An Examination of Technology Usage Levels of Pre-Service Mathematics Teachers' Microteaching Lesson Plans Based on the 5E Model: A Case Survey

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Abstract: The knowledge and skills that pre-service mathematics teachers (PMTs) should have for effective technology-enhanced mathematics teaching are essential for efficient classroom practices. This study aims to examine the PMTs' planning processes of technology-enhanced microteaching lessons based on the 5E (engage, explore, explain, elaborate, evaluate) model and determine their technology usage levels during the 5E phases. We designed a case survey model. The participants were 24 PMTs enrolled in a mathematics teacher preparation program at a state university in Istanbul. Data consisted of 24 PMTs' high school-level lesson plans and teaching notes. We analyzed the data using the Techno-Pedagogical Integration Matrix (TPIM), whose x-axis consists of the phases of the 5E instructional model, and the y-axis consists of the technology usage levels of the SAMR (substitution, augmentation, modification, redefinition) model. While the 5E phases during which participants used technology most were the engagement and exploration phases, the highest level of technology use, according to the SAMR model, was at the modification level in the exploration phase of the 5E model. This study serves as a valuable resource for researchers and educators seeking to incorporate the SAMR model into mathematics teaching, offering a clearer, more context-specific interpretation of the model.

Keywords: Technology-enhanced mathematics teaching, 5E model, SAMR, microteaching, pre-service mathematics teachers

INTRODUCTION

Digital technological tools in mathematics teaching have become widespread, especially in the last 40 years. Research on technology-enhanced mathematics teaching emphasizes that technology contributes to teaching by visualizing concepts (Zhang et al., 2023), using multiple representations and supporting conceptual understanding (Kaput, 2018; Goldin, 2020). Teachers should have adequate pedagogical and content knowledge to use technology effectively in the classroom. It is essential to support PMTs in this respect. In this context, in Türkiye, there are many courses in the undergraduate programs of faculties of education for PMTs to support them in successfully integrating technology into their lessons. Understanding how PMTs integrate technology into their microteaching lessons is crucial for improving teacher preparation programs. One approach to investigating this is analyzing PMTs' microteaching practices. In undergraduate teacher preparation programs in Türkiye, these practices are incorporated into courses such as Teaching Numbers and Operations, Teaching Algebra, and Teaching Geometry, among others. Still, the evaluation of microteaching lessons within the scope of technology integration is left to the initiative of the instructor giving the course. As such, it is essential to examine how PMTs use various teaching methods and strategies regarding technology integration in the planning and implementation processes of microteaching to train effective teachers. In this context, this study aims to examine PMTs' planning processes of the 5E model in technology-enhanced microteaching lessons and determine their technology usage levels during the 5E phases. In this context, this study attempts to answer the following research questions:

- How do PMTs plan each phase of the 5E model in technology-enhanced microteaching lessons?
- At which level do PMTs plan to use technology in each phase of the 5E model in technology-enhanced microteaching lessons?

LITERATURE REVIEW AND THE CONCEPTUAL FRAMEWORK

The Literature on the 5E Model

Karplus and Thier (1967) proposed the 5E model as a three-phase structure of a lesson: explore, explain, and elaborate. Later, the evaluation phase was introduced, transforming it into the 4E model. Finally, with the infusion of the constructivist approach, the engagement phase was integrated, completing the 5E model. The sequential phases are *engage*, *explore*, *explain*, *elaborate*, and *evaluate* (Bybee, 2014).

Engagement Phase: This phase aims to capture students' attention and interest. The teacher directs students' focus toward a situation, event, demonstration, or problem related to the content. Strategies such as questioning, problem-posing, and presenting unique events engage students and activate their prior knowledge.

Exploration Phase: At this stage, students engage in activities to resolve the disequilibrium introduced earlier. These activities are designed to introduce and clarify the concepts, practices, and skills associated with the instructional sequence. Students need experiences that help them explain, explore, observe, and develop cognitive and practical skills. In this phase, the teacher initiates the activity, explains the necessary background, provides adequate materials and equipment, and addresses misconceptions.

Explanation Phase: During this phase, emphasis is placed on the scientific comprehension of phenomena. Concepts and practices that students previously encountered and explored are now elucidated. The teacher concentrates on the essential elements from the preceding phases and seeks students' explanations. Subsequently, leveraging these explanations and experiences, the teacher introduces scientific or technological concepts. While verbal explanations are prevalent in this phase, videos, web resources, or software can also be effective instructional aids.

Elaboration Phase: Students participate in learning experiences to enrich the concepts established in the preceding phases. The objective is to facilitate transferring what has been learned to novel situations. A crucial aspect of this phase involves employing challenging activities that students can effectively accomplish. The teacher introduces a new scenario and fosters student interactions with resources like written materials, simulations, and web-based searches.

Evaluation Phase: Students receive ongoing informal feedback on their explanations throughout instruction, while the evaluation phase focuses on formally assessing and reporting learning outcomes. In this phase, the teacher engages students in activities that are comprehensible, consistent with previous phases, and aligned with their explanations. The teacher must discern the evidence of student learning and the methods for acquiring this evidence as part of the evaluation phase. This phase encourages students to evaluate their understanding and abilities while enabling teachers to assess their progress toward learning objectives.

The literature on the 5E model demonstrates its effectiveness in enhancing students' academic achievement across various levels and contexts (Cakir, 2017; Cakir & Güven, 2019; Guzel, 2016; Parveen, 2017; Dahal, 2023). Studies indicate that the 5E model positively influences students' attitudes toward specific subjects (Cakir, 2017; Guzel, 2016; Sotáková & Ganajová, 2023). It promotes conceptual learning (Grau et al., 2021) and enhances 21st-century skills such as critical and creative thinking (Asrizal et al., 2022). Consequently, this instructional model facilitates knowledge construction and aligns well with student-centered approaches (Triet et al., 2024; Yaman & Karaşah, 2018). However, incorporating the 5E model into education can pose challenges for teachers (Nawastheen, 2014) and pre-service teachers (Turan, 2021), underscoring the necessity for professional development in this domain (Nawastheen, 2014).

In addition to the previously mentioned studies, literature also examines the incorporation of the 5E model into mathematics lessons. These studies indicate that the 5E model enhances students' mathematics achievement (Akinyemi & Okwatojin, 2017; Tezer & Cumhur, 2017), their levels of conceptual and procedural knowledge (Bakri, 2021), and consequently, their conceptual understanding (Grau et al., 2021). Furthermore, it improves their performance in non-routine problems (Adu & Folson, 2023), increases their engagement in lessons (Turan & Matteson, 2020), and ignites their interest in the subject (Nguyen, 2021). Similarly, the literature underscores the positive impact of integrating the 5E model with technology in teaching. This fusion significantly boosts students' higher-order thinking skills (Shivam & Mohalik, 2022). Integrating educational technology, such as e-modules, into the 5E model enhances engagement, interactivity, and effectiveness in attaining learning objectives (Penelitian et al., 2023).

Literature on the SAMR Model

The SAMR model, introduced by Dr. Ruben Puentedura, serves as a framework for comprehending technology integration in education (Puentedura, 2010; 2014; 2020). It encourages teachers to contemplate how and why they use technology and how its integration can enhance their pedagogical practices as they gain proficiency (Puentedura, 2016). This model facilitates the assessment of the level and purposes of technology integration in instruction, organized into four sub-levels across two primary levels (see Table 1). The *enhancement* level encompasses the *substitution* and *augmentation* levels. Technology enhances and improves the learning experience at the *enhancement* level (Caukin & Trail, 2019). The *transformation* level encompasses the *modification* and *redefinition* levels. This level aids in transforming the learning experience (Caukin & Trail, 2019). The SAMR model can be conceptualized as a ladder, with *substitution* at the lowest rung and *redefinition* at the highest (Caukin & Trail, 2019). *Substitution* occurs when technology directly replaces a task without altering its function (Puentedura, 2010). At the *augmentation* level, technology is a direct tool for enhancing functionality (Puentedura, 2010). At the *modification* level, the task undergoes significant redesign through technology. Finally, at the *redefinition* level, technology enables the creation of entirely new tasks that are not feasible without its use (Caukin & Trail, 2019). Additionally, although not explicitly part of the SAMR model, the absence of technology, as emerged from the data of this study, has also been incorporated into Table 1.

Main levels	Levels	Brief descriptions
Transformation	Redefinition	Creation of entirely new tasks that are not possible without technology integration.
	Modification	Tasks are rearranged.
Enhancement	Augmentation	Technology is implemented for a functional reason.
	Substitution	Technology directly replaces a task without altering its function
	Not using technology	Technology is not utilized.

Table 1. Revised SAMR Model

Reviewing the literature on the SAMR model reveals that its integration into instruction has resulted in positive changes in student attitudes and achievements (Adulyasas et al., 2021; Romrell et al., 2014). Additionally, students have demonstrated increased reflection in their classes (Hilton, 2015). These findings underscore the SAMR model's contribution to enhancing instruction.

Conceptual Framework

This study examines how PMTs plan for technology-enhanced microteaching lessons and assesses the extent of technology integration across the phases of the 5E model. We developed a conceptual framework called the TPIM to accomplish this goal. The TPIM has two dimensions: the *x*-axis corresponds to the phases of the 5E instructional model, and the *y*-axis indicates the levels of technology utilization according to the SAMR model (see Figure 1). Şahin (2020) and Şahin & Akkoç (2020; 2021) integrated the Teaching Quality framework (Klieme et al., 2009) and the SAMR model (Puentedura, 2010) to investigate the pedagogical strategies employed by PMTs in addressing misconceptions regarding the concept of derivative. They termed this framework TPIM. In the framework applied in these studies, the *x*-axis represented the Teaching Quality framework, while the *y*-axis indicated SAMR levels. For this study, the *x*-axis has been adjusted as the phases of the 5E model to explore how technology is integrated into lessons at these stages.

METHODOLOGY

Research model

We designed this study as a case survey model. The survey model aims to describe a particular phenomenon. The case survey model, a specific type of this model, provides a more detailed examination of the phenomenon described (Yin, 2018). This study prefers this model since it allows the exploration of the lesson plans of all PMTs in a specific course, combining the breadth of a survey with the depth of case analysis.

Context of the study and participants

The study participants consisted of 24 PMTs enrolled in a mathematics teacher preparation program of an education faculty at a state university in Istanbul. The study was conducted within the scope of the Mathematics Teaching II course in the spring semester of the program's third year. All of the PMTs registered on the Mathematics Teaching II course participated in the study. The course instructor was the second author of this study. Due to the pandemic, the classes were taught using a hybrid method. We divided the class into two groups: one attended weekly face-to-face sessions, while the other participated simultaneously via the university's distance education platform. During the fall semester, the *Mathematics Teaching I* course covered various topics, including procedural and conceptual understanding, misconceptions, and student difficulties. Additionally, it addressed van Hiele's geometric thinking levels, principles of task design, and evaluation of mathematical tasks (Dede et al., 2020; Yeşildere-İmre, 2020).

Within the scope of the final assignment of this course, PMTs evaluated tasks based on the design principles of mathematical tasks (Yeşildere-İmre, 2020). First, they identified a learning outcome from the upper secondary mathematics curriculum (MoNE, 2018) and selected a task from various sources that aimed at this learning outcome. Then, they evaluated the tasks by considering task design principles (Yeşildere-İmre, 2020). They prepared and presented their evaluations as a written report. The Mathematics Teaching II course focused on teaching strategies and methods. The expository teaching approach (Ausubel, 1963), teaching through discovery, and inquiry-based teaching (Bruner, 1960) were discussed with examples. Afterward, the course instructor explained the 5E model using exemplary lesson plans and analyzed them according to the five phases of the model. The sample lesson plans covered topics such as the Pythagorean theorem, interpreting function graphs, right prisms, definite integrals, etc., and were divided into subsections according to each stage of the 5E model. A whole-class discussion focused on identifying the characteristics of each stage. The training on effective technology integration was conducted by the first author as part of the *Instructional Technologies and Material Design* course held during the same term. This course focused on the use of software such as Geogebra and Desmos and their integration into lesson planning. For the final assignment of the *Mathematics Teaching II* course, PMTs selected a learning outcome from the curriculum (MoNE, 2018) and designed a lesson plan according to the 5E model. The assignment instructions included selecting learning outcomes that were suitable for the 5E model, ensuring that the lesson plan contained subsections for each phase of the model, and writing teacher and student activities for each phase (See Table 2).

5E phases	Teacher activity	Student activity
Engagement	The teacher asks students about the perimeter, area, and circle. The teacher asks for their opinions to assess their prior knowledge.	Students engage in peer discussions to answer the questions posed by the teacher and articulate their perspectives.
Exploration	Teacher asked students to review the GeoGebra activity called "Icosahedron Planet."	Students are expected to derive the formula for the circumference of a circle through the GeoGebra activity *"Icosahedron Planet."* Throughout this process, they actively exchange information and engage in discussions with their group members.

Table 2. A section from the lesson plan template

The course instructor (the second author) gave feedback on participants' microteaching lessons based on the 5E model and technology integration.

Data Analysis

The data sources for this study consist of only lesson plans and teaching notes (e.g., worksheets, homework, slides) rather than microteaching lessons. Since the framework for data analysis and the lesson plans were well-structured, we analyzed the data manually. We analyzed the lesson plans to address the first research question by segmenting them according to the phases of the 5E instructional model. We identified the distinct types of teacher and student activities present in the plans and then calculated their frequency values. Then, each section underwent content analysis to examine how PMTs structured their lessons. Based on the findings, categories were then developed for each phase. In this context, teaching notes served as a supplementary data source. To address the second research question, we analyzed the level of technology integration in each phase of the 5E model using the SAMR framework. This methodological approach provided a comprehensive perspective on how PMTs incorporated technology into their lesson planning.

Validity and Reliability of the Study

Lincoln and Guba (1985) proposed four key criteria for ensuring trustworthiness in qualitative research: credibility, transferability, dependability, and confirmability. Credibility relates to how accurately findings reflect participants' experiences, transferability concerns their applicability to other contexts, dependability addresses consistency, and confirmability ensures findings are shaped by participants rather than researcher bias.

To enhance credibility, a case survey approach and data triangulation—using lesson plans and teaching notes—were employed. The second author observed and engaged with PMTs throughout the semester, contributing to data authenticity. The first author led the analysis, with consistency checked via Miles and Huberman's (1994) method. Two additional researchers—the course instructor and a qualitative expert—independently reviewed the lesson plans, adding diverse perspectives. The TPIM matrix supported systematic data analysis.

Transferability was addressed through detailed descriptions of the context and participant selection. An audit trail ensured dependability by documenting the research process. Confirmability was strengthened through triangulation and rigorous analysis. After the first author coded the data, inter-coder agreement was examined with the second author to ensure coding reliability. Coding reliability was confirmed with 100% inter-coder agreement between the first and second authors. Table 3 presents the results of this analysis.

RESULTS

Findings about the Phases of the 5E Model

This subsection will present findings regarding the first research question: "How do PMTs plan each phase of the 5E model in technology-enhanced microteaching lessons?" To answer this question, we examined the teacher and student activities outlined in the lesson plan template (See Table 2). The analysis focused on identifying the activities planned by PMTs for each phase of the 5E model in technology-enhanced microteaching sessions. Table 3 summarizes the lesson plans' teacher and student activities and their corresponding frequency values.

5E Phases	Teacher Activities	N	Student Activities	N
Engagement	• Examining students' readiness levels	20	• Participating in class discussions	20
	• Establishing a connection between the concept and daily life	15	• Finding examples related to the concept from daily life	5
	• Drawing attention to the lesson	11	• Watching videos	5
	• Pre-informing students about the lesson	4	• Being attentive to the lesson	4
	• Grouping students	1	• Sharing ideas through related visuals	2
			• Relating concepts/ideas	2
			• Being a passive listener	1
			• Making predictions about the topic	1
	TOTAL	**51**	**TOTAL**	**40**
Exploration	• Initiating the process of discovery with the help of activities and questions to students	24	• Participation in the activities and class discussions	24
			• Expressing the conclusions reached	3
	TOTAL	**24**	**TOTAL**	**27**
Explanation	• Explaining the ideas discovered by students in more detail	12	• Making sense of the definition provided by the teacher	7
	• Giving the definition after student explorations	12	• Expressing the topic/concept/situation correctly	6
	• Informing students about the use of the concept in other subjects	1	• Comparing/relating the concept with other concepts	2
	• Asking students questions about the concept	1	• Concentrating on conceptual understanding	1
	• Associating the concept with other concepts	1	• Interpreting peers' hypotheses	1
			• Presenting examples from daily life	1
			• Making connections between what emerges in classroom interaction and their conclusions	1
			• Learning the key points of the concept	1
			• Answering the teacher's questions	1
			• Producing different methods for solutions	1
	TOTAL	**27**	**TOTAL**	**22**
Elaboration	• Reinforcing the concept with new questions involving connections with other concepts	15	• Answering new questions using previously discovered facts	13
	• Relating the concept to other concepts	3	• Gaining more detailed information about the concept	3
	• Relating the concept to daily life	2	• Connecting the concept with other concepts	2
	• Mentioning situations that may create misconceptions about the subject	1	• Recognizing misconceptions	1
	• Providing information about the historical development of the concept	1	• Making the most comprehensive definition of the concept	1
	• Asking questions about the concept in more than one context	1	• Presenting examples from daily life and different disciplines	1
	• Building a model related to the concept	1	• Clarify parts that are mislearned or not fully understood	1
			• Model-building	1
	TOTAL	**24**	**TOTAL**	**23**
Evaluation	• Evaluating students through various platforms (Desmos, websites, GeoGebra, etc.), tests from textbooks, or worksheets	16	• Answering questions	16

• Asking students to self-assess	4	• Conducting self-assessment	4
• Asking students to evaluate the lesson	2	• Asking the teacher about unclear points	3
• Asking students to make presentations about their evaluations	1	• Creating a concept map	1
		• Presentation	1
		• Lesson evaluation	1
TOTAL	**23**	**TOTAL**	**26**

Table 3. Teacher and student activities identified in the lesson plan

In the *engagement* phase, *examining students' readiness levels (20 occurrences*), *establishing a connection between the concept and daily life (15)*, and *drawing attention to the lesson (11)* were the most favored teacher activities. Other teacher activities included *pre-informing students about the lesson (4)* and *grouping students (1)*. Regarding student activities, notable actions included *participating in class discussions (20)*, *finding examples related to the concept from daily life (5)*, *watching videos (4)*, and *being attentive to the lesson (4)*. Thus, while *determining students' readiness levels* emerged as the most emphasized teacher activity in this phase, *participating in class discussions* was the prominent student activity.

All 24 PMTs unanimously stated that teachers could initiate the exploration phase, by posing questions to students and guiding their discovery process through tasks. Regarding the student activities, they emphasized *student participation in the activity and class discussion* (24) and students' statements about *the conclusions reached* (3). The unanimity among PMTs regarding the teacher activity in the *exploration* phase is notable. In this respect, PMTs think teachers should realize this phase by asking questions or implementing tasks.

Teacher activities such as *explaining the ideas discovered by the students in more detail* (12) and *providing definitions after the student explorations* (12) are noteworthy activities in the *explanation* phase. Moreover, the *explanation* phase exhibited the highest variety of student activities. The most common ones were *making sense of the definition provided by the teacher* (7) and *correctly expressing the topic/concept/situation* (6). The findings underscore the importance of teachers providing the ideas discovered by students in the previous phase in a detailed and formal manner. Conversely, although student activities varied, the focus was on understanding the concept, expressing it, interpreting it, and establishing connections between concepts.

The *elaboration* phase exhibited the highest variety of teacher activities among the 5E phases. Notably, *reinforcing the concept with new questions involving connections with other concepts* (15) stood out. Additionally, *relating the concept to other concepts* (3) and *relating the concept to daily life* (2) were other teacher activities. Regarding student activities, *answering new questions using previously discovered facts* (15) were the most frequently cited. In this phase, both teachers and students aimed to deepen their knowledge by applying it to different situations and contexts.

The most noteworthy teacher activity in the *evaluation* phase was *evaluating student learning through various platforms (Desmos, websites, GeoGebra, etc.), tests from textbooks, or worksheets* (16). Other assessment approaches were *asking students to self-assess* (4) and *asking students to* *evaluate the lesson* (2). *Having students answer questions* (16) was the most mentioned student activity in the *evaluation* phase.

Table 4 shows a PMT's lesson plan excerpt, coded as "examining students' readiness levels" for teacher activity and "participating in class discussions" for student activity.

5E phases	Teacher activity	Student activity
Engagement (7 minutes)	Using the activity "Are We Driving Carefully?", students are asked questions related to perimeters, areas, and circles. Their ideas are elicited to assess their prior knowledge.	Students engage in discussions with their peers and express their ideas.
	Students are asked questions based on bicycle images to assess the level of their prior knowledge regarding the concept of perimeter.	

Table 4. An excerpt from a lesson plan (x-axis: engagement; y-axis: not using technology)

While there was no use of technology as can be seen in Table 4, another PMT used technology at the *substitution* level during the *engagement* phase as seen in Table 5.

5E phases	Teacher activity	Student activity
Engagement (5 minutes)	The teacher opens the quiz "Circumference and Area Questions in a Circle" in Desmos and gives students some time to complete the questions while closely monitoring their progress. The teacher reminds students that both their work process and outcomes will be assessed and will contribute to their grades.	The student works individually to solve the questions in Desmos and seeks assistance from the teacher when encountering difficulties.

Table 5. An excerpt from a lesson plan (x-axis: engagement and y-axis: substitution)

This excerpt was coded as "evaluating students through various platforms (Desmos, websites, GeoGebra, etc.), tests from textbooks, or worksheets" under teacher activity and "answering questions" under student activity.

While some PMTs accurately structured the phases of the 5E model in their lesson plans, others struggled to organize these phases effectively. Table 6 displays the errors identified in the lesson plans of the PMTs regarding identifying the phases of the 5E model.

PMTs	The 5E phase specified	Correct 5E phase
PMT1	Exploration	Explanation
PMT1	Elaboration	Evaluation
PMT3	Exploration	Engagement
PMT4	Exploration	Engagement

PMT4	Explanation	Exploration
PMT4	Explanation	Elaboration
PMT5	Exploration	Engagement
PMT13	Evaluation	Elaboration
PMT16	Elaboration	Exploration
PMT16	Elaboration	Explanation

Table 6. Errors detected in lesson plans (wrong positioning of the phases)

According to the table, we found ten errors in the lesson plans of six PMTs. For instance, an activity intended for the *exploration* phase was sometimes presented in other phases. In these cases, the study repositioned the activity to the phase where it should be and conducted the analysis accordingly. As seen in Table 6, PMT4 included a teacher activity in the *exploration* phase. He stated, "*The teacher relates the topic of probability to daily life and asks students to find examples.*" This activity, however, should be part of the *engagement* phase of the lesson rather than the *exploration* phase. Similarly, PMT1 mentioned that the *teacher gives the definition of the concept* during the *exploration* phase. However, the definition of the relevant concept should be presented during the *explanation* phase. Upon reviewing the lesson plan of PMT13, *comprehensive understanding utilized to underscore the relationship between the concept and other disciplines and everyday life* should ideally be situated within the *elaboration* phase rather than the *evaluation* phase. Consequently, this statement was re-coded as the *elaboration* phase. We detected analogous misplacements in the lesson plans of other PMTs, as outlined in Table 6 and rectified accordingly for the analysis of this study.

The Levels of Technology Use Planned in the Stages of the 5e Model

This sub-heading presents the findings concerning the second research question regarding the level of technology use in each phase of the 5E model in lesson plans. The levels of technology use in each phase of the 5E model in their technology-enhanced microteaching lessons are presented in Figure 1 within the framework of TPIM.

As illustrated in Figure 1, PMTs did not incorporate technology in 62 activities outlined in their lesson plans. Furthermore, activities at this level are uniformly dispersed across all phases of the 5E model, with 12 activities allocated to *engagement*, 11 to *exploration*, 13 to *explanation*, 11 to *elaboration*, and 15 to *evaluation*. In activities categorized as *not utilizing technology*, PMTs intended to use materials such as whiteboards, activity sheets, textbooks, etc., instead of technological resources.

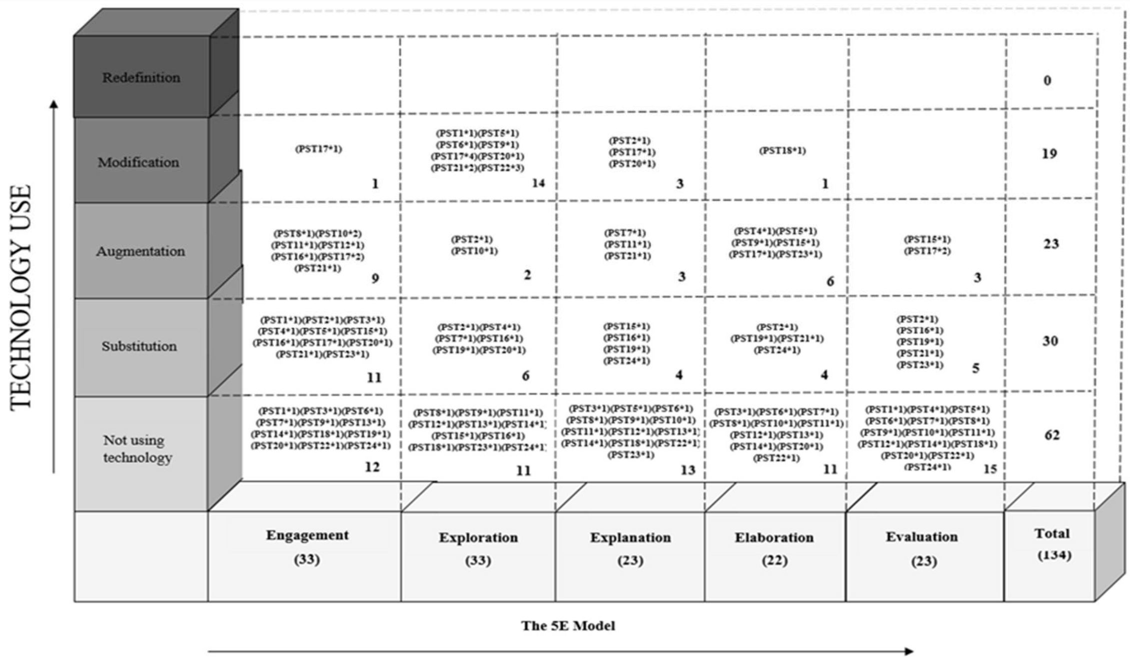

Figure 1. Techno-Pedagogical Integration Matrix (TPIM)

PMTs predominantly planned to integrate technology at the *substitution* level, with 30 instances recorded. Upon scrutinizing the distribution of the *substitution* level across the 5E phases, PMTs intended to employ this level most frequently during the *engagement* phase of the lesson, amounting to 11 instances. Specifically, they aimed to project lesson content onto the smart board. Figure 2 showcases a screenshot of the content projected onto the smart board by PMT17 at the onset of the lesson. PMT17 intended to project content featuring visuals illustrating the connection of the angle concept to daily life, alongside various related questions, to introduce the topic of angles at the beginning of the lesson.

Additionally, the *substitution* level demonstrates a relatively consistent distribution across the other four phases of the 5E model. PMTs aimed to incorporate *substitution*-level activities in six instances during the *exploration* phase, four during the *explanation* phase, four during the *elaboration* phase, and five during the *evaluation* phase. Throughout these phases, their primary approach involved projecting lesson content onto the smart board. Nevertheless, unlike others, PMTs intended to employ this level by administering virtual tests prepared in applications such as Desmos during the *elaboration* and *evaluation* phases.

PMTs incorporated a total of 23 activities at the *augmentation* level in their lesson plans concerning the utilization of technology. Upon examining the distribution of the *augmentation* level across the 5E phases, PMTs predominantly used technology in the *engagement* phase of the lesson. In this context, they intended to leverage technology by showcasing videos, graphing in GeoGebra, responding to questions in GeoGebra, conducting activities prepared in GeoGebra (without variable changes, providing a video-watching effect), or organizing the classroom using applications like Rakko (streamlining the grouping of students).

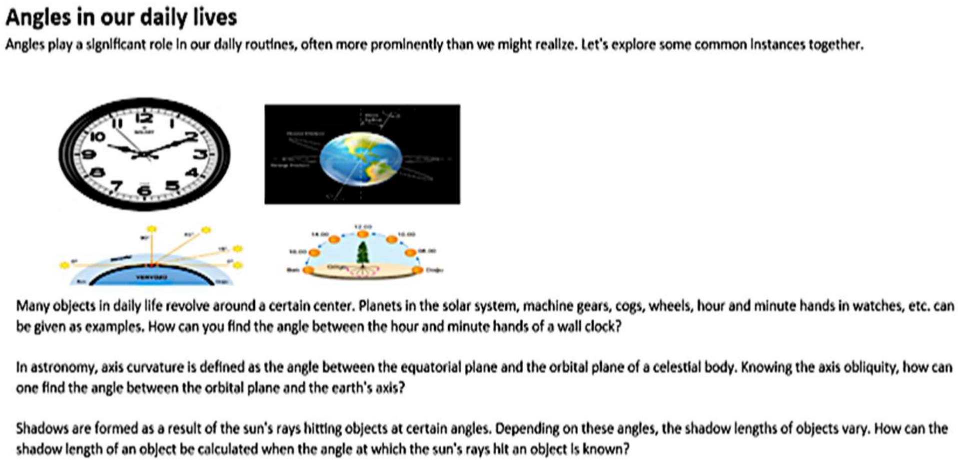

Figure 2. An example activity for the use of technology at the *substitution* level (PMT17)

Furthermore, PMTs strategically incorporated *augmentation*-level activities for various purposes across the other phases of the 5E model. They aimed to enhance students' inferential processes concerning the concept by utilizing tools such as GeoGebra's toolbox, graphing in Excel, generating new questions related to the concept using GeoGebra's random command, utilizing GeoGebra's calculator function, or solving questions related to the concept on various websites. As illustrated in Figure 3, PMT10 attempted to bolster students' inferential processes related to comprehension through graphing in GeoGebra. Consequently, PMT10 planned to implement technology at the *augmentation* level during the *exploration* phase of the 5E model.

There were 19 activities planned at the *modification* level. An examination of the distribution of activities at this level across the 5E model's phases shows that PMTs primarily aimed to utilize technology during the *exploration* phase (14). In doing so, they aimed to use GeoGebra's *slider* tool to enable students to make inferences based on different values . In this context, the planning at the *modification* level serves a single purpose, unlike other levels of technology. As seen in Figure 4, PMT21 planned to use GeoGebra's slider tool to introduce the concept to students during the *exploration* phase of the 5E model. The lesson prepared by PMT21 aimed to explore the formula for the area of a circle based on a polygon. In doing so, PMT21 focused on linking the two concepts by changing the number of sides of the polygon with the slider tool.

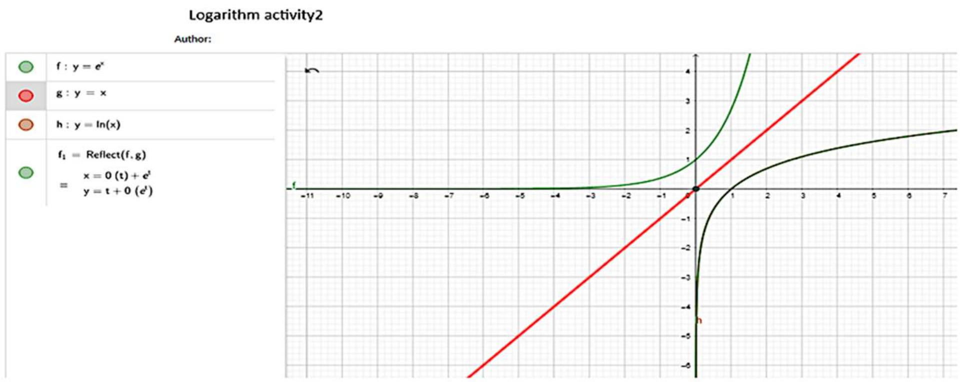

Figure 3. A sample activity section for the use of technology at the augmentation level (PMT10)

Additionally, as inferred from Figure 1, PMTs did not plan to use technology at the *redefinition* level. However, in the lesson plan of PMT18, the homework required designing an activity in GeoGebra similar to the activity used in the lesson. Although detailed information regarding this task was not offered in the plan, initially, the assignment might seem to be at the *redefinition* level. However, since the assignment solely entails technically designing a GeoGebra activity and is a repetition of an activity students have previously encountered, it does not meet the criteria for being classified at the *redefinition* level.

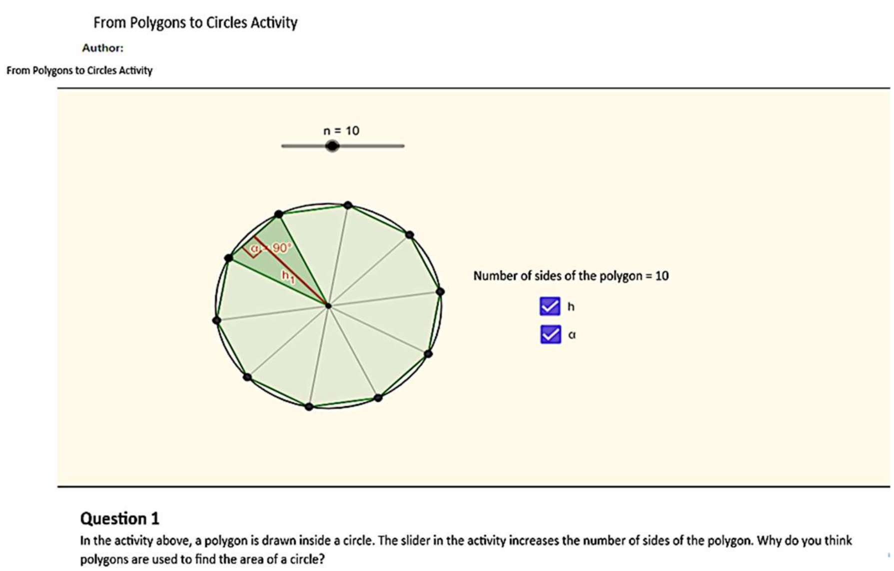

Figure 4. An example activity for the use of technology at the *modification* level (PMT21)

Finally, when evaluating the 5E model in general, PMTs have devised more activities in the *engagement* (33) and *exploration* (33) phases than in the other phases. In both phases, their plans primarily were at the level of *not using technology* or *substitution*. Particularly in the *exploration* phase, they aimed to employ GeoGebra to bolster students' inference-making (*modification level*).

DISCUSSION AND CONCLUSION

The findings indicate that PMTs primarily focused on teacher-led rather than student-centered activities in their lesson plans, suggesting an emphasis on teaching rather than learning. Notably, most teacher and student activities were concentrated in the *engagement* phase of the 5E model, a pattern also reflected in the TPIM framework (see Figure 1). PMTs planned most of the activities during this phase with or without technology. The study primarily emphasized assessing students' readiness levels and establishing connections to real-life contexts. Concerning to the findings about enhancing student engagement, teacher educators should: (1) promote interactive tasks that require active student participation, (2) provide structured guidance to ensure lesson plans include observable and measurable student actions, and (3) model effective strategies for facilitating student-centered learning instead of direct instruction.

Across all phases, student participation in class discussions was a prominent activity. However, PMTs appeared to assume that active student engagement would occur automatically. For instance, the lesson plan section for student activities during the *engagement* phase often listed "being interested in the lesson," which does not constitute a measurable or observable action. PMTs should incorporate clearly defined student activities that involve observable participation to improve lesson planning.

"Initiating the process of discovery with the help of activities and questions to students." was the only identified teacher activity in the *exploration* phase. Key teacher activities in other phases included "formally presenting the concept" (*explanation*), "reinforcing the concept in different contexts" (*elaboration*), and "assessing students' understanding" (*evaluation*). These findings align with the literature's definitions of the 5E model phases (Bybee, 2014).

Among the 5E phases, the *elaboration* phase exhibited the most variety of teacher activities (seven types), while the *exploration* phase showed the most diverse student activities (ten types). This finding suggests that PMTs recognized multiple ways to deepen students' conceptual understanding, from addressing misconceptions to model construction.

Some PMTs misidentified or misplaced the phases of the 5E model in their lesson plans. The *exploration* phase was often confused with the preceding *engagement* phase and the subsequent *explanation* phase. Similarly, the *evaluation* and *elaboration* phases were frequently misinterpreted. These findings suggest that some PMTs struggle to distinguish the transitions between successive 5E phases, a challenge also reported by Enugu and Hokayem (2017). Findings indicate the importance of strengthening PMTs' comprehension of the 5E instructional model. Teacher educators should offer explicit instruction on the distinctions between its phases through specific examples and structured templates, facilitate lesson-planning workshops that provide feedback on activity sequencing, and incorporate classroom simulations that allow for real-time application and reinforcement of phase implementation. Analysis of lesson plans through the TPIM framework revealed that PMTs incorporated the highest number of activities in the *engagement* and *exploration* phases, with a notable focus on technology use. Specifically, technology was planned for 21 out of 33 activities in the *engagement* phase and 22 out of 33 activities in the *exploration* phase.

In the *engagement* phase, they planned to use technology mainly at the *substitution* level by reflecting the relevant content on the smart board. PMTs employed technology at the *augmentation* level in the *exploration* phase, mainly through GeoGebra, to enhance students' mathematical discovery processes. To improve technology use in mathematics teaching, teacher educators should encourage PMTs to go beyond basic tools and use interactive digital tasks, like GeoGebra, for deeper learning. Since PMTs focus mostly on *engagement* and *exploration* while overlooking *elaboration* and *evaluation*, they should be guided to create more balanced lesson plans. This includes adding various activities in the *elaboration* phase and using better assessment methods in the *evaluation* phase.

Some PMTs aimed to integrate technology at the *modification* level for mathematical explanations. This finding is consistent with previous research (see Akkoç, et. al., 2022). However, no instances of *redefinition* were observed in their lesson plans, aligning with prior studies (Akkoç et. al., 2022; Akkoç & Hangül, 2023). Understanding and applying the TPACK and SAMR models can be challenging, even for experienced educators (Kirkland, 2017). Successful technology integration relies primarily on sound pedagogy rather than the technology itself (Dias & Atkinson, 2001). Effective technology integration requires more than technical skills; meaningful learning tasks must be thoughtfully designed. Therefore, a superficial comprehension of TPACK and SAMR models would be insufficient (Kirkland, 2017). However, educators should create opportunities for students to engage in innovative digital tasks, such as using augmented reality applications to design mathematical representations to foster this level of integration. Furthermore, teacher educators should incorporate research findings that effectively implemented the SAMR model (e.g., Adulyasas et al., 2021) to enhance instructional design and technology integration. The findings enhance the understanding of how TPIM and SAMR levels can be integrated into mathematics teaching. Puentedura's (2010) descriptions of SAMR levels tend to be general, lacking subject-specific applications, which may pose challenges for educators seeking to implement the model effectively. This study guides researchers and educators aiming to integrate the SAMR model into mathematics instruction, offering a more contextualized approach to its application.

These findings indicate that TPIM enhances the comprehensibility of the SAMR model's levels in the context of their integration into mathematics teaching. Analyzing the explanations of each level (see Puentedura, 2010) reveals their general nature, with notable limitations in domain-specific practices. This lack of specificity may pose challenges for researchers and educators seeking to implement the model effectively within their field. In this regard, the present study serves as a valuable resource for researchers and educators aiming to integrate the SAMR model into mathematics teaching, contributing to a clearer and more contextualized understanding of the model. Moreover, the TPIM framework helps PMTs better align their lesson planning with the 5E model and SAMR levels. By connecting phases such as *exploration* and *elaboration* with meaningful technology use, TPIM could guide PMTs to move beyond surface-level integration. This could contribute to more balanced, student-centered instructional design and support deeper learning in mathematics classrooms.

In summary, effective use of the 5E model in the context of technology-enhanced mathematics teaching requires a structured approach that prioritizes student-centered learning. Providing targeted training, clear lesson-planning guidelines, and professional development opportunities will help PMTs could develop their instructional strategies and enhance their ability to integrate technology meaningfully. By addressing these gaps, teacher educators can better equip PMTs to foster deeper conceptual understanding and more engaging learning experiences in mathematics classrooms.

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