Teaching and Learning Calculus with the TI-Nspire: A Design Experiment

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Abstract

A design experiment was conducted to examine the role of the TI-Nspire, the latest graphing calculator from Texas Instruments, in teaching and learning calculus. This paper reports details on, and preliminary results of, the design experiment involving the design and conduct of a TI-Nspire Intervention Programme for an intact class of thirty-six secondary four students (15-16 years) from a secondary school in Singapore. Use of the TI-Nspire was integrated into teaching and learning Calculus concepts with the aid of the TI Navigator, a wireless classroom network system that enables instant and active interaction between students and teachers. Mathematics attitudes surveys and structured interviews were administered to assess the effects of the use of the TI-Nspire on students' attitudes towards mathematics. It was found that appropriate use of graphical, numerical and algebraic representations of Calculus concepts using the TI-Nspire could enable the subjects to better visualize the concepts and make generalizations of relevant mathematical properties. Results of paired samples t-tests and interviews with students suggest that there the use of the TI-Nspire has a positive effect on students' confidence in and perceived usefulness of mathematics.

Introduction

It is widely acknowledged that calculus concepts are abstract and complex for students and that teaching and learning these concepts can be challenging and even exasperating at times (Gordon, 2004; Zachariades *et al*., 2007). Indeed, research has shown that many students have difficulties learning some of the key concepts of calculus (Harel, Selden & Selden, 2006; Artigue, Batanero & Kent, 2007) and it does not help that traditional calculus courses tend to focus more on algebraic drill and practice on calculus problems without understanding the underlying concepts (Gordon, 2004).

Many researchers have expressed their concern that over-emphasis on algebraic drill and practice method will produce students who are only able to regurgitate what has been taught and duplicate it in examinations (Gordon, 2004; Zachariades *et al*., 2007). The study conducted by Gordon (2004) reveals that algebraic solutions of problems and lengthy derivations of formulas are commonly expected among students in calculus. Gordon also pointed out that some calculus teachers felt that they were teaching algebra rather than the concepts of calculus. This phenomenon is also noted by Axtell (2006) who feels that conventional teaching of calculus fails to produce students who are able to understand the fundamentals of calculus. Teachers seem to focus more on procedures than understanding of the concepts among the students in teaching calculus (Zachariades *et al*, 2007). As a result, students approach differentiation or integration problems by simply applying the steps they have memorized without a good grasp of the calculus concepts.

Understandably, Gordon (2004) and Axtell (2006) advocate that the calculus curriculum should be reformed by putting more emphasis on conceptual understanding of the fundamentals of calculus and complementing the use of graphical, numerical, algebraic and verbal representation in the teaching and learning of calculus. This view is also supported by Roddick (2001) who highlighted the importance to shape students' understanding of calculus based on the emphasis on conceptual understanding over procedural understanding. Gordon (2004) further suggested that students must learn to select the right tools such as graphing calculators to help them in learning calculus and use a variety of approaches, algebraic, numeric and graphical, to solve calculus problems.

The purposes of the current design experiment were therefore to examine the role of the TI-Nspire, the latest graphing calculator from Texas Instruments, in teaching and learning calculus and investigate the effects of the use of the TI-Nspire on the attitudes of students towards mathematics. This paper reports details about, and preliminary results of, the first cycle of the design experiment involving the design and conduct of a TI-Nspire Intervention Programme for an intact class of thirty-six secondary four students (15-16 years) from a secondary school in Singapore. Use of the TI-Nspire was integrated into teaching and learning Calculus concepts with the aid of the TI Navigator, a wireless classroom network system that enables instant and active interaction between students and teachers.

Review of Relevant Literature

The graphing calculator has been widely used as a technological tool in teaching and learning mathematics. Many studies conducted to date have demonstrated the benefits of using graphing calculators in mathematics learning (e.g. Merriweather & Tharp, 1999; Sang, 2003; Abu-Naja, 2008; Chamblee, Slough & Wunsch, 2008; Lyublinskaya & Zhou, 2008). In addition, findings of Rich's (1991) study strongly suggest that the graphing calculator has a positive effect on students' understanding of the graphs and their connection to the algebraic representation while Zachariades *et al*. (2007) points out that the graphing calculator which affords dynamically linked graphical, numerical and symbolic functions is an appropriate tool in teaching calculus concepts.

The idea of using the graphing calculator to provide better connection between algebraic representation and graphical representation in calculus is further supported by the study by Tiwari (2007) which demonstrates that there was positive effect of using graphical and numerical capabilities of a graphing calculator when it is used as a supplementary instructional tool in achieving conceptual understanding and enhancing problem solving abilities of students in learning differential calculus. Furthermore, it was shown that students who used graphing calculators are more advanced in understanding graphical concepts and better skilled in discovering algebraic patterns related to graphs (Ruthven, 1990; Simmt,1997; Abu-Naja, 2008).

Alkhateeb and Wampler (2002) conducted a study on the influence of the use of graphing calculators on students' understanding of derivatives. The finding suggests that achievement of students who used the graphing calculator was higher than those who did not. More recently, studies by Sang (2003) and Abu-Naja (2008) found that the use of graphing calculators promoted development of significant mathematical thinking.

On the other hand, Crocker (1991) found that students who are using graphing calculator were more likely to try different approaches to solving problems in calculus. Harvey, Waits and Demana (1995) also observed that the response to questions that include graphic representation was improved among students who used the graphing calculator in learning mathematics. Furthermore, the study by Van Streun, Harskamp and Suhre (2000) found that the use of graphing calculator may lead to changes in students' approaches in problem solving and these changes have affected student achievement. Similar results were found in the study by Jones (2005) in which using graphing calculators enables students to approach problems graphically, numerically and algebraically. It was found that the use of various problem-solving approaches can support students' visualization in finding the solution and allow them to explore problem situations which they might otherwise not be able to handle. This will in turn boast students' confidence and encourage them to explore mathematics using various problem solving approaches. More importantly, when students attempt to use various solution approaches, they acquire the know-how to use given information in a flexible manner (Selden, Mason & Selden, 1989).

Methodology

The present study was conducted to answer the following research questions:

1. What is the role of the TI-Nspire in teaching and learning calculus?
2. What are the effects of the use of the TI-Nspire on students' attitudes towards mathematics?

The TI-Nspire was used in this study because it is a highly refined graphing calculator which has the potential to provide a learning platform for calculating, representing and communicating mathematically (SRI International Menlo Park, 2006) given its augmented capabilities to extend the usefulness of a normal graphing calculator. In particular, the TI-Nspire includes both new features on the graphing calculator and the classroom networking capabilities with the complementary use of the TI Navigator. Moreover, on the TI-Nspire, students can work in a "document" which is an organized presentation of multiple screens that can be saved, shared, annotated and revisited.

Research Design

This study employed the design experiment methodology that involves stating the goals, planning to achieve the goals, collecting and analyzing data, and revisiting the goals for the next iteration (MacDonald, 2008). The teacher of the participating class has worked in close partnership with the research team in incorporating the use of the TI-Nspire in lesson planning through examining the strengths and limitations of existing pedagogy and practice and acknowledging areas for future development with the TI-Nspire technology. Exploratory TI-Nspire activities were designed by the research team with inputs from the teacher with a view to promote opportunities for students to explore and generalize mathematical concepts, and to support the students in developing their confidence and ability to communicate mathematically. More importantly, the researchers and the teacher have worked closely in order to formulate a conceptual model for teaching and learning calculus with the use of the TI-Nspire. This paper aims to report preliminary findings of one cycle of the design experiment and the findings will be used for the next iteration of the research.

Subject

The subjects in this study were thirty-six secondary four students of an intact class from a secondary school in Singapore. Each student was loaned a TI-Nspire handheld, two cables for transferring files and a cradle for connection to the TI Navigator. Five training sessions were conducted for the students prior to the TI-Nspire Intervention Programme in which the use of the TI-Nspire was integrated into teaching and learning of calculus. The purpose of the training sessions was to introduce the interface design and to train the participating students in using algebraic, graphical and numerical functions of the TI-Nspire.

The TI-Nspire Intervention Programme

The preliminary framework for the use of the TI-Nspire in the intervention programme was based on that suggested by SRI International Menlo Park (2006):

a) Improve effectiveness of student learning through the use of TI-Nspire's calculator, algebra, graphing, table and geometry features that emphasize problem solving and conceptual understanding instead of just the right answers. Engage students with interactive exploration and to focus students' concepts understanding, strategies and justifications.
b) Enhance representation and communication of important mathematics by the use of TI-Nspire's clear and expressive representation that linked multiple representations such as equations, graphs, tables and geometric sketches that enable students to understand difficult concepts. This is further enhanced by the use of the TI Navigator classroom network to engage students in doing, presenting and communicating important mathematics ideas.
c) Create deeper opportunities to learn using the new document and classroom network of the TI-Nspire. The teacher can develop classroom practices and activities that could increase the time for more academic learning, provide scaffolding in terms of the supports and resources for mastering difficult concepts and skills; provides more participatory activities to increase student participation and tools to encourage reflection and revision.

To determine more precisely the role of the TI-Nspire in teaching and learning calculus for the participating class, the research team designed a TI-Npire-integrated calculus package focusing on differentiation and integration concepts. Students attended 2 to 3 one-hour lessons on calculus per week for a total of 15 weeks. The topics covered were Differentiation by First Principles, Equations of Tangent and Normal, Rate of change, Stationary Points, Derivatives of Trigonometric Functions, Derviatives of Exponential and Logarithmic Functions, Integrations and Indefinite Integrals, Definite Integrals, Integration of Trigonometric Functions, Integration of Exponential Functions and $\frac{1}{x}$, and Area of a Region.

In some studies in which the use of the graphing calculator failed to improve learning, the graphing calculator was used as an add-on to traditional teaching rather than in an integrated way (Kastberg & Leatham, 2005). Hence, in the present study the use of the TI-Nspire was integrated into teaching and learning processes through the design and use of TI-Nspire activities which offer intriguing mathematical starting points for students and promote exploration leading directly to mathematical generalization. The TI-Nspire was also employed to emphasize the complementary use of graphical, numerical and algebraic representations in teaching calculus concepts and demonstrating problem solving approach.

The TI-Nspire learning activities in the intervention programme can be broadly classified into two categories. In the first category, the activities focused on introducing mathematical concepts through explorations with the aid of the TI-Nspire. Students were encouraged to first examine the setting of a given problem or manipulate parameters of a simulation in a TI-Nspire document pre-loaded into their handhelds, then formulate conjectures, examine and confirm the conjectures, culminating in derivation of a formula, generalization of results, or summary of the underlying concepts. Figure 1 shows one such activity. The worksheet designed to accompany such an activity serves to facilitate the process of guided discovery or enquiry learning.

$$\frac{d}{dx}(\sin x) = \cos x$$

Notes:

a) Use the TI-Nspire to verify the above result (*diffTrigoA.tns*). The gradient of the tangent line to $y = \sin(x)$ at a given point gives the value of the derivative of $y = \sin(x)$ at that point.
b) Use the tangent line to trace an approximate graph of the derivative of $y = \sin(x)$. The slope of the tangent is shown at the top right of the screen. Your goal is to move the tangent line by grabbing and dragging the point of tangency such that the point of tangency is located directly above each of the 13 points, beginning with the leftmost point.
c) Inspect the resulting scatter plot, which represents the approximate graph of the derivative of the sine function. Write down your observations.
d) Use the Graphs and Geometry application on the next page to verify your answer.

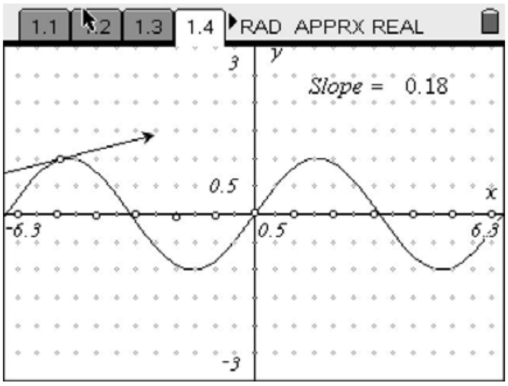

Figure 1: Learning activities with the TI-Nspire

In the second category, the students were assigned tasks to reinforce their conceptual understanding using the TI-Nspire. In a typical activity, an exercise consisting of problems related to the concept taught was given and a pre-prepared TI-Nspire document was sent to the students who were required to complete the exercise with the aid of the TI-Nspire. Figure 2 shows one such activity. Occasionally, a formative assessment with the use of “Quick Poll” function of the TI-Navigator will be conducted to assess student understanding. Where time permitted, students were invited to share their solution obtained using the TI-Nspire using the presenter function of the TI-Navigator.

Exercise: Find $\frac{d}{dx}(\tan x)$ by hand and use the TI-Nspire to verify your answer.

Notes:

- To find the derivative of tan *x* with respect to *x*, first write tan *x* in terms of sin *x* and cos *x*.
- Use the quotient rule to find the derivative of above function in terms of sin *x* and cos *x*.
- Verify your answer by graphing the derivative of tan(*x*). Enter **nDeriv(f1(x),x)** as **f3(x)**.

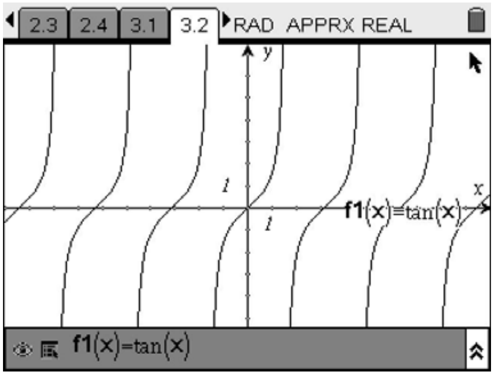

Figure 2: A class exercise with the TI-Nspire

All the activities and accompanying worksheets were designed after thorough discussions with the teacher of the participating class who co-taught the calculus package with a member of the research team. It is believed that the use of technology in the teaching of calculus can be beneficial if it is accompanied with appropriately designed activities (Zachariades *et al*., 2007; White-Clark, DiCarlo & Gilchriest, 2008). Therefore, activities such as guided-discovery and inquiry learning were used in the design of the worksheets. Some of the worksheets were adapted from those provided by users of the TI-Nspire which are available at http://education.ti.com.

Instrumentation

To investigate the effects of the TI-Npire intervention programme on students' attitudes towards mathematics, a mathematics attitude survey was administered to the participating class before and after the intervention programme. A pre-experimental design was utilized in the present study because no classes, other than the participating class, were available to participate in the study. The survey, which is an adaptation of the Fennema-Sherman mathematics attitude inventory scales, comprised five subscales: Attitude towards Success, Anxiety, Confidence, Effectance Motivation and Usefulness. Each subscale consists of twelve items, making up a total of sixty items in the survey. Students were asked to rate the extent to which they strongly agree or strongly disagree with statements reflecting their attitudes toward mathematics using a 5-point Likert scale.

Qualitative data were collected in the form of classroom observation, reflections and interviews. Observation, taking of field notes and video recording were carried out during each calculus lesson. Students were also asked to write reflections using a reflection form designed by the research team to determine which features of the TI-Nspire they had learned and the difficulties they encountered in using the TI-Nspire. Structured interviews were conducted with selected students in the participating class to clarify and triangulate findings that emerged from quantitative analyses.

Results and Discussions

The Role of the TI-Nspire in Teaching and Learning Calculus

The TI-Nspire was used as a pedagogical tool to complement the conventional teaching approach. During a typical lesson, the participating students used the TI-Nspire to examine the setting of a given problem, formulate conjectures or hypothesis, examine the hypothesis, recheck the solutions and finally generate a result (e.g. chain rule) or solution to the given problem. To facilitate exploratory learning and guided-discovery, worksheets were designed to guide the students in investigating and exploring mathematical concepts using the TI-Nspire. In some of the lessons, students were required to summarize their findings at the end of the exploration. The TI-Nspire was also used as a confirmatory tool to verify their answers to the given problems or conjecture for a particular calculus concept.

In the present study, we observed that the students tried to use various methods using the TI-Nspire to find the solutions when they were given problems in the exercise. This is consistent with findings of studies such as that by Crocker (1991) in which students who used graphing calculators were more likely to try different problem solving approaches in calculus. In addition, we also found that students have better understanding of the calculus concepts when they are able to use various approaches to solve problems. For instance, in the lesson on definite integral, we found that students who used a graphical method to solve the given problems tended to be those who have understood the concept of definite integral and area under the curve more fully. Figure 3 shows a student's solution for finding the area bounded by the line $y = 2x$, the curve $y = \dfrac{8}{x+3}$ and the y-axis using a graphical method on the TI-Nspire.

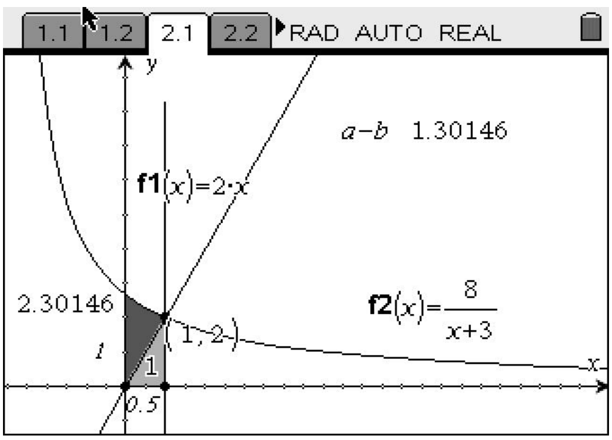

Figure 3: A student's solution for finding the bounded area

On the other hand, in solving problems involving maximum or minimum points, we found that some of the students tended to approach the problems from a conceptual viewpoint by using a graphical method and the graph tracing function of the TI-Nspire. Figure 4 shows a student's solution for finding a turning point using the TI-Nspire. This shows that the availability of TI-Nspire seemed to encourage a shift from a rigid to a more flexible technique of problem solving among the students which is a consequence of students achieving conceptual understanding.

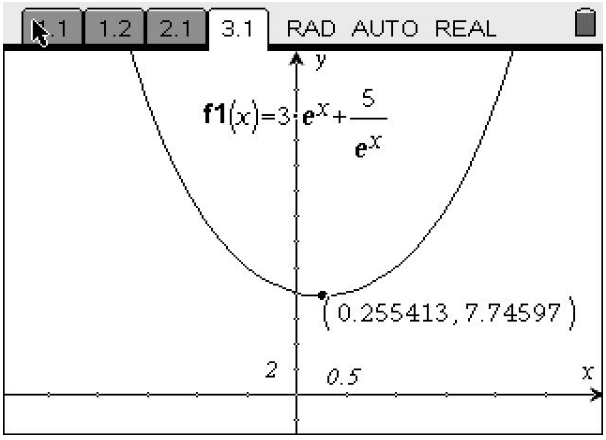

Figure 4: A student's solution for finding a turning point using a graphical method

In another lesson, students use the TI-Nspire to assist them in understanding the concept of differentiation of trigonometric functions. When they were asked to find the derivative of sin x with respect to x, they were able to give the correct answer using the first principle of differentiation and explain how they obtained the answer with the aid of the TI-Nspire. This illustrates that the students were able to communicate the concept of differentiation based on solid conceptual understanding instead of through memorization and regurgitation of rules or formulas.

Through classroom observations and analysis of students' TI-Nspire documents and regular reflections, the research team also attempted to find out what functions of the TI-Nspire the students have learnt, what they would like to try out using the TI-Nspire and what they would like to find out about the TI-Nspire. It was found that students used the TI-Nspire as a tool in several ways. For instance, students used the TI-Nspire as a visualization tool to better understand behavior of graphs, new concepts taught, or problem situations. They also learned how to use the TI-Nspire as a confirmatory tool to verify the correctness of their answers. Table 1 summarises the ways in which the TI-Nspire was actually used during the intervention programme either as a pedagogical tool in teaching or as a learning tool by the students.

Table 1: Using the TI-Nspire as a tool in teaching and learning calculus

Use of the TI-Nspire	Description
As an exploratory tool	The TI-Nspire was used to explore and understand concepts of differentiation and integration. For example, students explored differentiation of product of two functions with the TI-Nspire and derived the product rule.
As a confirmatory tool	Students used the TI-Nspire to verify their answers to the questions in the exercises. For instance, students first solved the given problems by hand and then confirmed their answers

	using the graphing functions of the TI-nspire-Nspire.
As a problem solving tool	Students used the TI-Nspire to try different approaches to solving a given calculus problem. For example, in solving problems involving turning points, students used algebraic, graphical and numerical approaches.
As a visualization tool	Students used the TI-Nspire to better visualize behaviours of functions, new concepts taught or problem situations. Also used by teachers to pre-construct simulation using the TI-Nspire to illustrate problem situations or new concepts. For example, a simulation was pre-constructed so that students can explore the concept of rate of change by manipulating variables and observing the dynamic changes in the graphs.
As a calculation tool	Students used the TI-Nspire to calculate values or evaluate complex expressions.
As a graphing tool	Students used the TI-Nspire to graph functions and to solve a given problem graphically. For instance, they used the Graph & Geometry application in the TI-Nspire to solve problems related to area under a curve.

Availability of the TI-Nspire offers students the means to not only explore the concepts of calculus, but also communicate the concepts mathematically. With the use of the TI Navigator which affords wireless network in the classroom, students were able to present their solutions and to provide feedback to the teachers during the lessons. In the present study, the “Quick Poll” feature of the TI Navigator was used to conduct formative assessments so as to evaluate student understanding. In addition, the teachers used the TI Navigator to monitor progress of students in in-class tasks by periodically viewing all students’ TI-Nspire screens on the teacher’s computer. Consequently, it was observed that the students were more active in participating in discussions and were more alert during the learning process.

Students’ Attitude towards Mathematics before and after the use of TI-Nspire

The mathematics attitude survey was administered before and after the intervention programme. Cronbach’s alpha reliability coefficients for the pre- and post-intervention surveys, as shown in Table 2, are high and thus show that the mathematic attitude survey could be accepted as a reliable instrument for the purpose of the present study.

Table 2: Cronbach’s alpha reliability coefficients for the pre- and post-intervention surveys

Method	Item	Cronbach’s Alpha
Pre-intervention Survey	Overall	.950
	Attitude Towards Success	.836
	Anxiety	.884
	Confidence	.941
	Effectance Motivation	.862
	Usefulness	.905
Post-intervention Survey	Overall	.920
	Attitude Towards Success	.838
	Anxiety	.860

Confidence	.874
Effectance Motivation	.834
Usefulness	.851

Paired-samples t-tests were employed to determine any difference in students' attitudes toward mathematics before and after the TI-Nspire Intervention Programme. Table 3 compares the means of the overall scores in the pre- and post-intervention surveys and shows that although the mean of the overall score for the post-intervention survey was higher than that for the pre-intervention, the difference between the mean scores was not statistically significant.

Table 3: Comparison of the means of overall scores in the pre- and post-intervention surveys

Analysis	Result
Mean of Overall Score (Pre-intervention Survey)	206.7222
Mean of Overall Score (Post-intervention Survey)	212.3056
t	-1.871
Significance	.070

Paired-samples t-tests were employed to determine any differences in students' scores on each of the five subscales, namely Attitude towards Success, Anxiety, Confidence, Effectance Motivation and Usefulness, before and after the TI-Nspire Intervention Programme. It was found that there were significant differences between the scores for the Confidence and Usefulness subscales in the pre-intervention survey as compared to those in the post-intervention survey. The corresponding differences for the Attitude towards Success, Anxiety, and Effectance Motivation subscales are not significant (see Table 4).

Table 4: Results of paired-samples t-tests on each subscale of the pre- and post-intervention surveys

Subscale	*T*	Significance (2-tailed)
Attitude towards Success	1.129	.283
Anxiety	-1.260	.234
Confidence	-2.354	.038
Effectance Motivation	-.857	.410
Usefulness	-3.156	.009

We acknowledge that drawing conclusions about the effects of the TI-Npire intervention programme on students' attitudes towards mathematics in the present study is fraught with difficulties because of the lack of a control group. Structured interviews with students were therefore conducted to corroborate the above finding and we found that the advanced functionality of the TI-Nspire afforded the user various options in mathematical explorations and problem solving and boasted students' confidence in mathematics and impacted positively their perception of usefulness of mathematics. This is consistent with the conclusion by Merriweather and Tharp (1999) that the use of graphing calculators which supports multiple representations in learning mathematics is likely to increase the competence and confidence of students.

Conclusion

The present study offers some insight into the way that the TI-Npire, a new technological tool for learning mathematics that allows the user to explicitly link variables within a range of mathematical representations, can be used in teaching and learning calculus. Usefulness information has been gleaned to help refine the next iteration of the design experiment. In particular, results of the present study supports our hypothesis that the new mathematical experiences afforded by the TI-Nspire will offer students a rich setting in which to explore calculus concepts. Dynamic features of graphing calculators such as multiple representations of mathematical concepts, if used appropriately, can improve the ability of students in making the connection between graphical and algebraic representations. This feature was found to be particularly useful in teaching and learning calculus. The use of the TI Navigator in the classroom has also raised the level of participation of the students during the lessons and strengthened their commitment to the learning process.

Though the present study did not justify convincingly the positive effects of the use of the TI-Nspire on students' attitudes towards mathematics in that it has produced inconclusive results in three of the subscales of the survey, namely, Attitude Toward Success, Effectance Motivation and Anxiety, results are statistically significant in a positive way for the subscales Confidence and Usefulness. It has provided an indication that the use of the TI-Nspire could have a positive effect on students' confidence in learning mathematics and their perceived usefulness of mathematics. This finding was corroborated by results of structured interviews with students.

Looking ahead, the TI-Nspire should be used to stimulate students to think mathematically so that they could engage strongly with mathematical structures and concepts in ways that are not possible with traditional paper and pencil approaches. Prior to that, training should be provided so that teachers and students could develop their familiarity with the affordances of TI-Nspire as a useful pedagogical tool. The transferability of the research approach of the present study to other school settings should also be explored.

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