Addressing the Issues Underlying Hand-held Technology Use in the Classroom

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Abstract. *Many mathematics departments have adopted plans for the appropriate use of instructional technology tools in the learning and teaching of mathematics, and in the assessment of mathematics learning. However the use of such new technology raises fundamental issues in pedagogy and assessment.*

The School of Mathematical Sciences at Universiti Sains Malaysia (USM) offers a Special Topic course on the integration of hand-held technology into the teaching and learning of mathematics beginning the 2001/2002 academic year. The course is taught in an inquiry-based format that highlights explorations and applications of mathematics in a data rich modeling environment. In addition, the course addresses issues related to the effective integration of such technologies into the mathematics and science curriculum. This paper discusses pedagogical and assessment strategies that have been implemented in the course and summarizes student reactions to the innovative learning mode. (ATCMA227)

1. Introduction

Technology has fundamentally transformed offices, factories, and retail establishments over the past several decades. However, its impact within the classrooms has generally been quite modest. In responding to concerns raised regarding the capacity of the educational system to meet the challenge of the information technology era, mathematics departments of many universities have begun to adopt plans for the appropriate use of instructional technology tools in the learning and teaching of mathematics, and in the assessment of mathematics learning.

According to Higgins and Muijs (1995), educators need to ask pertinent questions about the latest technology; for example,

- What does the new technology offer and how easy is it to use?
- Does it present mathematical concepts in a way that will support student's understanding?
- Can you teach the same content without the technology?
- Is the technology approach really more effective?

Efforts should be focused on the use of technology to enhance learning, and not only to learn about technology. Although both are worthy of attention, it is important to distinguish between technology as a subject area and the use of technology to facilitate learning about any subject area.

Thus technology should be integrated throughout the curriculum, and not simply used to impart technology-related knowledge and skills.

The School of Mathematical Sciences at USM has developed from the ground up a course based on the new learning modes made feasible, indeed imperative, by the graphic calculator enhanced with computer algebra systems (CAS). Students are introduced to the capabilities of the graphic calculator as an instructional tool. In addition, the course includes several seminars addressing issues driven by the integration of the new technologies into the classroom, e.g., pedagogical and curricular changes. In many countries, including Austria, France, Australia, USA, and Canada, it is taken for granted that many of the students will have access to a graphic calculator much of the time, if not at all times. In fact, beginning in the year 2001, neighboring Singapore has allowed the use of graphic calculators, without CAS, in the national exams *Further Mathematics* paper. The advent of technology has put at issue teaching pedagogy and strategies. This paper elucidates our development and testing of materials that incorporate the graphic calculators to enhance the understanding of concepts in the mathematics classroom.

2. The Graphic Calculators

The technology and levels of sophistication of graphic calculators have grown significantly over the last few years. The graphic calculators can plot graphs, visualize 3D surfaces, and are programmable. The CAS tools automate the execution of algebraic and calculus computations. CAS can simplify expressions, evaluate derivatives and integrals symbolically or numerically, perform matrix operations, and solve differential equations. CAS automates most of the calculation skills we teach in mathematics. In addition, a calculator can manage data, calculate standard statistical measures, perform all standard statistical tests and confidence intervals for means, proportions, chi-square analysis and regression. It can also generate a range of statistical graphics such as scatter plots, histograms, box plots with outliers, normal probability plots and residual plots.

The graphic calculator with its accessibility, portability, cost-effectiveness, powerful built-in functions, and varying CAS capabilities is increasingly seen as a significant tool for the integration of technology in mathematics. The graphic calculator also makes available a wide range of techniques to students to solve problems. It is clear that the graphic calculators do many of the menial tasks for the student; this frees students to work with mathematics at a higher cognitive level. It is very paradoxical that schools are encouraged to use IT for teaching and are provided with expensive and powerful computers and software but the use of a relatively inexpensive tool like graphic calculators is not capitalized on.

Since 1998, the School of Mathematical Sciences at USM has incorporated the use of graphic calculators to illustrate and illuminate several mathematical concepts in a software laboratory course. Details on its use can be found in Ali *et al*. (2000, 1998). The School, in collaboration with colleagues from the School of Educational Studies, has taken a new initiative in the use of graphic calculators through teaching a calculator based laboratory course beginning the 2001/2002 academic year.

3. Course Features

The Special Topic course in graphic calculators seeks to explore the impact of such instructional devices and the perspectives they provide. The course is developed for pre-service teachers and students in mathematics. The course objectives are:

- To acquaint students with the CAS calculators and its capabilities.
- To understand the relevance of calculator technology in the teaching and learning of mathematics and sciences.
- To familiarize students with the issues involved in the use of calculator technology in the classroom.
- To model the effective integration of technology into the mathematics curriculum.
- To teach the development of data rich technology explorations that is designed around the capabilities of the calculators.

The course content includes topics from calculus, linear algebra, differential equations, and statistics so a prerequisite is to have completed a first course in these subjects. The TI-92Plus graphic calculator was used throughout the course for calculus, linear algebra, and differential equations, while the TI-83Plus was used for statistics. Students were not required to purchase the graphic calculators; each student had a calculator checked out for the duration of the course. In addition, the CBL units, which are data collection units linking to the TI-83s, were incorporated to collect real data in a hands-on environment. There were 24 class meetings of about two hours. The primary teaching mode was alternately an interactive lecture mode and in class exploration activities. Class activities were supported with laboratory assignments that the students completed and turned in for assessment. The course was team-taught by faculty members from the School of Mathematical Sciences in collaboration with colleagues from the School of Educational Studies.

4. Alternative Teaching Strategies and Content

A graphic calculator is a powerful tool that can carry out complicated mathematical tasks, thus allowing students to spend more time on the understanding of concepts. When used effectively, it becomes a tool to help students actively construct their own knowledge bases and skill sets. Lim (2002) emphasized that not only should technology affect *how* we teach because technology makes different approaches possible, technology should also change *what* we teach because some topics are made obsolete with technology while others are made possible with it.

A report by the Panel on Educational Technology (1997) outlines the following "constructivist" paradigm on the potential of technology to support certain fundamental changes in the pedagogic models underlying our traditional approach to the educational enterprise:

- Greater attention is given to the acquisition of higher-order thinking and problem-solving skills, with less emphasis on the assimilation of a large body of isolated facts.
- Basic skills are learned not in isolation, but in the course of undertaking (often on a collaborative basis) higher-level "real-world" tasks whose execution requires the integration of a number of such skills.
- Information resources are made available to be accessed by the student at that point in time when they actually become useful in executing the particular task at hand.
- Fewer topics may be covered than is the case within the typical traditional curriculum, but these topics are often explored in greater depth.

- The student assumes a central role as the active architect of his or her own knowledge and skills, rather than passively absorbing information proffered by the teacher.

Many of the strategies have been incorporated into the Special Topic course on hand-held technology at USM. In what follows, we will elucidate how several of the indicated outcomes of the above strategies have come to fruition when the course was implemented.

There are three basic components to consider in the development of new lesson plans: statements of learning objectives, implementation, and evaluation of expected results. Learning objectives are classroom expectations of behavioral change at the end of the class or series of lectures. The objective statements normally make use of quantifiable verbs as the criteria for evaluation purposes. For example, in an exploration wherein the mean value theorem and derivative test were investigated the learning objectives are: "At the end of the exploration the students will be able to: (a) illustrate the mean value theorem geometrically, (b) describe the relationship between critical points, a function, and its first derivative, (c) describe the relationship between inflection points, a function, and its second derivative, (d) apply the appropriate first or second derivative test from the graphs of a function and its derivatives, and (e) apply the concept of derivative in real life situations." Instead, if the statement is written in the following form, "At the end of the lesson students will be able to *understand* the concept of derivative", then it is not acceptable because 'to understand' is not quantifiable.

The next step is the implementation of learning objectives, which relates to pedagogy and student activities. An instructor must determine appropriate teaching modes such as "a lecture method" or "an inquiry method", relevant teaching aids, and associated student activities. The role of a graphic calculator should match the objectives of a teaching lesson. For example, suppose an objective of a statistics class is "at the end of several teaching lessons students should be able to interpret statistical data by using concepts of variance and standard deviation." For a class without a graphic calculator, the lessons could be taught by asking students to manually compute standard deviation based on a simple data set and for the instructor to explain its meaning to the students. The objectives could therefore be achieved without the assistance of a graphic calculator or other statistical tools. Instead, for a class with graphic calculators, the instructor has the option of asking the students to use the tool to do the computations based on a large and real data set. In addition, the interpretation of answers within context will be more meaningful since the graphic calculator could generate varied patterns or results from manipulation of input data.

Our course is developed around the capabilities of the technology to enhance the understanding and learning of mathematical concepts and theories through scientific visualization and laboratory type explorations. Thus, particular attention was given to exploring the potential role of graphic calculators in achieving the learning outcomes through the use of innovative pedagogic methods based on a more active, student-centered approach to learning that emphasizes the development of higher-order reasoning and problem-solving skills. The graphic calculator allows student learning to occur at a higher cognitive level and serves to facilitate inquiries, explorations, and problem-solving activities. It was used as

- a tool for the symbolic manipulation or graphical display of mathematical functions and equations,
- a facility for the collection, examination and analysis of data,
- a tool to foster collaborative learning and teach students to work as a team ,

- a flexible laboratory instrument supporting the collection of scientific data using various physical sensors that allow for the immediate and flexible manipulation of this data,
- a tool to aid in solving realistic problems that enables the student to concentrate on problem aspects and interpretation rather than computational aspects, and
- a tool to discover, visualize, or investigate mathematical theories.

In Ali *et al.* (2001), a discussion of the pedagogical issues and theories underlying the development of materials and the implementation of teaching strategies for the graphic calculator course is presented. Additional references to many articles that address the integration of the graphic calculators into the classroom can be found in Laughbaum (2000).

5. Assessment

A final component to consider in the development of new lesson plans is assessment. In particular, if a student learns differently from a changed pedagogy, then assessment must be done differently. Several papers have been written about how graphic calculators have rendered some traditional examination questions obsolete and others problematic. Stacey (2002) observed that many of the standard tasks are trivialized by CAS and therefore are no longer fully viable as examination questions. New technology reinforces the need for further shifts away from questions that test routine procedures towards questions that test formulating mathematical models and interpreting what answers mean in context. This will also require an expansion in the modes of assessment, moving away from timed examinations. In addition, it challenges our creativity to design questions that will show how deeply-held mathematical values can be promoted in a new environment.

Learning objectives of each lesson provides an important guide to the task of matching test items with instructional contents. The leading criterion that is normally employed is cognitive levels of learning objectives. One of the most widely used taxonomies of cognitive levels of learning objectives is Bloom's Taxonomy. It contains hierarchical levels of the learning objectives namely: knowledge level, comprehension level, application, analysis level, synthesis level, and evaluation level. In selecting appropriate test items to ensure a valid test, all aspects of a test development plan have to be considered, which include determining cognitive levels of learning objectives and choice on types of items.

For an undergraduate level course, the emphasis should be of higher thinking order items. Knowledge and comprehension items should be included only as initial or starting items preceding the core items. The characteristics of a core item should reflect the objectives of the lesson and also how the related topics were taught. The core item should ask the students to use their graphic calculator to *apply* the concepts in a given problem or situation, and to *analyze* new data sets. Ideally, an instructor should prepare a test blueprint in the form of a specification table. This table has two dimensions: topics taught and level of thinking skills involved, and is intended to secure the validity of the two components, content and substantiveness.

Appendix A of this paper contains a specification table to guide the assessment of a TI-92Plus exploration on limits and limiting behavior, see Ali *et al.* (2001). The activity is designed to explore the concept of limits from calculus and contains real data on fish growth. The exploration was developed around the capabilities of the calculator to help students visualize concepts of limits and to provide visual and numerical evidence of results. The example and problem using real data allow students the opportunity to attach meaning to limits in the world around them. The specification table identifies objectives for each learning level and possible test items that could effectively measure the achievement of the objectives.

In our course, laboratory exercises were collected and assessed; students also had the opportunity to make corrections to their laboratory assignments. In-class examinations were given at the end of each topic that comprised problems requiring them to apply skills learned in completing their laboratory explorations, and their ability to make observations and interpretations from fresh data sets. However, students also learn about the technology of the graphic calculators. Their ability to use the devices effectively to solve problems should also be assessed. This leads to a new dimension that will augment the specification table, i.e., a measure of their calculator skills in handling each test item. Incorporating this added dimension into the specification table will transform its 2-dimensional structure into a 3-dimensional table. We hope to develop validation criteria associated with this 3-dimensional specification table that can be used as guidelines to prepare valid tests in a CAS environment.

6. Student Projects

The course culminates with a group project designed in part to facilitate student-initiated inquiries. For their terminal course project, students worked in groups to locate a fresh data set and to develop their own graphics calculator laboratory exploration. It is anticipated that some of the explorations developed by the students will be used in the course in the future. Performance expectations for the terminal projects include the cultivation of higher-order cognitive and problem-solving skills. This is the aspect of the course implementation that most strongly addresses the student's need to work at higher cognitive learning levels.

The projects are designed to foster students' knowledge and critical understanding of principles in mathematics and statistics. They are expected to apply the methods and techniques that they have learned to consolidate those underlying concepts and principles. They are also expected to demonstrate the ability to deploy appropriate approaches to solving problems, and to make use of scholarly sources as and when needed. Such group activities offer students of varying ability levels, and having different interests and prior experience, the opportunity to teach each other.

7. Survey Summary and Remarks

To monitor the impact of graphic calculators in the course, a topic-specific semi-structured survey was prepared and implemented upon completion of each component, i.e., calculus, linear algebra, differential equations, and statistics. This survey requested information on students' perception of their understanding and impression of each topic before taking the course, and also sought their views on the educational value of integrating the graphic calculator into the subject. The students in the class were pre-service teachers and mathematics students but the surveys did not make any distinction between these two groups. The tables below report the findings from student responses to the following items (for the other surveys, verbiage and concepts specific to calculus were changed to reflect the appropriate topics):

1. Before taking this course, did you feel that you had a good understanding of the theories and concepts of calculus?
2. Before taking this course, did you feel that calculus was (a) applicable in the real world, (b) interesting, or (c) could be fun to learn?

3. After attending this course for the last 4 weeks, your understanding or appreciation of calculus has changed.
4. The graphic calculator has enhanced your understanding of calculus.
5. Your experience working with the graphic calculator during the past 4 weeks has given you an insight into the value or limitations of integrating technology into the classroom.

Table 2. Percentage respondents to calculus survey
Number of respondents: 21 out of 25 (84%).

Item	1 (%)	2a (%)	2b (%)	2c (%)	3 (%)	4 (%)	5 (%)
SA / Agree	28.6	52.4	61.9	30.8	71.4	95.2	95.2
Not Sure	0.0	4.8	0.0	0.0	14.3	0.0	4.8
SD / Disagree	71.4	42.9	38.1	69.2	14.3	4.8	0.0

SA – Strongly Agree, SD – Strongly Disagree

The results suggest that 75.0% of the students had broadened and deepened their understanding and appreciation of calculus, and 95.2% felt that the graphic calculator has enhanced this understanding. Additionally, students were asked: *Write any new experience or insight that you have gained after attending this course for the last 4 weeks.* We may infer from their comments the following prevailing views:

- Students, who previously had seen calculus as not applicable or difficult to comprehend, now find calculus interesting, illuminating and exciting. The interaction and sharing of ideas creates an enjoyable environment that is more conducive to learning.
- The graphical and tabular approaches to the investigation of topics in calculus yield very encouraging results. Through this methodology, students can now visualize and appreciate important concepts in calculus, such as the limiting behavior of functions, the relationship between a function and its first and second derivatives, and finally the geometric interpretation of the mean value theorem.
- The use of real data promotes an appreciation of the applicability of calculus.
- The CAS graphic calculator reduces time spent on computational and manipulative procedures.
- The first course in calculus should have utilized graphic calculators.

Table 3. Percentage respondents to linear algebra survey
Number of respondents: 23 out of 25 (92%)

Item	1 (%)	2a (%)	2b (%)	2c (%)	3 (%)	4 (%)	5 (%)
SA / Agree	65.2	43.5	65.2	82.61	95.7	91.3	82.6
Not Sure	17.4	21.7	17.4	4.35	0.0	0.0	8.7
SD / Disagree	17.4	34.8	17.4	13.04	4.3	8.7	8.7

The results show that 95.7% of the students agreed that they better understood linear algebra, and 91.3% felt that the graphic calculator has enhanced this understanding. Other prevailing views are:

- Students were amazed how the graphic calculator can speed up their calculation in basic linear algebra problems such as finding the row-reduced form of a matrix and using the graph to get its eigenvalues.
- The exploration on secret coding of messages with matrix multiplication was a good application of linear algebra in information technology and that the exercise would have been difficult without the aid of the graphic calculator.
- The introduction of least squares method with fresh data provides new experience in using linear algebra to create models for real-life experiments.
- Having the graphic calculator to help in balancing chemical equations improved their understanding in this topic of chemistry, which they have learnt previously.

Table 4. Percentage respondents to differential equations survey
Number of respondents: 22 out of 25 (88%)

Item	1 (%)	2a (%)	2b (%)	2c (%)	3 (%)	4 (%)	5 (%)
SA / Agree	45.5	54.5	0.5	54.5	90.9	81.8	81.8
Not Sure	18.2	13.6	27.3	13.6	4.55	9.09	13.6
SD / Disagree	36.4	31.8	22.7	31.8	4.55	9.09	4.55

The results suggest that 90.9% of the students had broadened and deepened their understanding and appreciation of differential equations, and 81.8% felt that the graphic calculator has enhanced this understanding. Other prevailing views are:

- Students, who previously found the Existence and Uniqueness Theorem vague, now appreciate it better through the use of the slope field facility. Students can plot a family of solutions of a differential equation easily which provides visual representation that facilitates a deeper understanding of the theorem.
- Students do not have to engage in a great deal of tedious calculations and computations to obtain solutions of a differential equation. The time saved can be used to engage in learning activities to develop better understanding of the concepts of differential equations.
- The activities that involve discrete data of real life problems provide useful and exciting experiences in enhancing mathematics learning.
- Students find that obtaining real data from the Internet and modeling the acquired data is an enjoyable and exciting learning experience.

Table 5. Percentage of respondents to statistics survey
Number of respondents: 21 out of 25 (84%)

Item	1 (%)	2a (%)	2b (%)	2c (%)	3 (%)	4 (%)	5 (%)
SA / Agree	42.8	57.15	57.1	52.4	80.9	66.6	85.7
Not Sure	52.4	33.33	38.1	38.1	4.8	28.6	14.3
SD / Disagree	4.8	9.52	4.8	9.5	14.3	4.8	0.0

The results show that 80.9% of the students agreed that their understanding of statistics had somewhat increased, and 66.6% indicated an enhancement in understanding. Other prevailing views are:

- The use of graphic calculators saves them the trouble of memorizing formulae, speeds up calculations and graphing of data sets.
- Graphical displays, box plots and histograms in particular, are helpful in understanding the idea of the distribution of a data set; its central tendency, spread and shape.
- Statistical testing and the construction of confidence interval become easier. Nevertheless, they still need to know the appropriate test to use.

The surveys also noted several concerns and reservations in the use of graphic calculators:

- Students' over dependence on the calculator in solving problems.
- The cost of the calculator may present an equity issue.
- Students need to be equipped with theoretical and conceptual understanding of the topics before the use of graphic calculators.
- The graphics calculator takes a relatively long time to plot slope fields of differential equations.

In closing, we are very encouraged from the experience in running this course. While it is clear that there is a need to continue investigating the impact of the graphic calculator as an instructional technology, the survey suggests a positive student attitude and interest in the graphic calculator. The students' performance exceeded our expectations; indeed, the underlying goals of the course were attained early in the semester.

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APPENDIX A

A Specification Table For
Laboratory Explorations in Calculus with the TI-92Plus:
Limits and Limiting Behavior

A Specification Table for Student Assessment

Topics/ Objectives	Knowledge	Comprehension	Application	Analysis
Limits	(a) Ability to recall basic concepts and theorems on limits.	(c) Ability to visualize the nature of limits by using GC at specific points, $\pm\infty$, and indeterminate forms.	(d) Ability to make observations and interpretations from real data using GC.	(e) Ability to manage a fresh new data set.
	Test Items	***Test Items***	***Test Items***	***Test Items***
	Open-ended or MCQ on limit theorems, such as sum of limits, sandwich theorem, and L'Hopital rule.	Students' facility in using GC features, such as zoom, table, and plot features, in determining existence of limits.	Management of data; plotting; observation of specific math features of the graph; physical interpretations.	Take home assignment.
	(b) Ability to compute limits.			(f) Ability to develop a mathematical model from a data set.
	Test Items			***Test Items***
	Finding limits at specific points or at ∞.			Group presentation.