




## The impact of Plickers-supported formative assessment on achievement and learning experiences in grade 11 advanced mathematics trigonometry

Eric Machisi<sup>1\*</sup> , Anas Mahmoud Ahmad Alrababah<sup>1</sup> , Fabian Hennig<sup>2\*</sup> 

<sup>1</sup> Department of Mathematics, Fujairah Boys' School (Cycle 3), Fujairah, UNITED ARAB EMIRATES

<sup>2</sup> Institute of Physics Education, Faculty of Physics and Earth System Sciences, Leipzig University, Leipzig, GERMANY

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### Abstract

This study examined the impact of Plickers-supported formative assessment on grade 11 advanced mathematics students' achievement and learning experiences in trigonometry. Addressing persistent challenges in conceptual understanding and procedural accuracy in trigonometry, the study used a quasi-experimental pre-/post-test design with two intact classes ( $n = 42$ ) from a government secondary school in the United Arab Emirates. The experimental group received trigonometry instruction integrated with Plickers, whereas the control group was taught using traditional methods. Quantitative data were collected using a weighted multiple-choice trigonometry achievement test with established content validity and acceptable internal consistency. Qualitative data were gathered through an open-ended student questionnaire and analyzed thematically to capture learners' experiences. Quantitative results showed that students in the Plickers group significantly outperformed peers in the control group on the post-test, with a large effect size, even after controlling pre-test performance. Qualitative results indicated that students perceived Plickers as enhancing engagement, participation, immediate feedback, confidence, and psychological safety, particularly through anonymous whole-class responses and rapid error identification. Some students noted pacing challenges, underscoring the importance of instructional calibration. The findings suggest that Plickers, when embedded within a coherent formative assessment cycle, can meaningfully enhance both cognitive and affective learning outcomes in advanced trigonometry. The study recommends the strategic integration of low-threshold response systems to support diagnostic feedback, equitable participation, and instructional responsiveness in upper-secondary mathematics classrooms.

**Keywords:** advanced mathematics, formative assessment, trigonometry, Plickers, achievement, learning experience

### INTRODUCTION

The integration of digital technologies has profoundly transformed mathematics education by enhancing accessibility, promoting interactivity, and supporting student-centered learning environments (Picaza, 2023). These pedagogical shifts have been associated with increased learner engagement, improved conceptual understanding, and greater opportunities for formative assessment, positioning educational technology as a vital component of contemporary mathematics instruction (Tan & Yuan, 2024).

Information and communication technologies support active learning through dynamic representations, immediate feedback, and interactive practice, moving beyond the limitations of traditional lecture-based approaches (Patero, 2023; Sultana, 2025). In mathematics education, such tools are particularly valuable for developing conceptual understanding, procedural fluency, and mathematical reasoning. These skills are essential for success in advanced secondary-level mathematics (Asmida et al., 2018).

Despite these advantages, students at the upper-secondary level continue to face persistent challenges in learning trigonometry, particularly with abstract

### Contribution to the literature

- This study advances research on student response systems (SRS) by providing empirical evidence from grade 11 advanced mathematics, specifically in the area of trigonometry, which has been underrepresented in existing literature. It demonstrates that formative assessment technologies can enhance learning beyond basic mathematics topics.
- The findings reveal that learning gains are primarily driven by the effective use of real-time response data for diagnostic feedback and instructional adjustments, rather than by technology use alone. This contributes to formative assessment theory by illustrating how feedback cycles operate effectively in advanced mathematics contexts.
- Additionally, by integrating achievement data with student perceptions, the study shows how anonymity, immediate feedback, and inclusive participation foster confidence and engagement. These factors support learning in advanced mathematics, highlighting the interconnectedness of cognitive and affective dimensions of the learning process.

concepts such as trigonometric ratios, identities, exact values, and multi-step problem-solving (Dhungana et al., 2023). Grade 11 advanced mathematics represents a critical transition point where learners are expected to move beyond memorization toward deeper conceptual understanding and accurate procedural execution. Traditional instructional methods often struggle to provide timely feedback or sufficient opportunities for all students to actively engage with trigonometric concepts, leading to misconceptions, reduced confidence, and uneven participation.

Formative assessment plays a crucial role in addressing these challenges by allowing teachers to identify misconceptions early and adapt instruction accordingly (van der Steen et al., 2023). Among emerging digital assessment tools, the Plickers platform has gained attention as an effective SRS that enables real-time formative assessment without requiring individual student devices. By allowing all learners to respond simultaneously and anonymously, Plickers promotes inclusive participation, reduces anxiety associated with public errors, and provides immediate visual feedback to both students and teachers.

Although prior research has demonstrated the general benefits of Plickers and similar SRS in primary and lower-secondary education (e.g., Nunes et al., 2023), there remains a limited body of research examining their effectiveness in grade 11 advanced mathematics, particularly in the teaching and learning of trigonometry. Trigonometry is a content area that demands both conceptual clarity and procedural accuracy, making it well-suited to frequent formative assessment and immediate feedback. However, empirical evidence on how digital response systems support learning and engagement in this context remains limited (Engelbrecht & Borba, 2024; Sentriyo et al., 2023).

This study seeks to address this gap by investigating the impact of the Plickers platform on the academic achievement and learning experiences of grade 11 advanced mathematics students in trigonometry. By

examining both quantitative learning outcomes and qualitative student perceptions, the study aims to contribute to evidence-based instructional practices that support effective and engaging trigonometry instruction at the upper-secondary level.

Accordingly, the study is guided by the following research questions:

1. Does the use of Plickers have a statistically significant impact on grade 11 advanced mathematics students' academic achievement in learning trigonometry concepts?
2. What are the perceptions of grade 11 advanced mathematics students regarding the use of Plickers as a learning tool for exploring trigonometric concepts?

This study makes a distinct contribution by generating context-specific empirical evidence on the use of Plickers in grade 11 advanced mathematics trigonometry, an area that has received limited focused investigation. Rather than re-establishing the general benefits of digital tools, the study advances current knowledge by demonstrating how real-time formative assessment functions within a high-cognitive-demand mathematics topic, where accuracy, conceptual coherence, and procedural sequencing are critical. Its novelty lies in integrating achievement outcomes with learners' lived classroom experiences, offering insight into how immediate feedback shapes engagement, confidence, and error awareness during trigonometry instruction. By foregrounding formative assessment processes rather than technology adoption alone, the study provides practical and methodological insights for designing responsive instruction in advanced secondary mathematics, particularly in contexts where equitable participation and efficient feedback are pedagogical priorities.

## LITERATURE REVIEW

### Learning Challenges in Secondary School Trigonometry

Trigonometry is widely regarded as one of the more conceptually demanding areas of secondary mathematics because it requires learners to coordinate multiple representations (right-triangle ratios, unit-circle meanings, graphs, and algebraic symbolism) while maintaining procedural accuracy across multi-step tasks. Studies focusing on students' solution processes report recurring misconceptions and errors, particularly in solving trigonometric equations and manipulating identities, where learners often treat identities as "procedures" rather than equivalences and struggle to justify transformation steps (Rohimah & Prabawanto, 2019). A systematic review of research on misconceptions and errors in trigonometry similarly highlights that misunderstanding of core concepts (e.g., angle measure, ratio meaning, and quadrant-based sign conventions) combines with weak algebraic foundations to produce persistent errors across topics such as identities, equations, and problem-solving (Hamzah et al., 2021).

Recent empirical work continues to show that students make frequent errors when applying trigonometric concepts and procedures, including inappropriate identity selection, incorrect simplification, and breakdowns in multi-step reasoning under time constraints (Obeng et al., 2024). These findings suggest that trigonometry difficulties are not merely computational but are also linked to conceptual ambiguity and fragile reasoning. Consequently, effective instruction must provide frequent opportunities for practice, rapid diagnosis of misconceptions, and targeted feedback that help learners refine their conceptual understanding and procedural fluency (Hamzah et al., 2021; Obeng et al., 2024).

### Engagement, Motivation, and Mathematics Learning in the United Arab Emirates

Within the United Arab Emirates (UAE), improving mathematics learning outcomes remains a priority, and research increasingly points to the importance of learner-related factors, such as attitudes, engagement, and motivation, in shaping achievement patterns. For example, a UAE-based study examining the relationship between students' attitudes toward mathematics and mathematics achievement indicates that affective variables remain meaningfully connected to performance outcomes (Alalawi, 2025). In addition, large-scale evidence from Abu Dhabi using TIMSS data shows that student-level factors captured through questionnaires can predict mathematics achievement, reinforcing the view that supporting the learning environment and learner dispositions is integral to

improving performance rather than peripheral to it (Wardat et al., 2023).

These findings are directly relevant to advanced secondary mathematics classrooms where disengagement, manifested as low participation, reduced persistence, and limited willingness to attempt challenging problems, can undermine mastery of topics such as trigonometry that demand sustained attention and careful reasoning. If achievement is associated with learner factors in the UAE context (Alalawi, 2025; Wardat et al., 2023), then interventions that enhance participation, reduce fear of errors, and increase opportunities for meaningful practice and feedback are pedagogically justified.

### Formative Assessment as a Mechanism for Improving Learning and Participation

Formative assessment is consistently described as a high-leverage instructional practice because it supports teachers in identifying misconceptions during learning, adjusting instruction responsively, and providing feedback that helps students close learning gaps. Contemporary research syntheses emphasize that formative assessment can improve learning outcomes when it is embedded as an ongoing classroom process rather than as isolated testing events (Sortwell et al., 2024). In mathematics, formative assessment is particularly valuable because learners' misconceptions often appear in solution steps; timely feedback can prevent the reinforcement of incorrect procedures and can strengthen conceptual understanding through guided correction (Maskos et al., 2025).

From this perspective, trigonometry, where errors in identities, signs, and algebraic manipulation compound rapidly, benefits from instructional designs that enable frequent checking for understanding, immediate clarification, and structured opportunities for students to attempt, receive feedback, and re-attempt problems. This is especially important in advanced mathematics classes where cognitive demand is high and where the gap between surface-level familiarity and deep understanding can be substantial (Hamzah et al., 2021; Maskos et al., 2025).

### Student Response Systems and the Role of Immediate Feedback in Mathematics Learning

SRS operationalize formative assessment by allowing teachers to pose questions, collect whole-class responses efficiently, and provide immediate feedback. Recent studies investigating classroom response systems in mathematics report positive effects on achievement and knowledge retention, attributing these outcomes to increased interaction, continuous checking for understanding, and rapid feedback loops (Alviar & Gamorez, 2024). When implemented effectively, SRS tools can shift classroom participation from a few

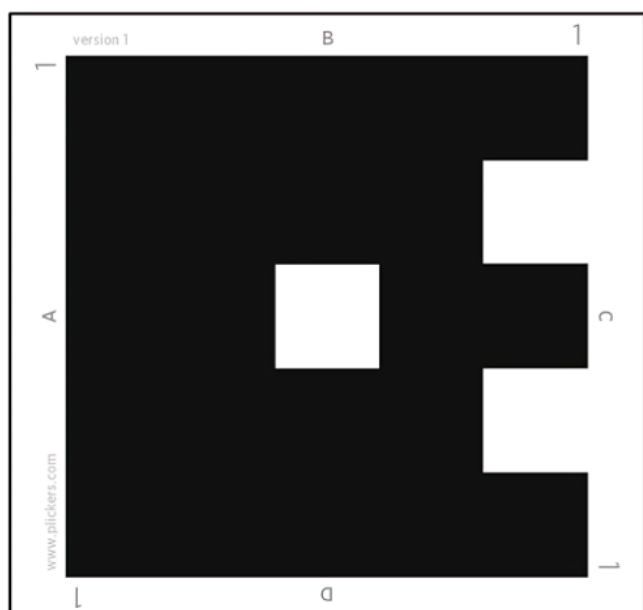
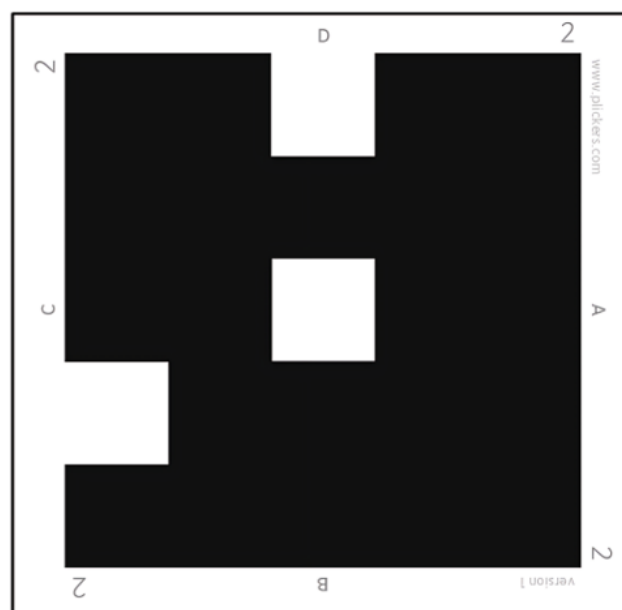


Figure 1. Plickers cards (the authors' own illustration)



volunteers to broad engagement, providing teachers with actionable evidence of learning in real time.

Importantly, gains in engagement alone are insufficient if not accompanied by instructional responses that address misconceptions. Therefore, the value of SRS in mathematics is greatest when teachers use response data diagnostically to identify common errors, prompt explanations, and support students in revising their reasoning. This aligns closely with the needs of trigonometry instruction, in which students benefit from short, frequent items that assess conceptual clarity (e.g., exact values, quadrant reasoning, identity equivalence) and procedural fluency (e.g., multi-step transformations), followed by immediate feedback and corrective explanation.

### Plickers as a Formative Assessment Tool in Mathematics Education

Plickers is a free SRS designed to support quick formative assessment using paper-based QR-style cards, commonly called paper clickers (Figure 1). These cards, scanned by the teacher, enable whole-class responses without requiring student devices. The application must be installed on a mobile device or computer, allowing teachers to create a personalized account associated with their classes (Kent, 2019; Topal, 2020). Each side of the QR code corresponds to one of four answer choices (A, B, C, or D), determined by the card's orientation. Every card is uniquely numbered to identify individual students. Plickers cards can be purchased pre-laminated in sets of 40 or downloaded for free and printed in various sizes from the official website; larger formats are designed for easier use, particularly by younger learners.

In addition to the Plickers cards and the mobile application teachers use to scan student cards, another component of the Plickers platform is the Plickers web

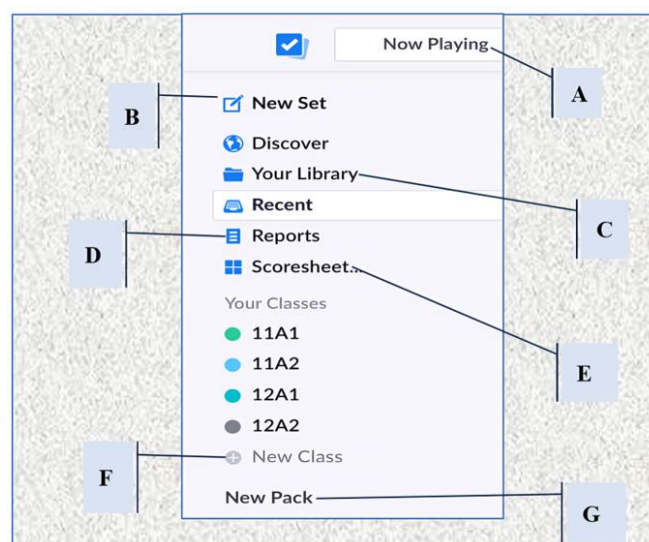


Figure 2. Main features of the Plickers platform (screenshot of the authors' Plickers platform)

portal (plickers.com), whose features are shown in Figure 2. The 'now playing' feature (part A) displays questions and results on a projector or screen, enhancing student engagement as they see their answers recorded. Feature B (new set) is used to set up new questions. The library (part C) stores past and present sets of questions that can be reused with other classes. Part D contains detailed, automatically generated reports for each student. All student response data are accessible in the platform's reports section, where results can be filtered by class and date. The platform provides detailed information for each question, including correct and incorrect responses, individual student answers, and the percentage of students who responded accurately. Additionally, a comprehensive class scoresheet (part E) is available, which, for any specified date range, displays the total number of questions attempted, each student's

responses, the percentage of correct answers per question and overall, and a cumulative accuracy percentage for each student across all attempted questions (Kent, 2019). Part F is used to create new classes, and part G is used to create a new pack of questions.

Using Plickers in the classroom provides several pedagogical advantages. It enhances student engagement and active participation, fosters critical thinking, and strengthens learners' confidence and self-esteem. Additionally, Plickers encourages collaborative learning and supports assessment preparation (Gapol et al., 2025). In studies on mathematics and related classroom contexts, Plickers is commonly used as a tool for real-time assessment of understanding. It enables the rapid identification of misconceptions and the immediate adjustment of instruction. Plickers can also help reduce equity constraints and minimize distractions from students' personal devices, while still providing the rapid feedback cycles typical of SRS-based instruction (Elmahdi et al., 2018).

Empirical evidence indicates that the Plickers platform's effectiveness lies in enabling teachers to efficiently collect whole-class responses and use the resulting data to guide feedback and lesson pacing. In the UAE, Shana et al. (2020) used a quasi-experimental design with elementary learners in Abu Dhabi and found that both traditional revision and Plickers-supported formative assessment improved students' mathematics performance; however, learners in the Plickers group showed greater gains over a short intervention period. Similarly, in Taiwan, Chou (2022) reported that integrating Plickers into elementary mathematics instruction in rural schools was associated with higher student performance on learning tasks and greater positive engagement than traditional response methods, indicating that classroom response systems can positively influence both cognitive outcomes and learners' affective responses to mathematics.

Beyond achievement, a consistent finding in the literature is that Plickers enhances student engagement, participation, and motivation. The tool's game-like features and anonymous response mechanism reduce the social risk associated with public error, thereby encouraging broader participation, particularly among hesitant learners. For example, research by Nunes et al. (2023) in Portugal, involving grade 7 learners studying the mathematics topic of similarity, documented positive shifts in learner engagement and classroom behavior alongside learning gains, and noted practical advantages such as rapid data capture and the reusability of response cards. These affordances position Plickers as a viable low-tech alternative to student-device-based systems, especially in classrooms where access to technology may be uneven.

Although the body of research on Plickers remains relatively limited, emerging studies continue to report positive outcomes across educational levels. Gapol et al. (2025), focusing on first-year education students at Initao College in the Philippines, found a statistically significant improvement in post-test scores following the use of Plickers as a classroom response system. Qualitative findings further revealed positive emotional responses, enhanced engagement, and increased inclusivity, with students reporting enjoyment and reduced anxiety during lessons. Similarly, Sarppa (2023) highlighted the effectiveness of Plickers for quizzes and polls, emphasizing its capacity to monitor student responses in real time and generate immediate assessment reports. Students perceived the tool as convenient and engaging, particularly because it did not require personal devices, reinforcing its potential to enhance participation and engagement across diverse learning contexts.

### The Research Gap

The literature on advanced secondary mathematics, particularly in trigonometry, remains uneven, with existing evidence on Plickers and similar formative assessment tools largely sourced from contexts outside upper-secondary advanced mathematics. Few studies have directly examined their influence on achievement and learner experiences in complex topics such as trigonometric identities and equations, highlighting a crucial research gap, particularly in the UAE context, where learner attitudes significantly impact mathematics achievement. This study seeks to address this gap by investigating the use of Plickers in grade 11 advanced mathematics trigonometry classrooms in Fujairah, focusing on its impact on academic achievement and students' perceptions of its usefulness for learning trigonometric concepts. While Plickers is noted for its rapid-response capabilities in formative assessment, most existing studies tend to focus on foundational mathematics topics and lower grade levels, often neglecting how these tools can foster conceptual understanding and address misconceptions in advanced mathematics. Evidence indicates that learning gains from Plickers are heightened when combined with well-structured diagnostic questions and feedback-led discussions; however, there is limited context-specific evidence from UAE government schools. Therefore, this study aims to explore how Plickers can effectively support engagement and achievement in advanced trigonometry, thereby enhancing students' learning experience in this demanding topic.

### Theoretical Framework

This study uses an integrated theoretical framework grounded in constructivist learning theory, formative assessment theory, and self-determination theory to examine how the Plickers platform can improve learning

outcomes and experiences in grade 11 advanced mathematics trigonometry.

From a constructivist perspective, learning is an active process where students construct mathematical knowledge through engagement, reflection on errors, and feedback (Piaget, 1970; Vygotsky, 1978). In trigonometry, students must navigate various representations while maintaining procedural accuracy. This complexity makes learning particularly vulnerable to misconceptions. Constructivist instructional approaches promote active participation and opportunities for learners to rethink and refine their understanding. Plickers facilitates this by having all students respond to questions, allowing for immediate conceptual adjustments.

Formative assessment theory emphasizes assessment as part of instruction rather than a final judgment (Black & Wiliam, 1998; Wiliam, 2011). It involves systematically gathering and interpreting evidence of student learning to address gaps. In mathematics education, formative assessment is powerful for addressing misconceptions that arise in reasoning processes. Plickers supports formative assessment by providing real-time responses, helping teachers identify errors and deliver immediate feedback, enhancing both conceptual understanding and procedural fluency in trigonometry.

Self-determination theory adds insight into the motivational aspects of learning (Deci & Ryan, 2000). It suggests that students engage better when their needs for autonomy, competence, and relatedness are met. Plickers meets these needs by allowing anonymous responses to reduce anxiety, offering immediate feedback to support competence, and encouraging whole-class participation to foster a sense of community. These features contribute to increased confidence, engagement, and willingness to participate in trigonometry.

Together, these three theories illustrate how Plickers functions beyond a simple tool. They show that it supports cognitive development through engagement, enhances learning with real-time feedback, and nurtures motivation and emotional well-being, thereby improving academic performance and experiences in advanced trigonometry.

## **METHODOLOGY**

### **Research Design**

This study used a quasi-experimental pre-/post-test design, appropriate for school-based research with intact classes when random assignment is not feasible (Creswell & Creswell, 2017). The design enabled a systematic comparison of academic achievement between a control group that received traditional instruction and an experimental group that received Plickers-supported formative assessment during

trigonometry instruction (Cohen et al., 2018). Such designs are widely used in mathematics education research to examine instructional interventions in authentic classroom conditions (Shadish et al., 2002; Slavin, 2008).

### **Participants and Research Context**

The participants were grade 11 advanced mathematics students from a government boys' secondary school in Fujairah, UAE. The school was selected based on the convenience and accessibility of participants to the researchers. Two intact classes ( $n = 21$  each) participated in the study. The two intact classes were randomly assigned to the experimental and control groups. Both groups were taught by the same teacher, followed the same curriculum sequence, and were allocated comparable instructional time to control for teacher and exposure effects.

The instructional content focused on core trigonometry topics, including trigonometric ratios, exact values, trigonometric identities, and multi-step problem-solving, which are conceptually demanding and prone to persistent misconceptions.

### **Implementation of Plickers in Trigonometry Teaching**

The Plickers platform was integrated into the experimental group's instruction as a formative assessment mechanism embedded within regular trigonometry lessons rather than as an isolated technological activity. Lessons followed a structured instructional sequence aligned with constructivist and formative assessment principles.

Each lesson began with a brief teacher explanation and worked examples to introduce or review a trigonometric concept. This was followed by the administration of Plickers-based multiple-choice questions targeting both conceptual understanding and procedural accuracy (Figure 3). Questions were designed to address common trigonometric misconceptions, such as incorrect identity selection, sign errors arising from quadrant reasoning, and confusion about reciprocal ratios.

Students responded simultaneously using Plickers cards, allowing the teacher to collect whole-class responses in real time. The distribution of responses was immediately displayed, enabling rapid identification of correct understanding and misconceptions across the class (Figure 4). These response patterns informed immediate instructional decisions, including clarification, re-explanation, and targeted questioning.

Following each question, the teacher provided explicit feedback, explaining correct solution steps, addressing incorrect options, and prompting students to reflect on their reasoning (Figure 5).

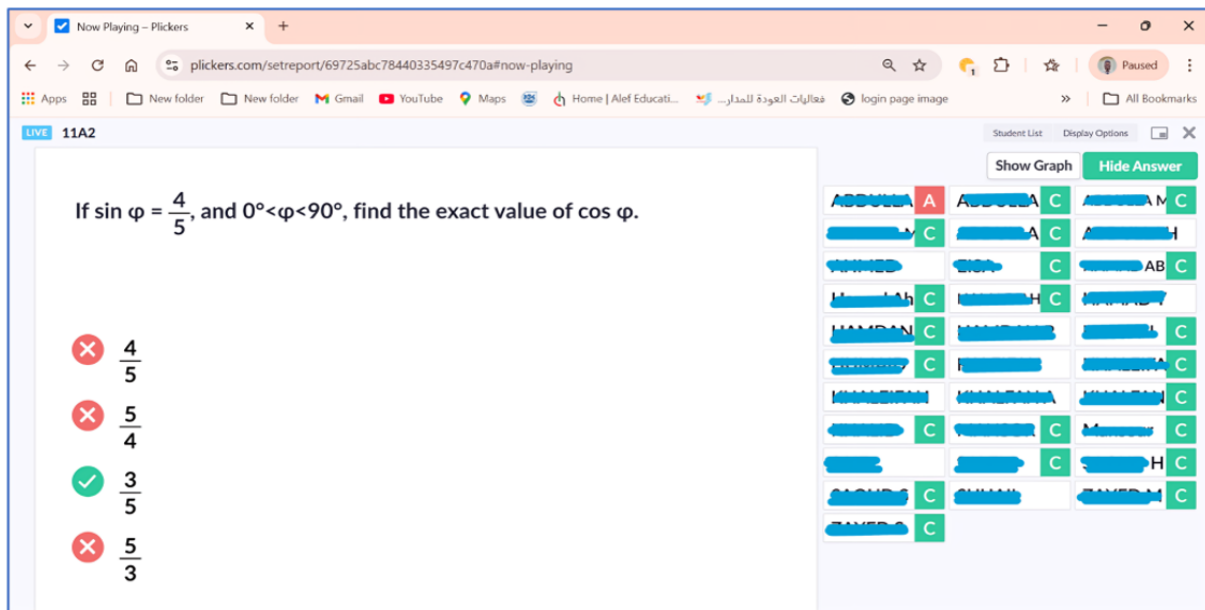


Figure 3. Plickers question presentation (screenshot of the authors' Plickers platform)

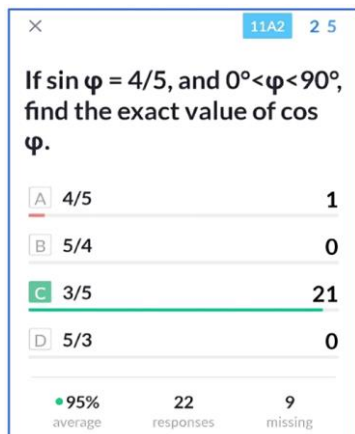


Figure 4. Real-time response distribution (screenshot of the authors' Plickers platform)

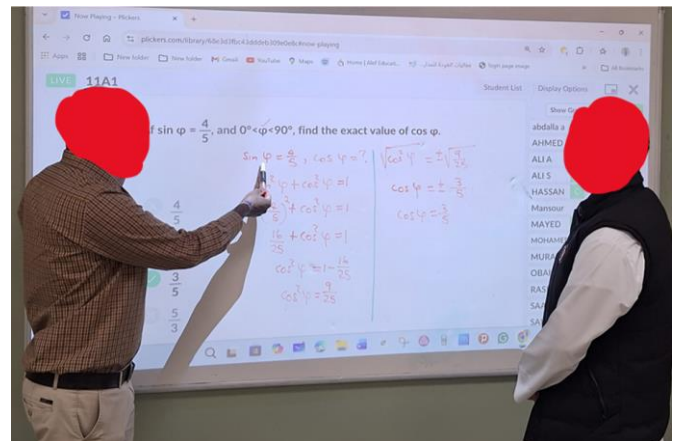


Figure 5. Teacher feedback and scaffolding (the authors' own illustration)

This feedback phase was critical in supporting conceptual understanding and procedural fluency. The anonymity of responses reduced fear of public error and encouraged participation from all students. The control group received instruction on the same trigonometry content using traditional explanation, questioning, and board work without the use of an SRS.

### Quantitative Instrument: Trigonometry Achievement Test

A multiple-choice trigonometry achievement test (see Appendix A) was developed and administered as both a pre- and a post-test. The test measured students' conceptual understanding of trigonometric relationships and identities, procedural fluency in calculating exact values, and ability to apply trigonometric concepts to multi-step problems. The multiple-choice format was selected to align with the Plickers platform and to enable objective scoring and statistical comparison.

Although the test employed a multiple-choice format, items were differentially weighted to reflect increasing cognitive demand, with more complex trigonometric reasoning tasks allocated higher marks (Table 1). This approach preserved objective scoring while enhancing sensitivity to variations in conceptual understanding and procedural fluency.

To ensure balanced content coverage and appropriate progression of cognitive demand, a test blueprint was developed prior to item construction (Table 2). The blueprint mapped key trigonometry concepts to three difficulty levels (easy, moderate, and challenging), guiding the selection and weighting of multiple-choice items. This structure ensured that foundational knowledge, procedural fluency, and higher-order reasoning were adequately represented in the achievement test.

**Table 1.** Mark distribution overview

Cognitive level	Difficulty	Number of items	Marks per item	Subtotal
Remember/understand	Easy	6	5	30
Apply	Moderate	5	8	40
Analyze/reason	Challenging	3	10	30
Total	-	14	-	100

**Table 2.** Test blueprint (content × cognitive level)

Topic	Easy	Moderate	Challenging
Trigonometric ratios and exact values	√	√	-
Quadrant and sign reasoning	√	√	-
Trigonometric identities	√	√	√
Trigonometric equations	-	√	√
Multi-step reasoning	-	-	√

### Validity of the instrument

Content validity was assessed through expert judgment by ten experienced advanced mathematics teachers. The level of agreement was quantified using the modified kappa statistic to correct for chance agreement. The overall content validity index of the test instrument was 0.96, indicating excellent content validity. This value exceeds commonly accepted thresholds for acceptable validity (Said et al., 2022) and suggests strong expert agreement regarding the relevance and appropriateness of the test items for assessing grade 11 advanced mathematics trigonometry achievement.

### Reliability of the instrument

Internal consistency reliability was estimated using the Kuder-Richardson formula 20 (KR-20), which is appropriate for tests composed of dichotomously scored items (correct/incorrect) (Kuder & Richardson, 1937). KR-20 estimates the extent to which test items consistently measure the same construct. KR-20 was computed using the formula shown below, where  $k$  represents the number of items,  $p$  and  $q$  represent the proportions of correct and incorrect responses, respectively, and  $\sigma_X^2$  is the variance of total test scores:

$$KR - 20 = \frac{k}{k-1} \left( 1 - \frac{\sum_{i=1}^k p_i q_i}{\sigma_X^2} \right). \quad (1)$$

KR-20 is frequently used in educational research to evaluate the reliability of achievement measures and is mathematically equivalent to Cronbach's alpha (Tavakol & Dennick, 2011). Although larger samples are generally recommended to enhance the stability of reliability estimates, smaller samples are commonly accepted in school-based educational research when intact classes are used. A rapid synthesis of educational research found that the median sample size across studies is around 30 participants per group, indicating that this magnitude is typical and acceptable for preliminary reliability estimation in classroom contexts. Moreover, minimum sample size recommendations for assessing

reliability measures, such as internal consistency, often cite approximately 30 respondents as sufficient for preliminary reliability checks, particularly when measuring straightforward achievement outcomes (Bujang et al., 2024). These considerations support the use of the present sample ( $n = 42$ ) to compute the KR-20 reliability index.

Because KR-20 is equivalent to Cronbach's alpha, the interpretation guidelines for Cronbach's alpha apply directly to KR-20 reliability estimates. KR-20 values of 0.70 or higher are typically considered acceptable indicators of internal consistency (Vrotsou et al., 2018). The KR-20 reliability estimate for the test instrument, based on pre-test correct and incorrect responses, was 0.74, which falls within the acceptable range.

### Qualitative Instrument: Open-Ended Student Questionnaire

An initial version of an open-ended student questionnaire was created to explore learners' experiences with the Plickers platform during grade 11 advanced mathematics trigonometry lessons. This preliminary instrument consisted of 13 open-ended questions organized around several themes: overall experience, engagement and participation, learning and understanding, feedback, confidence, comparison with traditional teaching methods, and recommendations.

The open-ended questionnaire was reviewed by five experts in qualitative research methodology from various universities. These experts were selected based on their experience in qualitative design, instrument development, and school-based research. Their feedback led to revisions aimed at reducing redundancy, improving clarity, and aligning the instrument more closely with the research questions. The number of experts consulted was considered sufficient for qualitative expert judgment, as depth of expertise is prioritized over sample size.

Incorporating their feedback, some questions were removed, and others were merged, resulting in a refined set of eight open-ended questions (see [Appendix B](#)).

This refinement strengthened the instrument by sharpening its focus, minimizing participant burden, and enhancing data quality. The final questionnaire maintained a balance between breadth and depth, allowing students to articulate their experiences in their own words while ensuring that responses remained closely aligned with the study's objectives. The streamlined structure facilitated thematic analysis, reduced redundancy during coding, and increased the credibility and trustworthiness of the qualitative findings.

### Data Collection

Data were collected during the first three weeks of January 2026. The control group received traditional instruction, while the experimental group was taught using the Plickers platform. The trigonometry achievement test was administered twice to students in the experimental and control groups: before instruction on the topic, and again at the end of the instructional period. Both administrations were conducted under standardized examination conditions to ensure consistency. Students were given 45 minutes to complete the assessment, which comprised 14 weighed multiple-choice items, with a total possible score of 100 marks. The test was administered electronically via the learning management system, a widely used digital learning platform in the UAE education system for monitoring and assessing students' academic progress.

An open-ended student questionnaire was administered to the 21 students in the experimental group via Google Forms. The questionnaire was presented in Arabic, the students' native language, to ensure clear comprehension of the questions and to enable participants to express their views freely and accurately without language-related constraints. Administering the instrument in students' first language was intended to enhance the authenticity and depth of qualitative responses, thereby improving the credibility of the collected data. Students were informed of their right to refuse participation and to withdraw at any time without providing reasons. Of the 21 students invited to participate, 10 submitted complete responses to the questionnaire. The number of responses was considered sufficient to achieve data saturation within the scope of the study. Using Google Forms also facilitated efficient distribution, completion, and secure collection of responses in a familiar digital environment.

### Data Analysis

Quantitative and qualitative data were analyzed using complementary procedures consistent with the study's mixed-methods design. Quantitative analyses addressed the first research question about the impact of Plickers on students' academic achievement in trigonometry, while qualitative analyses addressed the

second research question about students' perceptions and learning experiences.

### Quantitative data analysis

Quantitative data from the trigonometry achievement test were analyzed using IBM SPSS (version 29). Descriptive statistics, including means, standard deviations, skewness, and kurtosis, were computed for both the control and experimental groups at pre- and post-test. The normality of score distributions was assessed using the Shapiro-Wilk test, which indicated that although the control group's pre-test scores were not normally distributed, the post-test scores for both groups were approximately normal. Therefore, inferential analyses proceeded as the parametric tests are robust to minor violations.

To ensure baseline equivalence, an independent-samples t-test with Welch's correction was conducted on pre-test scores, checking for significant differences between groups before the intervention. For post-test achievement, another independent-samples t-test was performed, utilizing Levene's test for homogeneity of variances, and Cohen's  $d$  was calculated for effect size.

Given the quasi-experimental design, an analysis of covariance (ANCOVA) was conducted to compare post-test scores while controlling pre-test performance, confirming the homogeneity of regression slopes. Partial eta squared ( $\eta^2$ ) was used to quantify effect size, indicating the proportion of variance in post-test scores attributable to the instructional method, with all tests conducted at  $\alpha = .05$ .

### Qualitative data analysis

Qualitative data from the open-ended student questionnaire were translated by one of the study's researchers, who is proficient in both Arabic and English. Thematic analysis was then applied to the translated qualitative data. This approach was selected because it enables the systematic identification, organization, and interpretation of recurring patterns in participants' responses while remaining sufficiently flexible to capture nuanced learner experiences (Braun & Clarke, 2006; Nowell et al., 2017).

Analysis followed an iterative process. First, all responses were read multiple times to achieve familiarity with the data. Initial codes were then generated inductively by identifying meaningful units related to students' engagement, participation, learning support, feedback, confidence, perceived effectiveness, and challenges associated with using Plickers. Codes were refined through iterative comparison, with similar codes grouped into broader categories.

These categories were subsequently reviewed and consolidated into overarching themes that reflected shared patterns across student responses. The analysis continued until no substantive new themes emerged,

indicating data saturation within the scope of the study. To enhance credibility, representative verbatim quotations were selected to illustrate each theme and to ensure that interpretations were grounded in participants' own words (Nowell et al., 2017).

The qualitative findings were used to complement and contextualize the quantitative results by providing insight into how students experienced Plickers-supported instruction, particularly in relation to engagement, feedback, confidence, and learning processes during trigonometry lessons.

### *Integration of quantitative and qualitative findings*

Integration occurred at the interpretation stage, where qualitative themes were used to explain and enrich the quantitative results on trigonometry achievement. While statistical analyses established the effectiveness of Plickers in improving trigonometry achievement, qualitative findings illuminated the mechanisms underlying these gains, including increased participation, immediate feedback, reduced anxiety, and enhanced confidence. This convergence of findings strengthened the overall validity of the study's conclusions.

### **Ethical Considerations**

This study was conducted in the normal instructional environment of a government secondary school in the UAE, where teacher autonomy, professional innovation, and reflective practice are actively encouraged. Teachers are expected to explore instructional strategies that enhance student learning outcomes, provided these practices align with curriculum requirements and pose no physical, psychological, or academic risk to learners. The instructional approach examined in this study, therefore, constituted routine pedagogical practice rather than an experimental intervention outside standard classroom activity.

The research was conducted by the teachers responsible for the participating classes, within their usual teaching context, with students already familiar with them. This minimized disruption to instructional routines and reduced potential stress associated with unfamiliar researchers or settings. The instructional content, assessment tasks, and learning objectives aligned with the official grade 11 advanced mathematics curriculum, and no student was denied access to required learning opportunities.

Participation in the study was entirely voluntary. Students were informed of the study's purpose, the nature of the data being collected, and their right to decline participation or withdraw at any stage without academic penalty. Consent was obtained before administering the achievement tests and the open-ended questionnaire. Students' decisions regarding

participation had no impact on their grades, class standing, or relationship with the teacher.

To protect student confidentiality, all data were anonymized before analysis. No personally identifiable information was included in the dataset, and participants were referred to using coded identifiers. Digital data were stored securely and accessed only by the researchers for academic purposes. Any classroom images used for illustrative or reporting purposes were anonymized to prevent the identification of individual students.

Given the dual role of the researchers as both teachers and investigators, particular care was taken to mitigate potential researcher bias. Quantitative assessment data were scored objectively using predetermined marking schemes, and statistical analyses were conducted in accordance with established procedures. Qualitative data were analyzed systematically using thematic analysis, with themes derived from repeated patterns in student responses rather than researcher expectations. Direct verbatim quotations were used to ground interpretations in participants' own words, thereby enhancing credibility and reducing interpretive bias.

Formal institutional ethical approval was not required for this study, as it involved routine classroom practices, posed minimal risk to participants, and did not involve sensitive data or vulnerable populations beyond standard school settings. The study adhered to general ethical principles of voluntary participation, informed consent, confidentiality, and non-maleficence throughout the research process.

## **RESULTS**

### **Preliminary Analyses and Assumption Checks**

Prior to conducting inferential analyses, descriptive statistics and assumption checks were performed for both the control and experimental groups. Each group consisted of 21 grade 11 male students from a boys-only secondary school (**Table 3**).

Normality of score distributions was assessed using the Shapiro-Wilk test, complemented by skewness and kurtosis. For the pre-test, the control group violated the assumption of normality,  $W = 0.899$ ,  $p = .033$ , whereas the experimental group did not,  $W = 0.921$ ,  $p = .091$ . However, post-test scores for both the control group ( $W = 0.913$ ,  $p = .063$ ) and the experimental group ( $W = 0.943$ ,  $p = .247$ ) did not significantly deviate from normality. Skewness and kurtosis values for post-test scores were within acceptable limits ( $|\text{skewness}| < 1$ ,  $|\text{kurtosis}| < 2$ ), supporting the use of parametric statistical tests.

### **Baseline Equivalence of Groups: Pre-Test**

To determine whether the two groups were comparable prior to the intervention, an independent-

**Table 3.** Descriptive statistics and tests of normality for pre- and post-test scores by group

Group	Test	<i>n</i>	<i>M</i>	<i>SD</i>	Skewness	Kurtosis	Shapiro-Wilk <i>W</i>
Control	Pre-test	21	53.10	33.93	0.03	-1.00	0.899
	Post-test	21	60.00	14.05	0.82	-0.05	0.913
Experimental	Pre-test	21	51.90	32.19	-0.00	-0.72	0.921
	Post-test	21	79.76	12.19	0.04	-1.10	0.943

Note. Normality was assessed using the Shapiro-Wilk test & skewness and kurtosis values within ±1 and ±2, respectively, were considered acceptable for approximate normality

**Table 4.** Baseline comparison of pretest scores between control and experimental groups

Comparison	Control: <i>M (SD)</i>	Experimental: <i>M (SD)</i>	Mean difference	<i>t</i>	<i>df</i>	<i>p</i>	95% CI
Pre-test	53.10 (33.93)	51.90 (32.19)	-1.19	0.12	39.89	.908	[-21.82, 19.44]

Note. Welch’s independent-samples *t*-test was used due to unequal variances at the pre-test & mean difference is reported as the experimental group minus the control group

**Table 5.** Independent samples *t*-test comparing post-test scores between control and experimental groups

Group	<i>n</i>	<i>M</i>	<i>SD</i>	Mean difference	<i>t</i>	<i>df</i>	<i>p</i>	95% CI	Cohen’s <i>d</i>
Control	21	60.00	14.05	-	-	-	-	-	-
Experimental	21	79.76	12.19	19.76	-4.87	40	< .001	[11.55, 27.97]	1.50

Note. Mean difference is reported as the experimental group minus the control group; Levene’s test for equality of variances was non-significant (*p* = .932); Cohen’s *d* values of 0.20, 0.50, and 0.80 represent small, medium, and large effects, respectively

samples *t*-test (Welch correction) was conducted on pre-test scores. Results indicated no statistically significant difference between the control group (mean [*M*] = 53.10, standard deviation [*SD*] = 33.93) and the experimental group (*M* = 51.90, *SD* = 32.19), *t*(39.89) = 0.12, *p* = .908. This finding suggests that the groups were equivalent in their initial understanding of trigonometry concepts prior to treatment (Table 4).

### Post-Test Comparison Between Control and Experimental Groups

An independent-samples *t*-test was conducted to assess whether post-test performance differed significantly between the two instructional approaches. Levene’s test for equality of variances was non-significant (*p* = .932), indicating that the assumption of homogeneity of variances was met.

Results showed that the experimental group (*M* = 79.76, *SD* = 12.19) significantly outperformed the control group (*M* = 60.00, *SD* = 14.05) on the post-test, *t*(40) = -4.87, *p* < .001. The mean difference of 19.76 points (95% confidence interval (CI) [11.55, 27.97]) reflects a large effect size, Cohen’s *d* = 1.50, indicating a substantial impact of the Plickers-based instructional approach on students’ achievement in trigonometry (Table 5).

### ANCOVA Controlling for Pre-Test Scores

Given the quasi-experimental design involving intact classes, an ANCOVA was conducted to further examine post-test differences while statistically controlling pre-test scores. The assumption of homogeneity of regression slopes was satisfied, as the interaction

**Table 6.** ANCOVA for post-test scores controlling pre-test performance

Source	<i>F</i>	<i>df</i>	<i>p</i>	$\eta^2$
Pre-test (covariate)	0.91	1, 39	.345	-
Group	23.80	1, 39	< .001	.379

Note. Instructional group (0 = control, 1 = experimental) was entered as the fixed factor, and pre-test scores were entered as the covariate &  $\eta^2$  represents effect size, with .01 = small, .06 = medium, and .14 = large

between group and pre-test scores was not significant (*p* = .754).

The ANCOVA revealed a statistically significant main effect of instructional group on post-test performance after controlling pre-test scores, *F*(1, 39) = 23.80, *p* < .001, partial  $\eta^2$  = .379. This indicates that approximately 38% of the variance in post-test scores was attributable to the instructional method. Adjusted post-test means favored the experimental group, confirming that students taught using the Plickers platform demonstrated significantly higher achievement than those taught using traditional methods, even after accounting for initial differences (Table 6).

### Qualitative Data Analysis

#### Theme 1. Positive, enjoyable learning experience

Most students described their experience with Plickers during trigonometry lessons as enjoyable, engaging, and useful. For instance, one student, E20, noted, “My experience was fun and not boring,” highlighting the positive atmosphere created by the tool. Similarly, E12 mentioned, “My experience with Plickers was enjoyable and easy, and it helped me focus more

during the math lessons." This indicates that Plickers not only made the lessons more engaging but also improved students' focus and attention. E2 added, "Very good and useful," while E4 chimed in with, "Good and enjoyable." These quotes reflect a general student sentiment that Plickers contributed to a more dynamic classroom environment during trigonometry lessons.

### *Theme 2. Increased participation and attention*

Students have consistently reported that Plickers is associated with increased classroom participation, often noting that the platform allows everyone to respond simultaneously, fostering a more inclusive environment. One student, E14, stated, "My engagement increased because all students participated at the same time," highlighting the collective involvement that Plickers promotes. Another student, E20, remarked, "It made me more attentive and engaged in the lesson," suggesting that the tool enhances their focus during activities. E2 added, "It helped and encouraged us a lot to answer," indicating that Plickers motivates students to contribute more actively. Furthermore, E12 commented, "It made me participate more because I could answer without fear of making mistakes in front of my classmates," indicating that the anonymity provided by Plickers reduces anxiety about participation. Overall, these perceptions suggest that Plickers serves as a participation equalizer, transforming classroom engagement from a few vocal volunteers to broader involvement among all students.

### *Theme 3. Learning support for trigonometry concepts*

Students perceived Plickers as a valuable tool in enhancing their understanding, particularly through quick practice, reinforcement, and error awareness. For instance, one student, E12, noted, "Plickers helped me master trig identities through quick questions." Another student, E14, shared, "I didn't understand trig ideas well before, but Plickers helped reinforce the ideas." Additionally, E19 emphasized how the tool aided in distinguishing between correct and incorrect steps in solving trigonometry questions, stating, "It helped me distinguish between correct and incorrect steps in solving trig questions." Furthermore, E5 explained how the repetition of missed questions contributed to better retention, saying, "The problems that I missed got memorized better." This feedback suggests that students particularly valued the repeated retrieval and practice provided by Plickers, as well as the clearer distinction between accurate and inaccurate problem-solving steps, both of which were beneficial for mastering trigonometric identities and ensuring procedural accuracy.

### *Theme 4. Immediate feedback strengthens learning*

Several responses emphasize the provision of quick, direct feedback as a key benefit. For instance, one participant, E12, stated, "The feedback was immediate, and I knew right away if my answer was correct or not," highlighting the immediacy of the responses. Similarly, E14 remarked, "I liked the feedback because it showed my mistakes immediately," which underscores the value of learning from errors promptly. E19 added, "The feedback was clear and direct," reinforcing the importance of clarity in the feedback process. Overall, these insights illustrate the critical role of timely, straightforward feedback in the learning experience.

### *Theme 5. Confidence and psychological safety*

Many students reported increased confidence, linked to reduced fear of embarrassment and to less public exposure to mistakes. For instance, one student, E2, stated, "Yes, because no one would make fun of someone else's answer." Similarly, E18 expressed, "Yes, I felt more confident because mistakes were not embarrassing." E19 echoed this sentiment, saying, "Yes, my confidence increased because I could try without worry." These responses suggest that Plickers is largely perceived as a supportive tool for confidence in the learning environment.

### *Theme 6. Perceived effectiveness versus traditional methods*

Students often judged the Plickers platform more effective because it is interactive and includes everyone, although one student considered it less effective than traditional teaching. Student feedback emphasizes both the advantages and limitations of Plickers in the classroom. One student, E12, remarked, "I find it more effective than traditional methods because it makes the lesson interactive." Similarly, E14 noted, "It is more effective because it involves all students, not just one," highlighting its ability to engage the entire class. E4 added that Plickers is "excellent for energizing the class and breaking the routine." However, not all feedback was overwhelmingly positive. E7 commented, "It's a nice and enjoyable method, but it is less effective than traditional methods." This suggests that while students appreciate Plickers for its engagement and interactivity, some may still prefer traditional explanations for deeper concept development. Overall, it indicates a potential for a blended approach that includes explanations followed by Plickers checks to effectively address misconceptions.

### *Theme 7. Practical challenges*

One of the most consistent challenges students faced was the speed and time constraints of Plickers' platform assessments. Several students have expressed frustration with the pacing of the questions. For instance, E5 stated, "The time wasn't on my side," while E4



engagement outcomes (Nunes et al., 2023; Shana et al., 2020).

This study contributes to the literature by demonstrating that the benefits of SRS-based formative assessment extend beyond basic procedural topics to conceptually demanding trigonometry content, including identities, quadrant reasoning, and multi-step problem-solving. These topics are widely documented as persistent sources of misconceptions and errors in secondary mathematics (Hamzah et al., 2021; Obeng et al., 2024). By showing strong achievement gains in this context, the study provides empirical support for the claim that formative assessment technologies are particularly effective when instructional content is cognitively complex and error-prone.

Moreover, the large effect size observed (Cohen's  $d = 1.50$ ) exceeds those reported in many prior SRS studies, suggesting that instructional alignment, rather than the mere presence of technology, may be a key explanatory factor. In this study, Plickers was deliberately embedded in a formative assessment cycle that included diagnostic questioning, immediate feedback, and instructional adjustment. This finding aligns with research emphasizing that the effectiveness of formative assessment lies in how evidence of learning is used rather than simply collected (Sortwell et al., 2024; Wiliam, 2011).

### **Extending Formative Assessment Theory in Advanced Mathematics Contexts**

From a theoretical standpoint, the findings provide strong empirical support for formative assessment theory in advanced secondary mathematics. Although formative assessment is widely endorsed as a high-impact instructional practice, much of the empirical work has focused on general achievement gains without closely examining how formative processes operate within mathematically sophisticated topics. This study addresses that gap by showing how real-time response data can reveal misconceptions about identity equivalence, sign conventions, and procedural sequencing; areas where traditional questioning often fails to capture whole-class understanding.

The qualitative data illuminate the mechanisms through which formative assessment influenced learning. Students repeatedly emphasized the role of immediate feedback in helping them identify and correct errors, supporting existing evidence that feedback is most effective when it is timely, specific, and directly connected to learners' reasoning processes (Maskos et al., 2025). In trigonometry, where errors can propagate rapidly across steps, this immediacy appears to be especially consequential. Thus, the study contributes to the formative assessment literature by providing content-specific evidence of how feedback-driven

instruction supports conceptual coherence and procedural fluency in advanced mathematics.

### **Contribution to Engagement and Affective Dimensions of Mathematics Learning**

Beyond achievement, the study makes a meaningful contribution to the literature on engagement and affect in mathematics education. Students' reports of increased participation, attention, and confidence align with previous findings that SRS can broaden classroom participation and reduce the dominance of a small number of volunteers (Alviar & Gamorez, 2024). However, this study advances existing knowledge by demonstrating that these engagement gains are not merely peripheral but are closely intertwined with learning outcomes in advanced mathematics.

In the UAE context, prior research has shown that student attitudes and engagement are significantly associated with mathematics achievement (Alalawi, 2025; Wardat et al., 2023), the affective benefits of Plickers are particularly significant. Students' emphasis on anonymity and reduced fear of embarrassment suggests that Plickers helped establish a psychologically safe learning environment, enabling learners to take intellectual risks without social penalty. This finding aligns with self-determination theory, particularly the role of perceived competence and autonomy in sustaining engagement (Deci & Ryan, 2000). It provides empirical support for the argument that affective conditions are not ancillary but integral to learning in cognitively demanding mathematics classrooms.

### **Positioning the Study Within SRS and Technology-Integration Literature**

While the positive outcomes observed align with prior SRS research, this study offers a distinctive contribution by reframing Plickers not as a motivational tool but as a pedagogically consequential formative assessment mechanism. Several earlier studies highlight engagement, enjoyment, or convenience as primary benefits of Plickers (Nunes et al., 2023; Sarppa, 2023). In contrast, the present findings show that engagement gains translated into measurable learning improvements when paired with deliberate instructional responses to student data.

Importantly, students' mixed views on the effectiveness of Plickers relative to traditional instruction underscore the need for instructional coherence. The findings suggest that Plickers is most effective when used to complement explanations and worked examples rather than replace them. This supports calls in the literature for blended pedagogical approaches that integrate digital tools into well-structured instructional designs rather than positioning technology as a standalone solution (Engelbrecht & Borba, 2024).

## Teacher Perspective on the Use of Plickers

From the teacher's perspective, using Plickers during trigonometry instruction offered several practical advantages and some implementation challenges. One major advantage was the ability to obtain immediate whole-class feedback, which enabled rapid identification of misconceptions related to trigonometric identities, sign conventions, and procedural errors. This allowed instructional adjustments to be made in real time, improving responsiveness to students' needs. The platform also increased participation from students who would normally hesitate to respond publicly, creating a calmer and more inclusive classroom atmosphere. In addition, the automatic recording of student responses reduced the need for manual checking during lessons and provided useful diagnostic information for planning subsequent instruction.

However, using Plickers also required additional teacher preparation and classroom management. Effective implementation depended on carefully designing diagnostic multiple-choice questions that targeted common misconceptions while remaining aligned with the lesson's pacing. Preparing questions, organizing response cards, and managing scanning procedures initially increased teacher workload compared with traditional questioning approaches. Timing also emerged as an important instructional consideration, particularly for multi-step trigonometry problems, where some students required additional processing time. Furthermore, the platform's effectiveness depended not on the technology itself but on the teacher's ability to interpret response patterns and provide timely explanatory feedback. These findings suggest that while Plickers can enhance formative assessment practices, successful implementation requires thoughtful pedagogical planning and instructional flexibility.

Taken together, these teacher-related experiences reinforce the broader conclusion that the educational value of Plickers depends not only on the platform's technological features but also on its pedagogical integration into classroom instruction. The practical realities of question design, pacing, feedback delivery, and instructional responsiveness further highlight the interconnected cognitive, motivational, and instructional dimensions that underpin effective formative assessment in advanced mathematics classrooms. These insights have important theoretical and practical implications for mathematics teaching and technology integration.

## Theoretical and Practical Implications

This study advances theory by empirically integrating constructivist learning theory, formative assessment theory, and self-determination theory in an advanced mathematics context. It shows how formative

assessment technologies can simultaneously support cognitive restructuring, motivational regulation, and instructional responsiveness. In doing so, the study contributes to a more nuanced theoretical understanding of how digital tools mediate learning processes rather than act as independent causal agents.

For practitioners, the findings suggest that Plickers can be strategically used to support diagnostic assessment and feedback in trigonometry, particularly in classrooms where equitable participation is a concern. For curriculum designers and school leaders, the study underscores the importance of investing in formative assessment capacity (not merely technology adoption) through professional development focused on question design, feedback practices, and instructional decision-making.

## Limitations of the Study

Despite its contributions, the study is limited by its small, context-specific sample and short intervention duration. The exclusive focus on a boys' government school further constrains generalizability. Additionally, reliance on multiple-choice items limits insight into students' written reasoning, which is central to trigonometric understanding.

## Recommendations for Future Research

Future research should examine the longitudinal effects of Plickers-supported formative assessment on retention and transfer, replicate the study across diverse school contexts, and explore hybrid designs that combine SRS tools with peer discussion or written justification. Investigating teachers' real-time instructional decision-making using response data would further deepen understanding of how formative assessment is enacted. Future studies should also examine teachers' experiences implementing Plickers, including workload, lesson-preparation demands, classroom-management considerations, and long-term sustainability in advanced mathematics classrooms.

## CONCLUSION

In conclusion, this study provides robust evidence that Plickers-supported formative assessment can meaningfully enhance achievement and learning experiences in grade 11 advanced mathematics trigonometry. By foregrounding formative processes rather than technology use alone, the study extends the existing mathematics education literature and offers theoretically grounded, practice-relevant insights. The findings affirm the central role of formative assessment in advanced mathematics instruction and demonstrate how thoughtfully integrated digital tools can support both learning and engagement in cognitively demanding domains.

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## APPENDIX A: TEST ITEMS

### Instructions to Students

1. This test consists of 14 multiple-choice questions.
2. Read each question carefully before selecting your answer.
3. Each question has four options (A, B, C, or D). Only one option is correct.
4. Choose the best answer for each question.
5. Questions carry different marks. More challenging questions are worth more marks.
6. Show no working on the test paper; answers are recorded only by selecting the correct option.
7. Use of calculators, mobile phones, notes, or any other aids is not permitted, unless instructed by the teacher.
8. Answer all questions. There is no penalty for incorrect answers.
9. Manage your time carefully. Do not spend too long on one question.
10. Remain silent and follow all assessment rules during the test.

**Time allowed:** 45 minutes

**Total marks:** 100

### Section A: Foundational Understanding (6 × 5 = 30 Marks)

#### Question 1 (5 marks)

If  $\sin \theta = \frac{3}{5}$  and  $0^\circ < \theta < 90^\circ$ , find  $\cos \theta$ .

- A.  $\frac{4}{5}$
- B.  $\frac{5}{4}$
- C.  $\frac{3}{5}$
- D.  $\frac{5}{3}$

#### Question 2 (5 marks)

Which identity is always true?

- A.  $\sin^2 x + \cos^2 x = 1$
- B.  $\sin x + \cos x = 1$
- C.  $\tan x = \sin x + \cos x$
- D.  $\sin 2x = \sin x$

#### Question 3 (5 marks)

The exact value of  $\tan 45^\circ$  is:

- A. 0
- B.  $\frac{1}{\sqrt{3}}$
- C. 1
- D.  $\sqrt{3}$

#### Question 4 (5 marks)

In which quadrant is  $\cos \theta$  negative and  $\sin \theta$  positive?

- A. I
- B. II
- C. III
- D. IV

#### Question 5 (5 marks)

Which expression is equivalent to  $\sec x$ ?

- A.  $\frac{1}{\sin x}$
- B.  $\frac{1}{\cos x}$

- C.  $\frac{\sin x}{\cos x}$
- D.  $\frac{\cos x}{\sin x}$

**Question 6** (5 marks)

If  $\sin x = 0$  for  $0^\circ \leq x \leq 360^\circ$ , then  $x =$

- A.  $90^\circ$  only
- B.  $180^\circ$  only
- C.  $0^\circ, 180^\circ, 360^\circ$
- D.  $90^\circ, 270^\circ$

**Section B: Application** (5 × 8 = 40 Marks)

**Question 7** (8 marks)

Simplify:  $\frac{\sin x}{\cos x} \cdot \frac{1}{\tan x}$

- A. 0
- B. 1
- C.  $\sin^2 x$
- D.  $\cos^2 x$

**Question 8** (8 marks)

Find the exact value of  $\sin 150^\circ$ .

- A.  $\frac{1}{2}$
- B.  $-\frac{1}{2}$
- C.  $\frac{\sqrt{3}}{2}$
- D.  $-\frac{\sqrt{3}}{2}$

**Question 9** (8 marks)

Solve the equation:  $\cos x = \frac{1}{2}$  for  $0^\circ \leq x \leq 360^\circ$ :

- A.  $60^\circ$
- B.  $120^\circ$
- C.  $60^\circ, 300^\circ$
- D.  $120^\circ, 240^\circ$

**Question 10** (8 marks)

Which identity simplifies  $1 + \tan^2 x$  to a single trigonometric function?

- A.  $\sec^2 x$
- B.  $\csc^2 x$
- C.  $\sin^2 x$
- D.  $\cos^2 x$

**Question 11** (8 marks)

If  $\tan \theta = -\frac{4}{3}$  and  $\theta$  lies in Quadrant II, find  $\sin \theta$ .

- A.  $\frac{4}{5}$
- B.  $-\frac{4}{5}$
- C.  $\frac{3}{5}$
- D.  $-\frac{3}{5}$

**Section C: Higher-Order Reasoning (3 × 10 = 30 Marks)****Question 12 (10 marks)**

Simplify completely:  $\frac{1-\sin^2 x}{1+\tan^2 x}$

- A.  $\sin^2 x$
- B.  $\cos^2 x$
- C.  $\tan^2 x$
- D. 1

**Question 13 (10 marks)**

Solve:  $2\sin x - 1 = 0, 0^\circ \leq x \leq 360^\circ$

- A.  $30^\circ$
- B.  $150^\circ$
- C.  $30^\circ, 150^\circ$
- D.  $210^\circ, 330^\circ$

**Question 14 (10 marks)**

Which identity is required first to verify:  $\frac{\sin x}{1-\cos x} = \frac{1+\cos x}{\sin x}$

- A.  $\sin(2x) = 2 \sin x \cos x$
- B.  $1 - \cos^2 x = \sin^2 x$
- C.  $1 + \tan^2 x = \sec^2 x$
- D.  $\tan x = \frac{\sin x}{\cos x}$

## **APPENDIX B: OPEN-ENDED STUDENT QUESTIONNAIRE**

### **Purpose**

This questionnaire seeks to explore your experiences of using Plickers during Grade 11 Advanced Mathematics trigonometry lessons. There are no right or wrong answers. Please respond honestly based on your personal experience.

### **Instructions**

- Answer all questions in your own words.
- Write as clearly as possible.
- Your responses will remain anonymous and will be used for research purposes only.

### **Questions**

- Q1.** How would you describe your overall experience using Plickers during trigonometry lessons?
- Q2.** In what ways did Plickers affect your participation/engagement during the trigonometry lessons?
- Q3.** In what ways, if any, did using Plickers affect your learning of trigonometry lesson concepts?
- Q4.** How did you feel about the feedback you received when using Plickers during the trigonometry lessons?
- Q5.** Did the Plickers cards affect your confidence when answering questions in class? If so, how?
- Q6.** Compared with traditional teaching methods, how effective was Plickers in supporting your learning in trigonometry concepts?
- Q7.** What challenges, if any, did you face when using Plickers in learning trigonometry concepts?
- Q8.** Would you recommend using Plickers for other advanced mathematics topics? Why or why not?

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