explains 49.16% of the variance. This scale has a test-retest correlation of 0.761 and a Cronbach Alpha coefficient of 0.963. The academic literacy scale, created by Demir and Deniz (2020), has 23 items and explains 41.13% of the variance. This scale has a Cronbach Alpha coefficient of 0.87.

Data was collected voluntarily via Google Form at the beginning (03-11/10/2022) and end (17-23/01/2023) of the semester.

Analysis of data

As part of the analysis phase, we performed an initial evaluation of the data. We discovered that there were no missing values, but we did exclude observations that were all rated with a five and not taken seriously. Following that, we examined the Z scores to identify any extreme values, and removed any observations with a score above three from the analysis.

The data was tested for normality using Kolmogorov–Smirnov ($n > 30$) and Shapiro–Wilk ($n < 30$) tests. The results are presented in Table 3.

According to Table 3, the only significant posttest scores were in the special education category for the critical thinking tendency scale ($p < 0.05$). However, after evaluating the skewness and kurtosis values of the scores, it was concluded that the skewness value was 0.277 and the kurtosis value was −0.997. If the coefficient of skewness is within −1 and +1, it is considered that the distribution is normal. Moreover, kurtosis values below 2 indicate a normal distribution (Watkins, 2021). Thus, the posttest scores for special education are

Scales	Groups		p values Pretest	Posttest
Critical thinking tendency scale	Group-1	Mathematics	0.200	0.200
	Group-2	Special Education	0.200	0.024
	Group-3	English		0.661
	Group-4	Turkish		0.200
Academic literacy scale	Group-1	Mathematics	0.200	0.095
	Group-2	Special Education	0.200	0.200
	Group-3	English		0.148
	Group-4	Turkish		0.200

Table 3. Normality coefficients of data

Source(s): Table by authors

normally distributed. Similarly, the pretest and posttest scores for the academic literacy scale exhibit normal distributions too.

As the number of students in the Mathematics (66), Special Education (43) and Turkish (39) groups exceeds 30, and the groups exhibit normal distribution, it is appropriate to conduct parametric tests. Although the number of students in the English group (25) is slightly below 30, parametric tests can be applied since the number of subjects is $n \geq 10$ and the group exhibits normal distribution (Sümbüloğlu and Sümbüloğlu, 2007).

In the data analysis, the flow chart suggested by Walton Braver and Braver (1988) was used, and the analyses were carried out in this order. An analysis was done on the posttest scores of four groups (O2, O4, O5, O6) using the 2×2 ANOVA (Test A) for critical thinking tendency scale and academic literacy scale. The data was checked to ensure it met the requirements for the analysis. Three assumptions were considered: (1) Observations are independent of each other, (2) The dependent variable's measurements follow a normal distribution, (3) The groups being observed have equal variances.

Since each student was included in just one group, the assumption of independence was met. Additionally, it was found that the posttest scores for both scales followed a normal distribution. The homogeneity of variances was tested using Levene's test, and the results for both scales were insignificant (critical thinking tendency scale: $p = 0.107$, academic literacy scale: $p = 0.145$), indicating that the variances were homogeneous. Once the prerequisites were met, the 2×2 ANOVA analyses were performed, and it was found that the interaction was insignificant for both scales. The analyses continued without any issues.

We conducted a basic effect test (Test D) on the posttest scores of groups O2, O4, O5, and O6. This involved testing the effect of the "method" on both the critical thinking tendency scale and the academic literacy scale. We found that the method had a significant main effect on the critical thinking tendency scale ($p = 0.003$), so we stopped the analysis there. However, on the academic literacy scale, the method's main effect was not significant ($p = 0.939$), so we continued with further analyses.

An Analysis of Covariance (ANCOVA) was conducted on the scores of Group-1 and Group-2 (Test E) on academic literacy scale. Prior to analysis, it was ensured that the data met the necessary requirements. The ANCOVA analysis has five basic assumptions: (1) independence between observations, (2) normal distribution of dependent variable measurements, (3) equal variance within their respective groups, (4) linearity, (5) equality of intragroup regression coefficients.

Each student was assigned to only one group, thus meeting the assumption of independence between the groups. The academic literacy scale pretest and posttest scores were found to be normally distributed. Levene's test was used to test the homogeneity of variances, and the result was insignificant, indicating that the variances were homogeneous. Correlation analysis

revealed a linear relationship between the posttest scores (dependent variable) and the pretest scores (control variable), with a correlation coefficient ($R = 0.515$, $p = 0.00$) meeting the necessary condition for linearity ($R \geq 0.3$). Finally, the regression slopes for each group were examined, and it was found that the joint effect of the pretest scores and the two different methods on the posttest scores was insignificant (method × pretest = 0.685 > 0.05). After ensuring that all prerequisites were met, ANCOVA analysis was conducted, and the interaction was found to be insignificant, allowing the analysis to continue.

An independent *t*-test (Test H) was conducted on the posttest scores of Group-3 and Group-4, who did not take the academic literacy scale pretest. The results showed that there was no significant difference between the experimental and control groups ($p = 0.619$), and the analysis continued.

Meta-analysis was performed with Stouffer's *Z* method (Test I) to combine the ANCOVA result with the *t*-test result. The effect was found to be insignificant ($p = 0.589$), and the analysis was terminated.

Reliability

The Cronbach alpha reliability coefficients for the pretest and posttest of the measurement tools are given in Table 4.

Based on the data presented in Table 4, it is noted that the reliability coefficients fall within the range of 0.802–0.965. As per scholarly sources such as Coaley (2010) and Kline (1986), coefficients between 0.80 and 0.95 indicate a high-reliability level. It is observed that all the scales' pretest and posttest results demonstrate a high degree of reliability.

Results

In this section, the effects of the project-based 6E learning model and problem-based quantum learning model on students' critical thinking and academic literacy are examined.

Critical thinking

The mean scores for the pretest and posttest of the critical thinking tendency scale are presented in Table 5.

Table 5 shows that the special education pretest score was higher than Mathematics. During the posttest, Mathematics had the lowest score, while special education had the highest.

The results of the pretest and posttest for the critical thinking tendency scale are presented in Table 6.

Table 4. Reliability coefficients of measurement tools

Scales	Groups		*p*-values	
			Pretest	Posttest
Critical thinking tendency scale	Group-1	Mathematics	0.947	0.932
	Group-2	Special Education	0.956	0.964
	Group-3	English		0.951
	Group-4	Turkish		0.965
Academic literacy scale	Group-1	Mathematics	0.802	0.867
	Group-2	Special Education	0.901	0.875
	Group-3	English		0.901
	Group-4	Turkish		0.875

Source(s): Table by authors

Upon examining Table 6, it was found that there is no significant difference in the critical thinking tendency scale scores of students in Group-1 ($t = -1.534$, $p = 0.131$) in favor of the posttest. However, in Group-2 ($t = -3.084$, $p = 0.004$), there is a significant difference in favor of the posttest.

Additionally, the results of the 2 × 2 ANOVA test (Test-A) conducted on the critical thinking tendency scale posttest scores (O2, O4, O5 and O6) are presented in Table 7.

According to Table 7, the interaction between "pretest-method" was not significant ($p = 0.216$), indicating no effect on Critical Thinking Tendency Scale scores.

According to Table 7, test D shows that the method used (O2, O4, O5 and O6) has a significant effect ($p = 0.003$) on the critical thinking tendency scale. The results indicate that the problem-based quantum learning model is more effective than the project-based 6E learning model in developing critical thinking, based on the posttest scores.

Academic literacy

Table 8 displays the mean scores for the pretest and posttest of the academic literacy scale.

Table 8 shows a higher special education pretest score than Mathematics. In the posttest, English has the highest score and Mathematics has the lowest.

Table 9 displays the results of the *t*-test for the pretest and posttest of the academic literacy scale.

There was a significant difference in the academic literacy scale scores of students in Group-1 and Group-2 in favor of the posttest when examining Table 9 ($t = -2.914$, $p = 0.005$ and $t = -2.629$, $p = 0.012$, respectively).

Table 5. Critical thinking tendency scale pretest – posttest mean scores

Groups		Mean (X)	
		Pretest	Posttest
Group-1	Mathematics	190.734	194.326
Group-2	Special Education	196.875	208.525
Group-3	English	–	197.625
Group-4	Turkish	–	203.540

Source(s): Table by authors

Table 6. Critical thinking tendency scale group-1 and group-2 pretest – posttest *t*-test results

Groups	Test	*n*	X	Ss	*t*	*p*
Group-1	Pretest	49	190.73	18.716	−1,534	0.131
	Posttest	49	194.33	15.672		
Group-2	Pretest	40	196.88	20.795	−3,084	0.004
	Posttest	40	208.53	20.248		

Source(s): Table by authors

Table 7. Critical thinking tendency scale posttest scores 2 × 2 ANOVA results

Source	df	MS	F	p
Pre-test	1	24.913	0.064	0.801
Method	1	3545.721	9.090	0.003
Pretest × method	1	601.278	1.541	0.216
Error	146	390.066		

Source(s): Table by authors

The results of the 2 × 2 ANOVA test for the posttest scores of the academic literacy scale (O2, O4, O5 and O6) are shown in Table 10.

Table 10 shows that the "pretest-method" interaction has no significant effect ($p = 0.487$) on academic literacy scale scores.

As seen in Table 10, the study examined the effect of the method on academic literacy scale posttest scores (O2, O4, O5 and O6) using Test D. However, the result was not significant ($p = 0.939$).

An ANCOVA analysis (Test E) was conducted on the scores of Group-1 and Group-2 for the academic literacy scale. The results of the analysis are presented in Table 11.

According to Table 11, the difference in posttest scores between the groups was insignificant when controlling for pre-test scores in the ANCOVA analysis ($p = 0.789$).

Groups		Mean (X) Pretest	Pretest
Group-1	Mathematics	87.346	90.596
Group-2	Special Education	88.300	91.500
Group-3	English		92.360
Group-4	Turkish		91.105

Source(s): Table by authors

Table 8. Academic literacy scale pretest – posttest mean scores

Groups	Test	*n*	X	Ss	*t*	*p*
Group-1	Pretest	52	87.346	6.709	−2,914	0.005
	Posttest	52	90.596	7.463		
Group-2	Pretest	40	88.300	9.148	−2,629	0.012
	Posttest	40	91.500	8.938		

Source(s): Table by authors

Table 9. Academic literacy scale group-1 and group-2 pretest – posttest *t*-test results

Source	df	MS	*F*	*p*
Pretest	1	20.332	0.262	0.609
Method	1	0.462	0.006	0.939
Pretest × Method	1	37.620	0.486	0.487
Error	152	77.468		

Source(s): Table by authors

Table 10. Academic literacy scale posttest scores 2 × 2 ANOVA results

Source	df	MS	*F*	*p*
Pretest	1	1568.621	31.816	0.000
Method	1	3.554	0.072	0.789
Error	89	49.302		

Source(s): Table by authors

Table 11. ANCOVA analysis results for academic literacy scale group-1 and group-2 scores

An independent samples *t*-test was conducted on posttest scores (O5 and O6) of Group-3 and Group-4 on the academic literacy scale. The results of the analysis can be found in Table 12.

According to Table 12, the *t*-test result shows no significant difference between posttest scores of Group-3 and Group-4 ($p = 0.619$).

Stouffer's *Z* method was used to combine ANCOVA and *t*-test results in a meta-analysis (Test I). However, the result was insignificant (Zmeta = 0.540, $p = 0.589$).

Upon thorough analysis, it was concluded that the academic literacy scale posttest scores were not improved by the method. Furthermore, there was no discernible difference in the effectiveness of the problem-based quantum learning model and the project-based 6E learning model in enhancing students' academic literacy skills.

Discussion and conclusions

It was concluded that the project-based 6E learning model was effective in developing critical thinking in students, though not significantly. Project-based learning is a highly effective teaching method that fosters higher-level and critical thinking skills in students (Aksela and Haatainen, 2018; Wahyuni, 2014). Through active participation in various stages of a project, students can shape their ideas and express their perspectives, which in turn enhance their critical thinking ability (Zoller, 1991). Several studies have indicated that the learning cycle can significantly improve students' reasoning and critical thinking abilities (Racheal, 2019; Sam *et al.*, 2018). Therefore, the findings of this study align with the existing literature on this subject.

Şahin and Kılıç (2023a) conducted a study which showed that using the project-based 6E learning model helped improve students' research skills. This included their ability to identify problems, collect data, analyze information, draw conclusions, report their findings and make presentations. This finding supports the idea that critical thinking involves defining arguments, processing and assessing information, analyzing and evaluating situations, and making informed decisions, as explained by Bassham *et al.* (2011). Therefore, it can be concluded that these two research outcomes are compatible.

In a study conducted by Şahin and Kılıç (2023a), it was found that the project-based 6E learning model is effective in helping students to question and strengthen their values, as well as acquire new ones. Furthermore, another study by the same authors (Şahin and Kılıç, 2023c) showed that the model shifts students' perception of education from being centered on the teacher to being centered on the student. In a parallel study (Şahin and Kılıç, 2023b), it was concluded that the project-based 6E learning model has a positive impact on students' perception of democracy. All of these accomplishments are tied to the development of critical thinking skills in students. As a result, it can be inferred that modeling improves students' critical thinking abilities.

It has been concluded that the problem-based quantum learning model has a significant impact on improving students' critical thinking skills. Several studies have found that problem-based learning can enhance the critical thinking abilities of students (Duch *et al.*, 2001; Purba *et al.*, 2020; Seibert, 2021). Quantum learning is a teaching approach that aims to

Table 12. Academic literacy scale group-3 and group-4 posttest scores *t*-test results

Groups		*n*	X	Ss	*t*	*p*
Group-3	English	25	92.360	9.869	0.500	0.619
Group-4	Turkish	38	91.105	9.666		

Source(s): Table by authors

expand students' cognitive capacities. According to Johnson (2002), quantum learning involves "learning at the highest level of people's thinking potential." The results of this study are consistent with previous research. Ökmen *et al.* (2023) discovered that the problem-based quantum learning model positively impacted pre-service teachers' problem-solving, critical thinking, research and decision-making skills. These findings suggest that the problem-based quantum learning model is a useful tool for enhancing critical thinking skills.

At the conclusion of a study, it was found that the project-based 6E learning model significantly improved students' academic literacy. A study conducted by Şahin and Kılıç (2023a) demonstrated that this learning model helped students develop skills such as problem identification, data collection and analysis, inference, reporting and presentation. These findings suggest that implementing the project-based 6E learning model can be an effective way to boost students' academic literacy. Weideman and van Dyk (2014) argue that activities that encourage students to plan, infer, conclude and solve problems are critical for improving academic literacy at all educational levels. Based on this, it can be concluded that the activities involved in the project-based 6E learning model can effectively improve students' academic writing skills.

It has been concluded that the problem-based quantum learning model has a significant impact on improving students' academic literacy. According to Demir (2006), quantum learning model helps students to acquire academic literacy skills through various activities such as quantum note-taking, quantum memory, quantum writing and quantum reading. Li (2022) further explains that purposeful, structured and meaningful learning activities that are genuine and emotionally valuable can help students develop advanced literacy skills. Our research has discovered that the problem-based quantum learning model activities are highly effective in enhancing students' academic literacy skills. These activities include various techniques such as clustering, rapid writing, summary writing using the Cornell technique, letter writing, memoir writing, story writing, drama writing, acrostic writing, slogan writing, analysis, classification, mind mapping, concept map creation, fishbone preparation, structured grid preparation, puzzle preparation, opposite panel, circle technique, six hats thinking technique, snowball technique and argumentation.

Research has shown that the problem-based quantum learning model is better at improving critical thinking skills than the project-based 6E learning model. However, there doesn't seem to be any noticeable difference in academic literacy development of students between the problem-based quantum learning model and the project-based 6E learning model.

Acquiring valuable competencies such as critical thinking and academic literacy is essential to improving the quality of teaching. Educators should design and facilitate experiences that enable students to develop and apply these skills to all aspects of their lives, irrespective of the level or subject. The problem-based quantum learning model and the project-based 6E learning model should be promoted and adopted by educators at all levels, ranging from early childhood to higher education. These models should be implemented in diverse subject areas and evaluated through rigorous research to ensure their effectiveness. Additionally, similar studies can be conducted across different educational institutions to compare and contrast the outcomes.

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