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Abstract

The 5E instructional model is known for increasing student engagement and participation in the learning process. While viewing the video recorded lessons of middle school mathematics teachers, the researchers noticed teachers had a difficult time implementing the 5E model with fidelity. This case study explored the extent to which mathematics teachers used the 5E instructional model in their classrooms through analyzing video recorded lessons. The findings illustrate that the challenges of the teacher varied. They had difficulty finding activities related to the phases and moving away from a teacher-centered approach to a student-centered approach were identified as challenges of the teachers. The findings of this study inform educators about the difficulty's teachers have in implementing the 5E model with fidelity. Also, the researchers elaborate on what phases need to be addressed specifically when teachers are provided professional development regarding lesson instruction.

Introduction

An instructional model is the specific instructional plans, which are designed according to the concerned learnings theories. It provides a comprehensive blueprint for curriculum, instructional materials, lesson plans, teacher-student roles, supports aids, and so forth. Additionally, the instructional model serves as a blueprint for teaching because it allows the teacher to be structured with an organized flow from the beginning to the end of the lesson. In fact, teacher effectiveness starts with the teacher's ability to implement instructional models successfully (Marshall & Smart, 2013).

The 5E instructional model is one of the developed instructional practices based on constructivism. The Biological Science Curriculum Study (BSCS) team, led by Rodger Bybee, augmented the learning cycle model of Atkins and Karplus (1962), which had three stages: exploration, invention, and discovery. In the modified model, the 5Es represent the five phases of the lesson model: engagement, exploration, explanation, elaboration, and evaluation (Bybee et al., 2006). The 5E learning cycle calls for the teacher to complete the following sequence of activities: introduce the lesson by *engaging* students with a new concept, have students *explore* an idea or skill, *explain* the result of the targeted concept, *elaborate* each idea or skill through additional practice, and finally *evaluate* their progress in a new setting throughout the lesson.

Toraman and Demir's (2016) meta-analysis of 43 studies showed that research on the effectiveness of the 5E instructional model has been conducted in a variety of disciplines and teaching contexts from elementary school through college level. However, the focus of the majority of existing literature has been on investigating the use of the 5E learning model in teaching science (e.g., Lawson, 2001) or technology (Toraman & Denmir, 2016). However, empirical studies suggest that the 5E instructional model is also effective for teaching mathematics (e.g., Bybee et al., 2006; Walia, 2012).

Furthermore, the 5E instructional model was introduced in 1980, but the application of the learning cycle in classroom instruction continues to be a challenging task for teachers at all levels (e.g., Yildiz & Kocak Usluel, 2016). For example, Yildiz and Kocak Usluel (2016) and Biber et al. (2015) examined how the 5E learning cycle was implemented and effectively integrated into a mathematics lesson. Both studies concluded that the teachers struggled with the cycles in the phases of engagement, explanation, and evaluation. The scarce number of studies that examined mathematics teachers' knowledge of the 5E model suggests that mathematics teachers have found using the 5E model in their daily practice to be a challenge. To address this gap in the literature, this study sought to examine how mathematics teachers use the 5E instructional model in their daily practices.

Theoretical Framework

The 5E model was derived from the philosophical lineage of Johann Friedrich Herbart and John Dewey. The main idea behind constructivism is that individuals must be provided opportunities to construct their own knowledge and understanding (Herbart, 1901). Therefore, the learning environment needs to be designed as learner-centered, one in which students are afforded opportunities to actively engage in the learning process (Dewey, 1971).

Learner-centered is crucial to constructivism because teaching is not just transmitting knowledge from a resource to a receiver. Instead, the focus is on the process of facilitating "the learner's active engagement in assembling, extending, restoring, interpreting…knowledge out of the raw materials of experience and provided information" (Salomon & Perkins, 1996, p. 5). In a learner-centered environment with the 5E instructional model, teacher and student roles are no longer traditional. In other words, the teacher allows students to control their own learning and construct new knowledge based on their prior knowledge and experiences (Brooks & Brooks, 1999).

While teachers often believe they have created a learner-centered environment in the classroom, often this is not the case. Teachers often retain control of critical aspects of the lesson. Since the 5E instructional model has distinct elements, this qualitative case study answered the following research question: To what degree do teachers use the 5E instructional model in their math classrooms?

Relevant Literature

In examining the relevant literature, we honed in on two distinct components. First, we focused on the historical background of the development of the 5E lesson model. Then we examined the pertinent literature in which the 5E model has been used in mathematics settings. While there are numerous studies of the 5E model with a science focus, there are significantly fewer studies involving mathematics settings. In the early 1960s, Robert Karplus incorporated Jean Piaget's cognitive development processes of assimilation, accommodation, and equilibration into a learning cycle (Atkin & Karplus, 1962). Karplus believed that children build, or construct, their own internal mental schemas for knowing science as they experience the world (Fuller, 2003). Atkin and Karplus (1962) took Piaget's work into account for science curriculum development, and their learning cycles consist of three distinct phases: exploration, invention, and discovery. Karplus and colleagues used these principles in developing K-6 science curriculum (Fuller, 2003).

Discovery Learning Cycle

According to Atkin and Karplus (1962), in the first phase, exploration, students learn through their own actions in a new situation, wherein they explore new material and new topics with minimal guidance. In the second phase, invention, students perpetuate their learning through studying (defining) the new terms, by discovering patterns during the exploration. During the third phase, discovery, students extend the range of applicability of the new concept; thus, they apply the new terms or thinking to novel situations (problems). The effectiveness of the Atkin and Karplus learning cycle has been studied extensively. For example, Lawson (1995) reviewed more than 50 studies focused on the Atkin and Karplus learning cycle and found that the use of this cycle has positive effects on students' learning in science. Particularly, Lawson underlined the effects of the learning cycle on the following areas: enhancing mastery of the subject matter, developing scientific reasoning, and increasing interest in and positive attitudes toward science.

After Juraschek (1983) argued that the Atkin and Karplus learning cycle could also make a contribution to math education, researchers applied the learning cycle to math instruction and found that student understanding and achievement in mathematics was increased (e.g., Francis et al., 1991; Stephen, 1984). Thus, researchers concluded that the guided discovery learning cycle can be used to design effective science and math instruction. The Atkin and Karplus learning cycle is a very flexible model for instruction. For this reason, Bybee and his BSCS colleagues (2006) decided to modify the cycle further by adding more stages. The 5E instructional model retains the three main stages of the guided discovery learning cycle but two more stages were added. The three original stages of the guided discovery learning cycle—exploration, invention, and discovery—correspond to the middle three stages of Bybee's learning cycle—engagement, exploration, and evaluation.

5E Instructional Model

Bybee et al. (2006) described the 5E model as a "direct descendant of the Atkin and Karplus learning cycle" (p. 2) and recommended the following expanded sequence of five key elements for effective instruction:

engagement, exploration, explanation, elaboration, and evaluation. Every element of the 5E model is carefully crafted to promote students' construction of knowledge. The following section describes each stage and attempts to develop an operational definition for each.

Engagement: In the engagement phase of a lesson, students are given real-life related activities that reveal their prior learning and engage them with the new concepts being covered in the particular lesson. In this phase, connections between prior knowledge and new knowledge are built. In engagement activities, students' curiosity to learn is promoted and their thinking is stimulated.

Exploration: In the exploration phase, students should explore the new concept well enough to explain it to the other students. During the exploration phase, the teacher provides activities as an opportunity for students to construct their own understanding. Exploration experiences are opportunities for developing students' metacognitive skills. In exploration, students have a chance to think about what they do and do not understand conceptually about the topic and identify gaps in their understanding (Tanner, 2010).

Explanation: The explanation phase involves active communication between teachers and students. Students begin to explain and refine what they have learned, and teachers give formal definitions and academic explanations. This phase also includes student–teacher interaction and peer interaction.

Elaboration: In the elaboration phase, students are expected to be provided with novel situations (e.g., real-life related problems) that challenge them with respect to what they have learned in the earlier phases of the lesson. Although this phase precedes formal evaluation of students' learning, it can also be considered as the extension of the explanation phase.

Evaluation: Evaluation takes place throughout the learning experiences. It is important for both teachers and students to determine how much learning and understanding have occurred.

The Impact of 5E Model on Student Achievement and Attitudes in Math

The 5E instructional model (Bybee, 1990) transformed instructional methods generally used for science learning, as was based on experimental activities. However, the model has been used for other areas, including mathematics (Bybee et al., 2006) with evidence to suggest that this model can be used effectively in this subject area. A study conducted by Alshehri (2016) was an exploration of the impact of the 5E instructional model on fifth-grade students' math achievement and retention of learning. The researchers randomly chose students at Khamiss Mushayt province, Saudi Arabia to participate in either experimental or control groups. The experimental group was taught using the 5E constructivist model of teaching, while the control group was taught by a traditional method. Alshehri found significant differences in achievement between the control and experimental groups. Alshehri concluded that the 5E constructivist model affected not only the experimental group's learning but also their retention of learning. In a similar study, Nayak (2007) conducted an experimental study of elementary students' mathematical learning through a constructivist approach with two groups (experimental and control) of primary school students at three different urban schools in India. The experimental group received instruction using the 5E constructivist model of teaching, while the control group was taught by a traditional method. This study took 20 weeks to complete, and a researcher-created math test provided the data for the study. Math achievement test scores were collected at the beginning of the study and immediately after the intervention for the two groups. The test results revealed significant differences between the groups on the post achievement tests and attitude scales in favor of the experimental group.

For the middle school level, Walia (2012) used a purposeful sample of 32 middle school students; students from one school of Kurukshetra city of Haryana, India were divided into two groups. The control group was taught using traditional methods while the experimental group was instructed with a teaching approach based on the 5E instructional model. The results of Walia's study suggested significant effectiveness of the 5E instructional model on mathematical creativity. Alazmh (2015) found the same result in a study that examined the math achievement of a control and experiment groups of middle grade students.

Tuna and Kacar (2013) conducted an experimental study with 10^{th}-grade students at a high school in Turkey in which the effect of the model on high school students' mathematics achievement and retention of their knowledge were examined. A treatment group received instruction in trigonometry from a researcher in an environment in which the 5E learning model approach was used. The control group received instruction in the same content from a mathematics teacher in a traditional environment in which the activities of the standard mathematics curriculum were used. The two groups took the same pretest with similar results, but the posttest results of the two groups were significantly different. Tuna and Kacar concluded that students who were taught trigonometry concepts with the instruction based on the 5E instructional model had better learning outcomes and retention of knowledge than those who were taught with the activities of the standard curriculum.

Omotayo and Adeleke (2017) conducted a quasi-experimental study to examine differences between the control group (traditional model) and the treatment group (5E model). Omotayo and Adeleke used an experimental approach with the pretests and posttests. The study sample was composed of 155 senior secondary school students in Ibadan Metropolis, Oyo State of Nigeria. The researcher divided the students into two groups: experimental and control groups. The experimental group students were taught using learning cycle strategy. The control group students were taught in the usual way. The aim of the study was to document the effect of using a strategic learning cycle in teaching mathematics on mathematical achievement and interest. Before treatment, the researcher found no difference in students' achievement and interest in mathematics. However, after teaching with 5E instructional model, Omotayo and Adeleke found a significant posttest effect of the treatment on students' mathematics achievement $t(170) = 4.45$, $p < 0.05$ and interest $t(170) = 4.22$, $p < 0.05$. They found a significant effect of treatment on students' achievement in mathematics.

Taken as a whole, these studies show that the 5E instructional model has had positive effects on students' math achievement. All studies found students' achievement improved after applying the 5E learning cycle approach and enhanced a long-lasting knowledge and understanding of the math concepts. Moreover, the 5E model was linked to a positive improvement in students' attitudes toward mathematics.

Difficulties of Teachers with the 5E Model

According to Bybee et al. (2006), the goals set by the National Research Council supported the design and sequence of the 5E instructional model. As the literature review indicated, the 5E model appears to be broadly effective (Goldston et al., 2013; Hanuscin & Lee, 2008; Lawson, 2001). A Google search showed uses for curriculum frameworks, course outlines, lesson plans, professional development, and various other curriculum materials, including

> 235,000 lesson plans developed and implemented using the BSCS 5E Instructional Model; more than 97,000 posted and discrete examples of universities using the 5E model in their course syllabi; more than 73,000 examples of curriculum materials developed using the 5E model; more than 131,000 posted and discrete examples of teacher education programs. (Bybee et al., 2006, p. 2)

Even, state educational agencies have also found the 5E instructional model to be effective. Connecticut, Maryland, and Texas Education Agencies strongly recommend the implementation of the 5E instructional model (Bybee et al., 2006). For example, "The Texas Education Agency (TEA) encourages teachers to develop lessons using a 5E format and to help colleagues understand and apply the 5Es" (Bybee et al., 2006, p. 59). However, the application of the 5E instructional model in classroom instruction has proven to be a challenging task for teachers at all levels in a variety of disciplines and teaching contexts. The researchers addressed some of the specific challenges faced by teachers in implementing the learning cycle. For example, teachers faced classroom management issues when they tried to implement the 5E instructional model in their classrooms (Polgampala, 2016), some did not have time to prepare the 5E instructional model lesson plan (Metin et al., 2011), some reported not having enough resources to implement the 5E instructional model in their classrooms (Demirhan-Iscan et al., 2015), some complained about a lack of professional development to implement the 5E instructional model appropriately (McHenr & Borger, 2013), some expressed concern that the contents were not appropriate for implementing the 5E instructional model in their classrooms (Qablan & DeBaz, 2015), and some attributed their failure to use the model on the state test (Namdar & Kucuk, 2018).

While several studies have examined teachers' understanding of the 5E instructional model (e.g., Goldston et al., 2013; Hanuscin & Lee, 2008; Lawson, 2001), only a few extended their examination to the implementation of the 5E instructional model in the math classroom. For example, Yildiz and Kocak Usluel (2016) examined how the 5E learning cycle was implemented and effectively integrated into a math lesson plan. Their study was conducted with 47 Turkish pre-service mathematics teachers, nine male and 38 females. Data collected and analyzed included video recordings of lessons and lesson plans. Yildiz and Kocak Usluel showed that the pre-service teachers struggled with the phases of engagement, explanation, and evaluation.

Similarly, Biber et al. (2015) studied mathematics teachers' perceptions of the 5E instructional model. Observational and survey methods were used to collect descriptive data on teachers' perceptions of using the 5E instructional model in their teaching practices. Biber et al. found that teachers who used the 5E model experienced difficulty with the engagement and exploration phases. Biber et al.'s analysis also revealed that classroom activities presented in the engagement phase were actually more suitable for the exploration phase of the 5E learning cycle.

Althauser (2018) explored how 347 preservice teachers changed in their levels of teacher self-efficacy after using the 5E instructional model. Althauser examined changes in the teacher self-efficacy following a methods course based on the 5E instructional model. They found a significant difference between the pretest and posttest scores ($t = 12.45$, $p < .001$) in the preservice elementary teachers' self-efficacy for teaching mathematics after engaging in the elementary methods course. Althauser found the preservice elementary teachers' self-efficacy for teaching mathematics after engaging in the elementary methods course was significantly improved. However, after interviewing 12 teachers and observing those teachers' lessons, Althauser's results showed that the preservice teachers faced classroom management issues, students exhibited off-task behaviors while using manipulatives, and teachers had a hard time of handling multiple practice.

The scarce number of studies examining teachers' knowledge of the 5E model suggests that mathematics teachers have found using the 5E model in their daily practice to be a challenge. There is very limited information from prior studies as to the reason behind their difficulties applying the model in mathematics lessons. To address this gap in the literature, this study examined how mathematics teachers use 5E instructional model in their daily practices, the barriers and challenges to implementing of 5E instructional model, and the reasons behind their difficulties applying the model in mathematics lessons.

Methodology

A case study design is recommended when the aim of a study is to explore a phenomenon to address "how" and "why" type research questions (Yin, 2003). Drawing upon these ideas, a case study design was chosen for the present study to examine how the middle level math teachers designed and implemented their instruction based on the 5E instructional model. Choosing a case for this study is intrinsic because the researcher is interested in a phenomenon and wants to understand it rather than simply generalize findings (Stake, 1995). The aim of an intrinsic study is to understand a particular case because the case itself is of interest (e.g., how teachers implement the model). A case may be of interest because it has particular features or because it is ordinary. In an intrinsic case study, a researcher examines the case for its own sake.

Participants

The participants of the study were selected from a group of middle school mathematics teachers who were provided pedagogical and content support through a federally funded research project. All the participants of the project were middle school mathematics in an urban school district located in the Southwestern United States. Briefly, with this federally funded research project, the teachers video-recorded their own lessons five times throughout a school year and shared (via an online server) their videoed lessons with university personnel from a state university, who viewed and scored the videos using the Teacher Excellence Initiative rubric.

We recruited the seven teacher participants from the research grant by employing the convenience sampling approach (e.g., Creswell & Miller, 2000). Convenience sampling "maximizes the researcher's ability to identify emerging themes that take adequately account of contextual conditions and cultural norms" (Erlandson et al., 1993, p. 82). This approach allowed the researchers to leverage the expertise of the teachers. Moreover, it was critical to the researchers that the participants were a good representation of the population of middle school math teachers in the district.

In this case study, we had seven teachers and call them T1, T2, and so on. T2 and T3 are sixth-grade teachers, both of them are female. T1, T4, T5, T6, and T7 are seventh-grade teachers; only T5 and T7 are male, and T2, T4, and T6 are female. Upon completion of the selection of the participants, we communicated with the coordinator of the research project to obtain access to their lesson plans and videoed lessons. In this study, the video observations were the primary data source because videos permitted us to pause and replay the lesson videos to deeply and accurately analyze the daily practices of teachers, regarding lesson instruction.

Data Sources

This qualitative research drew upon multiple sources of evidence in search of convergence and corroboration through the use of different methods (Yin, 1994). This case study used data gathered from observations and lesson plans. The participating teachers of the research grant shared access to their videoed lessons and lesson plans with the co-principal investigators (Co-PIs) of the grant. One of the grant's Co-PIs was asked for permission to access the existing data (i.e., video lessons, lesson plans) for use in this study. A total of 14 videoed lessons from the seven teachers served as the core data source of this study.

Observation

According to Merriam and Tisdell (2016), "The observation is the major means of collecting data in the research" (p. 160). Therefore, the videoed observations of the mathematics lessons were integral data sources of this study, which focused on closely examining the instructional sequence of the teachers. Two videoed lessons of each selected teacher were observed and transcribed verbatim by the first author of the study. The duration of each video was estimated to be 45–50 minutes.

Documents

Physical artifacts were the second data source of the proposed study. The participating teachers in the research grant video recorded their lessons and uploaded and shared access to lessons plans and other teaching materials with the Co-PIs of the grant. During the data analysis, all the related documents (e.g., lesson plan, handouts) were examined to ensure the trustworthiness of the proposed study. The general attribution of examining documents is to learn more about the classroom (situation), person (teacher), and event (teaching) being investigated (Merriam & Tisdell, 2016). The lesson plans and handouts provided an overview of the classroom and a narrative explanation of what the teacher intended to accomplish during class time. The artifacts were natural products of the teachers and were not created for the purpose of satisfying evaluation requirements. However, the artifacts were useful for data triangulation.

Field Notes

Field notes of each video observation were recorded; these included a general description of the lesson (e.g., teacher spent 5 minutes for engagement) as well as reflective notes documenting the researchers' perspectives and interpretations of the lesson (e.g., teacher spent more time in phase of exploration). Field notes from the classroom observation were used to triangulate data and assess the relationship between the constructivist theory underpinning the 5E instructional model and what the teachers did in actual practice. Admittedly, more complete excerpts of classroom instruction had been acquired through observation of the video recording of the lesson.

5E Rubric

Additionally, the first author coded each one of the 14 videoed lessons and the applicable field notes and reflective notes, using a check list, *The BSCS 5E Instructional Model: What the Teacher Does* (see Table 1), which served as a checklist during the coding process. The 5E rubric, which included indicators of the 5E instructional model, was used to standardize the documentation of the strategies used by the teacher. After the warm-up portion of the class lesson, a 5E lesson presented by the teacher was expected to have been divided into five parts: (a) engagement, (b) exploration, (c) explanation, (d), elaboration, and (e) evaluation. To ensure the 5E rubric was used with fidelity, the first author developed Table 1 so that any individual rating a lesson would be able to understand what evidence would indicate a specific stage of the model.

Table 1. The BSCS 5E Instructional Model: What the Teacher Does

Stage of the Instructional Model	The BSCS 5E Instructional Model What the Teacher Does	
	That is consistent with this model	1 (*present*) or 0 (*absent*)
Engage	• Creates interest	• …
	• Generates curiosity	• …
	• Raises questions	• …
	• Elicits responses that uncover what the students know or think about the concept or topic	• … Subtotal: ... (0-4 point)
Explore	• Encourages the students to work together without direct instruction from the teacher	• …
	• Observes and listens to the students as they interact	• …
	• Asks probing questions to redirect the students' investigations when necessary	• …
	• Provides time for the students to puzzle through problems	• …

	• Acts as a consultant for students • Creates a "need to know" setting	Subtotal: ... (0-4 point)
Explain	• Encourages the students to explain concepts and definitions in their own words • Asks for justification (evidence) and clarification from students • Formally clarifies definitions, explanations, and new labels when needed • Uses students' previous experiences as the basis for explaining concepts • Assesses students' growing understanding	• … • … • … • ... Subtotal: ... (0-4 point)
Elaborate	• Expects the students to use formal labels, definitions, and explanations provided previously • Encourages the students to apply or extend the concepts and skills in new situations • Reminds the students of alternate explanations • Refers the students to existing data and evidence and asks, "What do you already know?" "Why do you think ...?" (Strategies from exploration also apply here.)	• … • … • … • … Subtotal: ... (0-4 point)
Evaluate	• Observes the students as they apply new concepts and skills • Assesses students' knowledge and skills • Looks for evidence that the students have changed their thinking or behaviors • Asks open-ended questions such as, Why do you think…? What evidence do you have? What do you know about x? How would you explain x? • Allows students to assess their own learning and group-processing skills	• … • … • … • … Subtotal: ... (0-4 point)
		Total: … (0-20 point)

[Adapted from *The BSCS 5E Instructional Model: Origins, Effectiveness, and Applications* (p. 34), by R. W. Bybee, A. J. Taylor, A. Gardner, P. Van Scotteer, J. C. Powell, A. Westbrook, and N. Landes, 2006. Biological Science Curriculum Study. Copyright 2006 BSCS Science Learning. Reprinted with permission.]

Data Analysis

The 5E learning cycle calls for students to complete a sequence of activities, which include engaging with a new concept, exploring an idea or skill, listening to a guided explanation of the idea or skill presented by their teacher, expanding on the idea or skill through additional practice, and finally, evaluating the progress in a new setting. Analysis of the data sources focused on this learning sequence. During data analysis, all the related lesson artifacts (e.g., lesson plan, handouts) were employed to ensure the trustworthiness of the proposed study. The first author of the study viewed and coded each videoed lesson, using the 5E rubric. During the coding process, each lesson was assigned a score of 1 (present) or 0 (absent) for each descriptor of the rubric. For example, the descriptor “introduces relevant vocabulary” is one of the descriptors of the exploration stage on the rubric (Table 1). After scoring each lesson on each descriptor, each stage of the instructional model was assigned an overall score, which was the sum of the individual scores of its corresponding descriptors. However, the researcher also documented evidence from the videoed lesson as the justification of the score assigned to each descriptor. To control for observer inference and optimize sematic precision in category definition, another one of the research assistants who worked on the grant was trained on the 5E rubric and viewed and coded a randomly selected videoed lessons, using the rubric. The set of rubric scores for the videos was compared and the percentage of agreement was calculated for each descriptor and stage to determine inter-rater reliability. There was an 87% agreement between raters. After the video observations were scored, using the 5E rubric, supporting examples were located in the data sources. The information in Table 1 was very helpful in locating excerpts from the transcripts and supporting information in the documents and field notes. This carefully matched information is used in the presentation of the results of the study.

Trustworthiness

The trustworthiness of the study was ensured through following the four criteria identified by Lincoln and Guba (1985) of credibility transferability, confirmability, and dependability (see Table 2).

Table 2. The Trustworthiness of the Study

Quality criterion	Provision made by researcher	How
Credibility	Triangulation	Multiple data sources: Observation transcripts, field notes and lesson plan of the teachers.
	Persistent observation	Multiple videos (two per teacher) were used.
	Independent analysis of data by two researchers	One videoed lesson was coded by the research assistant for the coder-reliability (87%).
	Verbatim quotes	Excerpts were used from the videoed lessons.
Transferability	Thick description	Explanation of the data collection procedures and data analysis.
	Purposive sampling	The target group of this study was middle

		school math teachers.
Dependability	Audit trail	Raw data, observation notes and transcriptions, documents and records collected from the field, rubric scores and field notes.
Confirmability	Audit trail	A coding system was developed and used when excerpts were used in reporting the findings of the study in order to document where quoted material appeared the actual dataset. Ex., (T1, V1, p1) which stands for "Teacher 1, Video 1, and page 1 (of the video transcript)."

Credibility. Credibility has been defined as confidence in the "truth" of findings (Lincoln & Guba, 1985, p. 290). According to Merriam (1998), credibility deals with the question "How congruent are the findings with reality?" (p. 25). Although Lincoln and Guba (1985) proposed various strategies for ensuring credibility, two strategies, triangulation and persistent observation, were used. In this study, triangulation of data was achieved by gathering data from multiple sources such as field notes, lesson plans, and videoed lessons. Additionally, we persistently observed participants by analyzing two of their videoed lessons, which helped address the credibility of this study.

Transferability. Transferability implies that findings can be transferred or applied to other contexts (Lincoln & Guba, 1985; Merriam, 1998). Providing thick description and conducting purposive sampling are two strategies that can be employed to achieve transferability (Erlandson et al., 1993; Guba, 1978). We promoted transferability through thick descriptions of the research context to help the reader determine how closely their situation matches that of the study and, thus, whether the findings could be transferred (Merriam, 1998). Furthermore, purposive sampling ensured the transferability of the findings of the study to other individuals or groups of math teachers.

Confirmability. Confirmability refers to the degree to which the outcomes could be confirmed or corroborated by other people. The most crucial strategy to address confirmability is the "audit trail," which involves the disclosure of the step-by-step research process and the data analyses. We developed an audit trail for all data sources and described in detail the methods of data collection, analysis, and interpretation.

Dependability. Dependability was established with the audit trail; the dependability audit can be conducted at the same time as the confirmability audit (Mertens, 1998). We reviewed the entire process for each stage of inquiry, including the methodology of the study.

Findings

The observation rubric for the 5E instructional model consists of four descriptors per step. All stages of two lessons for each teacher were evaluated based on the 20 descriptors. Score analysis for each teacher was completed by taking the average of their scores on each stage, as reported in Table 3. Then, the average scores of each phase were calculated for the whole group (n = 14).

Table 3. The Average Scores by Phase

Teacher (*n* = number of videos/scores)	Engagement (4 indicators)	Exploration (4 indicators)	Explanation (4 indicators)	Elaboration (4 indicators)	Evaluation (4 indicators)
T1 (*n* = 2)	3	2	2	-	3
T2 (*n* = 2)	2	2	1	-	2
T3 (*n* = 2)	3	3	2	-	2
T4 (*n* = 2)	3	3	1	-	2
T5 (*n* = 2)	2	3	1	-	1
T6 (*n* = 2)	2	3	2	-	2
T7 (*n* = 2)	3	2	2	-	2
Total (*N* = 14)	2.6	2.6	1.6	-	2

According to the findings of this study, the stages in which the teachers, as a whole group, scored highest were engagement and exploration. The overall average score of the engagement stage (*N* = 14) was 2.6. In addition to the score analysis, comments from the video transcripts showed the participating teachers were usually able to create student interest and ask questions with appropriate wait time to activate and assess students' prior knowledge on the concept or topic taught by the teachers. For instance, the lesson objective of T1's first lesson was to "write and solve equations using geometry concepts," including "the sum of the angles in a triangle, and angle relationships" (T1, V1, p. 1). In the transcripts to follow, S stands for one student, Ss stands for more than one student, and T stands for one teacher. The following transcript of the lesson indicates how the teacher interacted with her students in regard to the lesson objective:

T: So, based on our lesson objective, what are the things that we already know how to do?

Ss: Write and solve equations.

T: That is the same thing that we have been covering already. What is going to be new that we are going to be applying now?

Ss: Geometry.

T: Geometry concepts, and what else?

S: The angles.

T: The angles are new. What else?

S: Triangles.

T: And also applying it to our triangles. (T1, V1, p. 2)

Similarly, as a whole the teachers were proficient in the exploration step. The overall average exploration score was 2.6. After reviewing the lesson objective, most of the teachers provided activities and encouraged the students to work together. Teachers observed and listened to the students' interactions; sometimes the teachers asked probing questions when necessary to redirect the students' investigations. T3's lesson on finding the volume of 3-dimensional shapes provided an example of redirection.

T: Kimmy and John were comparing their answers to a rectangular prism shaped classroom. The classroom dimensions are 12 ft wide, 17 ft tall, and 14 ft long.
Kimmy says the answer is 2856 ft3, and John said the answer 952 yd3. I want to know who is right and who is wrong. You may work with your group members on this question.

T: The equation for volume is what?

S: Length times width times height.

T: Pay attention to the units that Kimmy gave, and that John gave. (T3, V2, p. 2)

The overall score on the evaluation stage was 2, proficient performance, for all the teachers. In the evaluation stage teachers observed the students while they explored new concepts and asked probing questions to redirect the students' exploration. However, the teachers did not assess the students, as there was little time available to ask open-ended questions. Continuing with the previous example, T3 asked students to complete a ticket-out-the-door, also called "DOL" (demonstrations of learning), "T: You have about 10 minutes to complete your DOL. We did not get to the DOL. I am going to give you DOL as a homework, and I want it back" (T3, V2, p. 4).

The lowest performance of the teachers as a whole was observed in the explanation stage. The overall average explanation score was 1.75. All aspects of the 5E model assume active participation by students, and the explanation phase is no exception and optimally involves active participation by both teacher and students. Participating teachers in this study did not guide students to explain their experiences after exploration. Teachers just offered additional information and correct terminology rather than ask students to explain their understandings or findings, as shown by T4.

T: So, the complementary angles are two angles whose sum totals 90º. So here (. . . showed the angle chart attached to the blackboard . . .) this is given to you. This is an angle chart. This is an angle, and this is angle. The line in the middle splits the two. But together, they make 90 degrees. (T4, V1, p. 6)

A total of 14 videoed lessons were analyzed, but the elaboration phase was not present in any of the lessons. In general, the purpose of the elaboration phase is to give students activities to practice skills and behaviors gained during the exploration stage. Participating teachers of this study stated they did not have enough time to finish their lesson; each lesson was concluded after one or two activities.

Discussion

An important finding of this study is that many of the mathematics teachers had difficulty in implementing the 5E model in their classroom instruction. This outcome is consistent with the findings of other researchers who have reported mixed outcomes in the practices in their studied classrooms (e.g., Yildiz & Kocak Usluel, 2016).

The 5E instructional model served as a blueprint for planning and teaching math lesson. Although, just as blueprints do not dictate all actions of engineers, the instructional model is not intended to dictate the actions of teachers. This model shows what the role of the teacher is during teaching. Our findings showed that most of the teacher participants retained their initial practice: utilized a teacher-centered approach in their classroom practices. These teachers maintained that posing questions or problems to students and having them answer/respond was the most essential feature of inquiry-based instruction. The teacher's role in this model is that of a facilitator. The teachers were facilitators in the exploration stage, but in the explanation stage, we only heard the teachers' voices not those of the students. Moreover, the elaboration stage was not observed. Bybee (2014) argued that it might not be possible to implement all 5 stages in one short class period.

The challenges in implementing the 5E instructional model varied for each of the phases and was dependent upon the teachers' understanding of the 5E instructional model. The teachers sometimes had difficulty finding activities related to the phases of engagement and elaboration. During the explanation phase, the teachers used a more teacher-centered approach. The pre-service teachers also did not use time effectively when evaluating students. According to Maier and Marek (2006), teachers must understand the learning cycle's theoretical underpinnings to successfully implement the model in their lesson practice. The results of the case study showed there were various challenges when the teacher had a limited understanding of the 5E instructional model. A number of teachers were unsure about the requirements and roles they would take in implementing 5E instructional model. If teachers identify and adopt the thinking behind the 5E instructional model, they are likely to transform their practice, rather than simply use the sequence of the 5E instructional model while maintaining their traditional practice (Spillane & Zeuli, 1999). Only in this way will the teacher's classroom practice change. Decisions about content may change somewhat, but one's teaching must reflect the principles, values, and key competencies, as well as develop the processes outlined in the 5E instructional model.

The impetus for this study was the desire to determine which areas of the 5E model are most problematic for the math teacher and to uncover what factors hinder teachers from implementing the model with fidelity. If teachers are trained on the 5E model during their preservice methods classes, they will have a deeper understanding concerning the characteristics of the steps and how to best enact the model in practice. This knowledge should positively impact the opportunities for implementing the 5E model in their lessons.

Limitations

Although the use of video data provided us a unique opportunity to pause and play the videos again and again to examine the quality of the math instruction more closely, this re-examination was also the main limitation of this study. Teaching is a complex and dynamic activity. During an observation of classroom instruction, many things occur simultaneously, and observing all interactions is not possible. While the number of students engaged in completing an activity can be directly observable, determining whether student engagement is an indication of interest or disinterest is not possible. Additionally, the presence of a camera in a classroom influences the nature of the lesson, making the lesson atypical of the teacher's usual teaching style. For all these reasons, information that is gained through observation needs to be clarified through discussions to understand the meaning of what has been observed. The findings of this case study have been limited by the sensitivity and integrity of the researchers who are the primary instruments of data collection and analysis.

Conclusions

Based on the review of the literature, only a limited number of studies have examined the quality of teachers' math lessons based on the 5E instructional model. This study provided the opportunity to observe seven middle school math teachers, which yielded a wealth of data for analysis and application to classroom practice. Findings from this case study for the field of mathematics education have identified problematic steps of the 5E model, which may lead to future studies that focus on specific steps of the model. The implications of the 5E instructional model for teaching programs and teacher practice must be clearly understood to develop curriculum with relevant thinking and planning. If teachers identify and adopt the constructivist perspective behind the 5E instructional model, they will be able to transform their practice through the constructivist perspective, rather than simply use the terminology while maintaining their traditional practices.

Recommendations

We investigated seven particular middle grade math teacher's daily practice. I became interested in high school math teachers and which phases are problematic in applying the 5E instructional model in their daily practices. This would certainly be a consideration for future research, as this study could potentially identify additional sources for increasing teacher usage of the model. Additional research with a larger group of teachers could be useful in identifying which steps of the 5E model need to be addressed in teacher preparation courses and professional development sessions.

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