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Technology Enhanced Formative Assessment for Students Learning in Mathematics at Elementary Level

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Abstract

Technology Enhanced Formative Assessment is an innovative and verified pedagogical method for mathematics and science instruction using clickers as a tool to achieve learning gains. Question-based instruction, dialogical discourse, formative assessment, and meta-level communication are the four main rules on which this Classroom Response System (clickers) based pedagogy is constructed. An iterative question cycle helps in executing these principles in the classroom. Non-equivalent comparison group quasi-experimental design was applied on a sample of 183 participants. These participants were taken from two urban high schools (i.e., boys and girls). This intervention lasted for eight weeks. The study members comprised 42 females and 47 males in the experimental group. 54 females and 40 males were in the control group of the 8th mathematics class. Multiple choice questions-based achievement test (both Pre and Post-intervention) was administered to both groups at the same time. The results of One-way ANCOVA showed that the intervention was effective. The results of the Post-test analysis showed that the experimental group achieved considerably higher than the control group. The study implications for curriculum developers, school administrators, and teachers are discussed.

Keywords: Classroom Response System, Pedagogy, Mathematics, Achievement, Formative Assessment

Introduction

Social interaction results in learning (Vygotsky, 1978): the students learn a lot by communicating and interacting with their social group, trainers, society, and surroundings to acquire awareness. In traditional math classrooms, however, the instructor usually authoritatively conveys knowledge to the class. In such classrooms, teachers can have a problem identifying the difference between concepts of students and comprehension of what the instructors are communicating. Black and Wiliam (1998) observed that coaching and receiving knowledge should be based on communication. The researchers stressed the importance of formative assessment. Formative assessment is an assessment for students' understanding and acquiring knowledge for further development and assistance to both teacher and student. Instructors can generate significant learning improvements in different age groups, subjects, and across different countries with the help of formative assessment (Black & Wiliam, 1998).

Teachers often have problems collecting the whole class's viewpoints and answering them properly and suitably during teaching. Luckily, the advancements in classroom response equipment can assist to resolve these issues. Technology-Enhanced Formative Assessment is one such helpful pedagogy for teaching with clickers (classroom response equipment) (Beatty *et* al., 2009)

A clicker is an instrument by which responses of the whole class students can be assembled in a very short time. By clickers, instructors can check the students' attendance and it can be utilized for managing the summative tests also (Duncan, 2006). A pedagogy was developed in 1996 by using Class Response Systems for formative assessment purposes (Dufresne et al. 1996). It was further expanded into Technology-Enhanced Formative Assessment (TEFA) (Beatty & Gerace, 2009). TEFA is constructed on four fundamental philosophies categorized: *"question-driven instruction",*

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"dialogical discourse", "formative assessment" and "meta-level communication". The first "*question-driven instruction"* suggests that a conceptual question that is related to students' zone of proximal development should be asked by the teacher (Vygotsky, 1978). The second principle "*dialogical discourse"* engages students and teachers in the discussion. Teachers facilitate class discussion, rather than simply conveying knowledge to students. The information gained from CRS (clickers) histogram and classroom discussion is used for "*formative assessment"*. This information helps teachers to get students more involved and motivated (Gallagher, 2000). In this way, instructors and learners become more up-to-date with the learners' comprehension and the steps that can be further taken to speed up improvement (Ramaprasad, 1983 and Sadler, 1989). The fourth principle "*meta-level communication"* helps students to participate in the teaching-learning process more attentively and efficiently. This principle gives a sense to the students of what they are doing and why they are doing it. These four principles are best implemented in the class through the below question cycle.

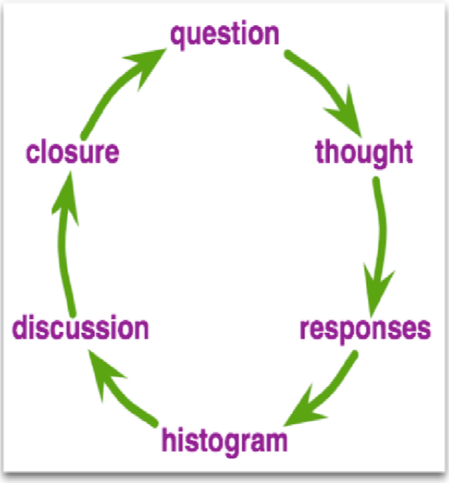


Fig 1. Question Cycle

Formative Assessment and Classroom response system (clickers)

Promoting significant learning between learners is a continuing apprehension for instructors. Presently, instructors are struggling in the direction to regulate their instructions and delivering styles to the requirements of the students who have developed in a scientific and technical domain and who have diverse requirements as compared to the students in the previous era (Prensky, 2008). It is however essential that instructors must develop theoretical and research-based judgments while developing the students' skills (Kelly, 2011). In this regard, formative assessment is a favorable teaching practice for promoting teaching and learning processes. Stiggin (2002) described that classroom assessment plays a crucial role in improving students' learning.

Though teachers value formative assessment, they often have problems collecting the whole class responses and answering them properly and suitably during teaching. In this regard, technology can assist an instructor in informatively measuring students learning and giving critical responses in real-time.

The clicker is a technology which helps the teacher in collecting students' responses in the form of histogram, pie charts and providing them feedback in real-time accordingly. Clickers utilize simple keypads as learners' input devices, which connect the instructor's computer using electromagnetic signs and let learners show their responses to multiple-choice questions. The software swiftly organizes entered responses and displays a histogram of students' responses on teachers' computers (Beatty, 2004).

The questions are presented on the screen or communicating board (King, & Robinson, 2009). Mostly they are based on PowerPoint presentations. The questions may have numerous options in which there are three distractors and one correct option. It can have many types of questions like fill in the blanks and true false. (Sutherlin, Sutherlin & Akpanudo, 2013).

Fig 2. Interactive Classroom Response System (clickers)

Furthermore, new technologies can be introduced in the actual classrooms. However, the introduction of innovative technology does not mean that desired goals will be achieved only by using technologies (Liu, 2007). Some research studies indicated that the use of clickers in the classroom does not contribute to better learning performance than does other types of instruction (Paschal, 2002). Lantz (2010) found that some principles are needed to enhance the effects of clicker-based instruction, but these are currently still lacking. Therefore, designing and developing a suitable CRS-based pedagogy is needed to enhance the potential benefits of clickers. The next section will discuss the CRS-based pedagogies.

CRS Pedagogies

As discussed earlier, a CRS is only an instrument, and like any other instrument, it may be used for different purposes effectively or even counterproductively. Several pedagogies are associated with the Constructivist, Socio-cultural change tradition and Active learning philosophies, and application of CRS technology. Penuel *et al.* (2007) suggested that different CRS-based pedagogies exist. All these pedagogies have some small differences, and some have common elements also. Common elements include questioning techniques, display of students' responses via histogram or graph, and discussion on students' responses. These pedagogies contain Peer Instruction (Crouch & Mazur, 2001), Assessing to Learn (Dufrense & Gerace, 2004), Question Driven Instruction (Beatty et al., 2006), Technology-Enhanced Formative Assessment (Beatty & Gerace, 2009). These pedagogies have their roots in university physics instruction; Fies and Marshall (2006) indicated that the use of CRS and research on it has extremely happened in the discipline of physics. Therefore, its implementation in mathematics at the elementary level is needed.

Peer Instruction and Concept tests

The first CRS pedagogy "peer instruction" asks the questions about the topic being taught. These questions are in the form of multiple-choice questions and are inserted during lessons through CRS at planned intervals. If many students respond negatively, the class again discourse the problem in groups and then try to solve the issues. This method improves learning, enhances student involvement, provides feedback about student comprehension to the teacher, and fosters knowledge among students. Quantitative verification also supports that Peer Instruction enhances learners' comprehension (Mazur, 1997).

Assessing-to-Learn

The second CRS pedagogy is Assessing-to-Learn (Dufresne *et al*., 1996) or Question-Driven Instruction (Beatty *et al*., 2006) and it is advanced by the University of Massachusetts Physics Education Research Group (UMPERG).

Dufresne *et al*. (2000) relate the pedagogy, Assessing-to-Learn, with assessment for learning because it communicates instructors about the views of the learners and at the same time it conveys to students what their fellow learners think, and it states individuals what they have viewed. An important dissimilarity between Peer Instruction and Assessing to Learn is that Mazur's Concept-based tests use multiple-choice questions with the traditional method of instruction to improve and pave the way about that direction, while Assessing to Learn makes the basic shape of class activity, with "micro-lectures" or another type of instructions introduced when required and encouraged through the inquiries and conversation.

Ohio State University Question Sets

Third pedagogy measures instructional objectives by asking sets of related questions. Quantitative evidence shows gain in conceptual learning by this pedagogy (Reay et al., 2008). It has been developed through the Ohio State University having Physics Education Research Group for CRS.

Technology Enhanced Formative Assessment

The fourth CRS-based pedagogy, Technology-Enhanced Formative Assessment (TEFA), has been evolved from assessing to learn pedagogy. Preliminary findings on TEFA show that it can be transformative and highly effective for science and math tutoring at the secondary level (Beatty *et al*., 2008). This pedagogy is applied in the classroom through the TEFA question cycle.

During the TEFA question cycle, posing challenging questions, peer and whole-class discussion may play important role in promoting cognitive benefits. TEFA is based upon four essential doctrines. Those doctrines include:

- Question-based instructions.
- Dialogical discourse
- Formative assessment
- Meta-level communication

Effectiveness in planning inquisitive questions to increase theoretical knowledge and concepts has been highlighted (Beatty *et al*., 2006).

Results of meta-analysis (Hunsu *et al*., 2016) recommended the impact of clicker-based skills vanished by the same questioning technique is used in both clicker and non-clicker classrooms. It shows that the supposed effect of clicker was only evident when similar questioning techniques have not been used in non-clicker classrooms. It shows that effective clicker questions make a distinction between the clicker and non-clicker classrooms. This effect was observed across 41 studies. This aspect strongly recommends that the use of clicker-based technology solely does not produce any important educational benefit in the actual classrooms until and unless an effective questioning technique is used with CRS.

Further, peer instruction is also an operational technique of energetic learning in clicker classrooms. Students answered many questions as accurate while they were asked about the similar question after a fruitful discussion with their peers in the clicker classrooms. A combination of peer conversation with instructor clarification may provide effective instructions that can lead positive impact on knowledgeable experience (Smith *et al*. 2009).

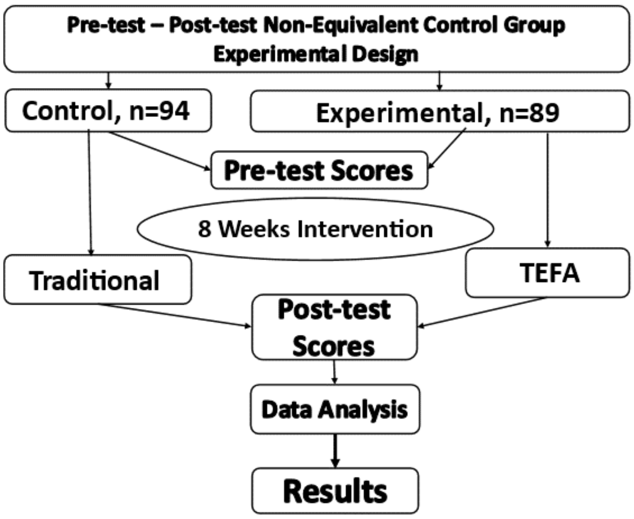
A very limited number of articles discuss CRS use at the elementary level. Most of the studies about CRS use are available at higher levels (Lively, 2010; Rigdon, 2010). Further, these studies focused on CRS use and not on the pedagogy required. Research on CRS recommends that this technology increases the learning gains when used with research-based instruction (Beatty & Gerace, 2009). But it has not yet been tested at the elementary and secondary levels. To bridge this gap, the present study has been designed to explore the effectiveness of TEFA for students' mathematics learning at the elementary level. To examine this effect, the following research question was designed.

To what extent Technology-Enhanced Formative Assessment pedagogical technique is effective in enhancing learners' achievement as compared to the conventional teaching method in mathematics at the elementary level?

Methods

Nonequivalent comparison group-wise quasi-experimental design was implemented to perform the present research. A convenient sampling technique was used for the selection of two urban high schools i.e., one from boys and the other from girls' high schools in district Haripur.

The entire process of research study activities is explained in the given diagram.



Participants of the study

The study was organized in two urban high schools. One from each boy and girl selected for study from the Haripur district Khyber Pakhtunkhwa Province, Pakistan. Two sections from each school of grade 8th were taken as a sample of the study. One unit was nominated as an experimental group and the other was named as a control group in each of the institutes. The sample size from each school is shown in the following table.

Table 1 Sample size

Division	Control Group	Experimental Group	Overall
School for boys	40	47	87
School for girls	54	42	96
Overall	94	89	183

Data Collection Instrument

The 8th-grade mathematics selected units' SLOs (i.e., students learning outcome) based multiple-choice achievement test was designed. There were 60 MCQs in the test.

Reliability and Validity of Achievement Test

For reliability and validity, a test standardization process was carried out. The content and face validity of test items were checked by subject experts. Items with difficulty levels greater than .80 and discrimination less than .30 were eliminated. As a result, 44 items were retained. The average difficulty and discrimination levels of these items were .63 and .53. Reliability was calculated by using the Kuder-Richardson-20 formula which was .78. These refined items covered four content areas/units (1) *Polynomials* (2) *Factorization*, *Simultaneous Equations* (3) *Geometry (area and volume)*, and (4) *Trigonometry* of 8th-grade math.

Pretests using the standardized achievement test consisting of 44 MCQs were conducted on the students of both groups to check the present achievement and learning level of students in mathematics. There were overall 94 students in the control and 89 in the experimental group. Students from both groups were performed in the pretest. An independent sample t-test was executed to check whether the groups were similar on the pretest or not. Groups were hardly dissimilar on pretest as there was no statistically significant difference between groups on pretest ($t = .451$, $p = .652$). Pretest scores were noted down and used as a covariate for more data analysis.

The procedure of the study

The study was conducted for eight weeks. Felman and Capobianco (2008) suggested that teachers need to gain expertise in four broad areas to apply formative assessment with a CRS (clickers). These areas are the use of CRS hardware and software, creating good questions for formative assessment; organizing creative session discussion; and incorporating the pedagogy into their greater programs. Therefore, one-month training was given to experimental group mathematics teachers on TEFA pedagogy in the above aforesaid areas. Participants of the study in the experimental group at both schools (i.e., boys and girls) were trained on using clickers. It was done for one week.

During the intervention, the control group at both chosen schools (i.e., boys and girls) were taught with the traditional instructional method. There were six periods in a week. Each period had a duration of 60 minutes. Students noted down the questions on notebooks and were bound to repeat the similar work on their assignment copies on the following day.

TEFA pedagogy was executed in an experimental group class. This class was specially managed for implementing CRS-based pedagogy. Clickers were used as a classroom response system for collecting the responses of the students to multiple-choice questions. A distinctive ID number was assigned to every student. Each student was recognized on the teacher's computer through this ID digit along with their names. Clickers were connected to the teacher's computer through wireless technology. Questions were displayed to students on multimedia and students used clickers for answering questions. Students' answers were recorded on teachers' computers in the form of a table, histogram, and pie chart in real-time. Hence, the teacher used this data for judging the students' comprehension and tailor their instructions in real-time to boost students' learning achievements.

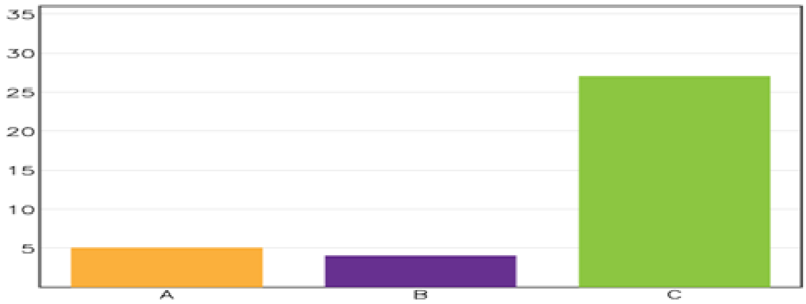


Fig. 3 a histogram of learners' answers to a query modeled by the teacher.

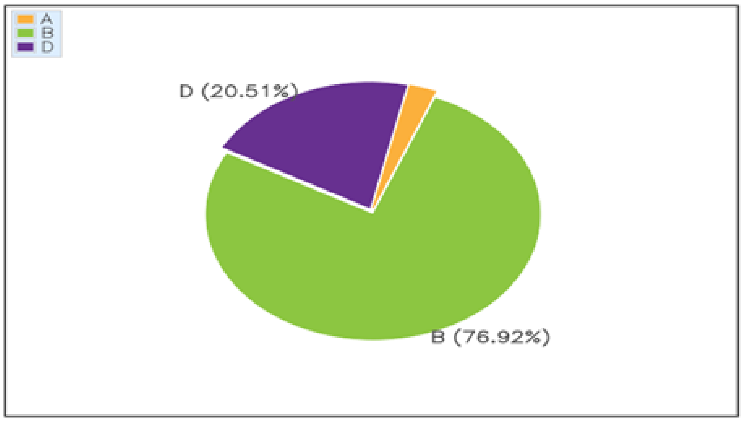


Fig. 4 A Pie Chart of learners' answers to a query modeled through the instructor.

Post-test was conducted at the end of the experiment to both groups by using the same achievement test consisting of 44 MCQs.

Results and Findings

Effect of TEFA on Students Mathematics Learning

The purpose of the current study was to determine the impact of Technology-Enhanced Formative Assessment pedagogy on the academic accomplishment of math learners at the elementary level in two high schools in Haripur District. During the first stage of the study, the researcher collected statistics on pre-test (as a covariate) earlier to the experiment. The data was collected on posttest after the intervention. Descriptive and inferential statistical analyses were carried out on the statistics obtained from learners' math accomplishment tests.

Descriptive statistics

Table 2. Group-wise Mean and Standard Deviation of Pre-test and Posttest Marks of Math Achievement Test

	Control Group Mean (SD)	Experimental Group Mean (SD)
Pretest scores	12.54(6.5)	12.97 (6.2)
Post-test scores	25.09 (6.6)	28.73(6.6)

Table 2 indicated an overall summary of descriptive statistics acquired by pretest and posttest marks of math accomplishment test in control and experimental groups. As shown in the table, the pretest means, and standard deviation of the control group is 12.54 (SD = 6.5) whereas the posttest means the total is 25.09 (SD = 6.6). Furthermore, the experimental group pretest has a mean score in the similar test is 12.97 (SD = 6.2) while the posttest means the total is 28.73 (SD = 6.598). As a result, in the control group the increase is 12.55 which constitutes 28.52% while in the experimental group, the increase concerning the students' pretest mean scores and posttest mean scores is 15.76 which constitutes 35.82%.

It appeared that TEFA pedagogy was successful in improving students' mathematics achievement on the post-test. Further ANCOVA was performed for statistical significance of the results.

ANCOVA was performed between the groups to search the efficiency of TEFA pedagogy on learners' math accomplishment. Preliminary analysis was performed to ensure that all assumptions required to conduct an ANCOVA were met. Statistically, a significant difference was found, after adjusting for pretest differences, between-group with traditional instructional method and group with TEFA pedagogy on posttest mean scores (F (1,180) = 20.595, *p= .000*, partial eta squared= *.104)* and observed power was .995(results presented in table 3). These effects indicated that the TEFA was effective and made a statistically significant difference in post-test scores across groups.

Table No. 3 One-way ANCOVA Results for Mathematics Achievement Posttest

Source	Df	F	Sig.	Partial Eta Squared
Corrected Model	2	83.012	.000	.48
Pretest	1	141.232	.000	.44
Group	1	20.595	.000	.104
Error	180			
Total	183			

Participants in both experimental and control groups were further distributed into three categories of achievers (i.e., highest 27%, average 46%, and lowest 27%). Bonferroni post hoc analysis showed that TEFA pedagogy equally improved low (i.e., hedges' *g = 1.14*), average (i.e., hedges' *g = 1.19*), and high (i.e., hedges' *g = .95*) performing students on Post-test whereas average ability students received more benefit from TEFA pedagogy. Thus, the effects of treatment indicated that TEFA equally and efficiently improved low, average, and high achievers' capability on academic achievement tests in mathematics at the elementary level (results presented in table 3 and fig. 5).

Table 4 Low, Average, and High Achievers Achievement Levels.

Group	Achievement Levels	Mean (SD)	Effect size (Hedges g)
Controlled	III (Lowest 27%)	16.60(2.901)	
Investigational	III (Lowest 27%)	21.33(5.096)	1.14
Controlled	II (Average 46%)	25.39(2.903)	
Investigational	II (Average 46%)	28.85(2.912)	1.19
Controlled	I (Highest 27%)	33.04(1.925)	
Investigational	I (Highest 27%)	35.92(3.855)	.95

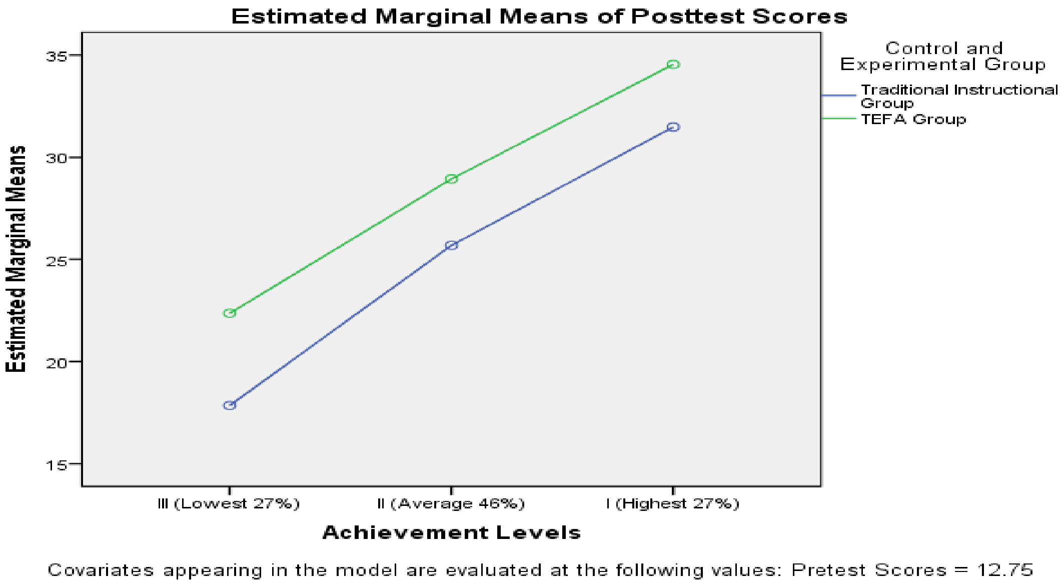


Fig. 7 Students Posttest Scores across Groups and Ability Levels

Fig. 5

Discussion and conclusion

The present study examined to what extent Technology-Enhanced Formative Assessment pedagogical technique is effective in refining learners' accomplishment as compared to conventional teaching methods in mathematics at the elementary level.

This study answers the foresaid research question that TEFA significantly improved students' mathematics achievement on reliable and valid test for components (1) *Polynomials* (2) *Factorization, Simultaneous Equations* (3) *Geometry (area and volume)* and, (4) *Trigonometry* of 8^{th}-grade mathematics.

Analysis of the Process of the Experimental Group Intervention.

Communications in conventional classrooms are frequently impeded by various problems. It included learners' hesitation, response delay, and only one student becomes able to convey one's opinions at one time. As a result, only a small number of learners in a traditional class get an opportunity to communicate their viewpoints. In such a situation, engagement of learners in learning activities becomes difficult (Mayer et al., 2009). Clickers are a useful tool for solving such problems and have been widely used in universities. It gives real-time responses and display histogram on the teacher's computer. Thus, instructions can be regulated according to students' responses to question in real-time (Kay & LeSage, 2009). Furthermore, the introduction of a novel technology does not give assurance that all the educational advantages will be realized (Liu, 2007). Simply, Classroom Response System (clickers), effective clicker questions, peer conversation may help learners endure devotion, knowledge, and skill advancement and stay interested to acquire more (Cain, Black, Rohr, 2009).

Posing a challenging inquisitive question is realized as a valuable technique for motivating the conceptual understanding of the students. But the execution of successful questioning in conventional classrooms is difficult (Mayer et al., 2009). In the TEFA pedagogy, through the support of clickers, the inquiring strategy may be effectively applied in actual classrooms, promoting learners by motivating and engaging their thinking, thus boosting their understanding of the subject. In TEFA, posing a challenging question is counted as a stimulus for whole class participation. In the TEFA question cycle, all the students are encouraged to think about the question, make a peer or small group discussion and then individually communicate their answers using the clickers. After all the students' responses were displayed in the form of a bar chart or histogram on the teacher's computer. In the next step of the question cycle, the teacher invited the students to provide reasons for specific answers. In this way, the students seemed to be separated into different groups according to their choices, and each such group had a sense of commitment to its answer (Roschelle & Pea, 2002). This commitment directs students to play a more active role in the different stages of the TEFA question cycle, hence getting more involved in thinking about the concept to be learned. Some studies have shown that CRS grounded pedagogies increase student learning at higher education level (Crouch et al., 2007; Guiliodori et al., 2006; Lasry et al., 2008; Mazur, 2011; Allison, 2012); this was also supported by the results of the present study at the elementary level.

Contribution of the study

The current study contributes to the field of existing research by adding a quantitative study on the impact of CRS-based instruction TEFA on math student achievement at the elementary level. The available research on CRS is mostly at the higher education level. Most available studies at the elementary level studied the views of students and teachers about the use of CRS and comparison of the student achievement in classrooms that use CRS with those students that do not use CRS. No such previous research study exists in literature at the elementary level using TEFA. Hence present study has contributed to the research on the use of TEFA pedagogy and its impact on mathematics achievement at the elementary level which is an addition to the existing literature on TEFA at the elementary level.

Recommendation

The study results recommended that the implementation of TEFA in real classroom settings has the efficacy to improve students learning gains in mathematics at the elementary level. Thus, to achieve the required learning level in mathematics the TEFA is one of the most appropriate and advanced research-based pedagogical approaches to meet 21^{st}-century challenges in mathematics at the elementary level.

Conclusion and implications

The findings of the present research provide useful implications for both school administrators and class teachers who are zealous to enhance the achievement of their students in mathematics at the elementary level. Further, the policymakers, curriculum developers, and pedagogical planners should integrate Classroom Response System (clickers) along with a pedagogy such as TEFA to achieve the National Standards in mathematics at the elementary level.

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