The Effect of Exploratory Computer-Based Instruction on Secondary Four Students' Learning of Exponential and Logarithmic Curves

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Abstract: The study investigated the effect of exploratory computer-based instruction on pupils' conceptual and procedural knowledge of graphs. Many previous studies compared the effect of computer-assisted instruction with traditional teacher-directed teaching and any difference in performance might be due to a different pedagogical approach instead of the use of information technology (IT). In this study, both the experimental and control classes were taught using a guided discovery method to explore the characteristics of the exponential and logarithmic curves. One class used an interactive computer algebra system called LiveMath, while the other did not have access to IT. The findings indicated a significant difference in pupils' conceptual and procedural knowledge. This seemed to suggest that there was an inherent advantage of using IT to explore mathematical concepts.

1. Introduction

With the advance of technology, our lives have been changed dramatically. The ways we communicate, interact and do business have revolved around the computer. With such an impact on our society, it is inevitable that educators desire to harness technology to develop their pupils to the fullest potential (Mariotti, 2002; Nickerson, 1988). The Cockcroft Report (1982) in the United Kingdom, the NCTM Curriculum and Evaluation Standards (1989) in the United States and the IT Masterplan (Ministry of Education, 1997) in Singapore are all attempts by educators to use technology to enhance teaching and learning in the classroom. These have resulted in billions of dollars being spent on computer hardware and software. But are educators successful in utilising technology effectively to enhance pupils' learning of mathematics?

Noble (1998) pointed out that most teachers in the United States have never used a computer despite the fact that they celebrate the importance of computers in schools. A study of 220 mathematics classrooms in the United States in 1994 yielded a mere 1% computer usage (Huang & Waxman, cited in Leong & Lim-Teo, 2002). Research in Singapore has also suggested that teachers are not convinced of the relevance and benefits of the use of computers in education (Ang, 1999; Cheong, 2001; Ong-Chee, 2000). This may be the result of ineffectual use of technology to support the existing curriculum, for example, putting lecture notes on the World Wide Web (Roberts & Jones, 2000). Educators who use such methods are regarded as having a closed mindset: they do not take into account that they may have to change their pedagogy in order to make use of technology effectively (Jensen & Williams, 1993). The IT Masterplan 2 in Singapore hopes to address this issue of integrating IT into the design of a more flexible and dynamic curriculum by taking into account new teaching methods that are made possible by technology (Shanmugaratnam, 2002).

Barton's (2000) meta-analysis of more than 60 studies on the effect of IT on mathematics education indicated that pupils in the experimental group performed significantly better in conceptual knowledge test than pupils in the control group but there was no significant difference in their procedure knowledge test. Research in Singapore, for example, Ho (1997) and Ong (2002), showed that the pupils in the experimental groups performed better in procedural knowledge test. However Oppenheimer (1997) questioned the validity of such studies because they did not control for other influences such as differences between teaching methods. Most local research compared pupils who used IT to explore mathematical concepts with those taught using the traditional teacher-directed teaching. In fact, Barton (2000) defined the control group for the 60 odd studies as "*the group that was typically taught in a traditional manner*" (p. 3). With such a difference in pedagogy, the better performance of the experimental group may be due to the pedagogy itself instead of the use of IT. If this is the case, then why should we spend so much money on computer hardware and software? We might as well employ a guided discovery method for pupils to explore mathematics without the use of IT and the effect may still be the same.

In this study, both the experimental and control classes were taught using the same guided discovery approach to explore the characteristics of the exponential and logarithmic curves. The pupils in the experimental class used an interactive computer algebra system called *LiveMath*, while the pupils in the control class did not have access to IT. There were pre-built models in *LiveMath* which enabled the pupils in the experimental class to explore the characteristics of the exponential and logarithmic curves. It was hoped that any difference in performance between the experimental and control classes would not be identified as a result of the difference in pedagogy as indicated by Barton (2000). The research questions for this study are indicated as follows:

(1) What is the effect of exploratory computer-based learning on pupils' understanding of exponential and logarithmic curves?
(2) What is the effect of exploratory computer-based learning on developing pupils' procedural skills?

2. Research Method

This study was carried out using a quasi-experimental pretest-posttest control group design (Frankfort-Nachmias & Nachmias, 1996) based on a sample of 65 Secondary Four pupils from two middle-ability Express classes in an independent boys' school in Singapore. The two intact classes were selected based on their Secondary Three Elementary and Additional Mathematics Final Examinations results. Two t-tests were run to show that the classes selected had no significant difference in their academic achievement in mathematics before the treatment. The classes were randomly assigned experimental and control groups and both classes were taught by the first author. There were a total of ten 40-minute intervention sessions for each class.

The Intervention

The experimental class used an interactive computer algebra system (CAS) called *LiveMath* to explore the graphs of exponential and logarithmic functions. Previously known as *Theorist* or *MathView*, this software is unlike most other CAS because it is designed as a cognitive tool rather than a computing tool. Even Kaput (1992) found *Theorist* "intriguing because of a unique user interface that allows one to perform 'natural' algebraic maneuvers even more 'naturally' than one can achieve them on paper" (p. 534).

Figure 1 shows a pre-designed *LiveMath* template used to explore the effect of the constant c on the exponential function of the form $y = e^x + c$. The user just needs to change the value of c and the graph and its equation will change instantaneously. This interactive feature of *LiveMath* allows the user to observe the effect immediately without having to re-type the whole equation and re-plot the corresponding graph.

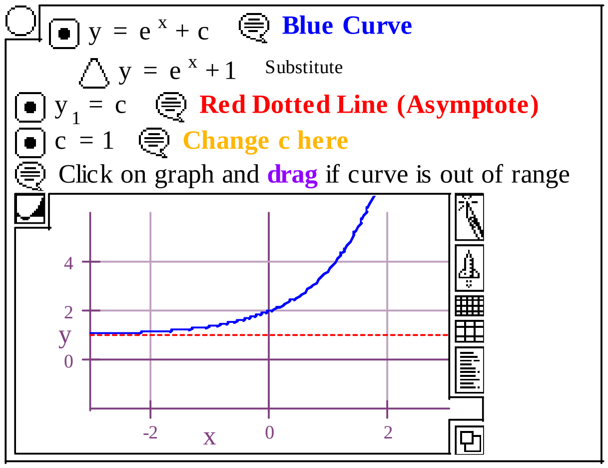

Figure 1. Example of an Interactive LiveMath Template

Figure 2 shows another pre-designed *LiveMath* template that allows the user to animate the graph of the exponential function of the form $y = e^x + c$ where c increases from –2 to 4 in steps of 1. Such animation helps the user to visualise the effect of c on the graph of the exponential function.

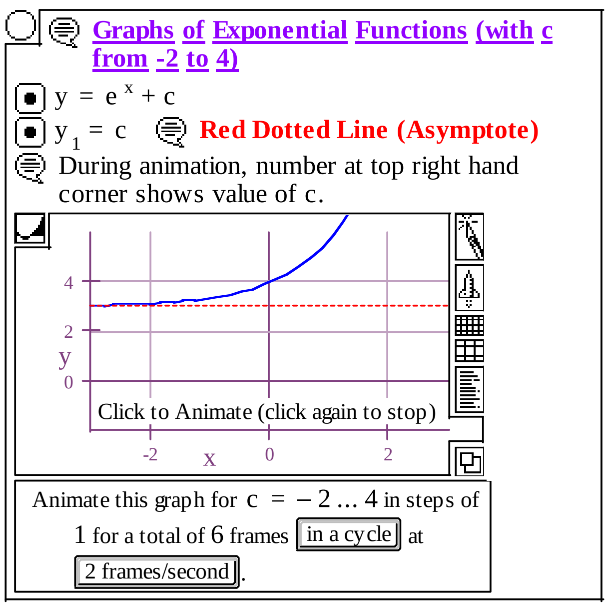

Figure 2. LiveMath Template showing Animation

The pupils in the experimental class did not need additional lessons to learn the software because all the templates were pre-designed by the first author (Yeo, 2001) and all the pupils needed to do was to follow the corresponding worksheets, change the values of the variables and observe the effects immediately. The pupils in the control class did not have access to IT. Instead all the graphs that they needed were printed on worksheets and the pupils were guided to discover for themselves certain properties of the curves. This was in sharp contrast to most research where the control class was taught using traditional teacher-directed teaching.

Test Instruments

There were two test instruments: Conceptual Knowledge Test (CK) and Procedural Knowledge Test (PK). The CK Test aimed to examine how much pupils have understood about the nature of the curves and their asymptotes using real-life examples like the cooling curve of a cup of hot coffee. The PK Test aimed to examine how much pupils have learnt about certain procedures: curve sketching, types of transformations from one curve to another, and graphical solution. Three experienced teachers were asked to validate the test instruments and all of them believed that the CK and the PK Tests were trying to measure pupils' procedural and conceptual knowledge respectively.

The test was also piloted with a previous batch of secondary four pupils and some questions were modified based on pupils' verbal feedback during the test and based on their answers. The statistical software, SPSS, was used to calculate the reliability of both the CK and PK Tests. The results are shown in Table 1. Since all the values of the Cronbach's alpha were 0.5 and above, the two tests passed the reliability test for achievement tests (Nunnally & Bernstein, 1994).

Table 1. Cronbach's Alpha for Conceptual and Procedural Knowledge Tests

	Pilot Test	Main Study
Sample Size	52	65
CK Test	0.710	0.739
PK Test	0.580	0.501
Overall	0.748	0.684

Table 2 below shows the mean scores of CK Test, PK Test and the overall mean scores for both classes combined during the pilot test and main study. This was to measure the facility of both tests.

Table 2. Mean Scores of Conceptual and Procedural Knowledge Tests

	Pilot Test	Main Study
Sample Size	52	65
CK Test /25	17.8	18.2
PK Test /25	19.3	18.8
Overall /50	37.1	37.0

Since the mean scores were about 74%, both the conceptual and procedural knowledge tests were of average difficulty.

Data Analysis

Appropriate statistical tests were run to test the four null hypotheses for this research. The Shapiro-Wilk test was first run to test whether all the different sets of data were normally distributed (Field, 2000). For example, the pretest data based on the pupils' Secondary Three Elementary and Additional Mathematics Final Examinations results were found to be normally distributed and so the Independent-Samples t-test was used to show that there was no significant difference in the results between the experimental and control classes.

However, some of the CK and PK Tests results for either one of the two classes were found not to be normally distributed. Therefore parametric tests, such as the t-tests, could not be used to analyse the data. Instead a non-parametric test, the Mann-Whitney test, was used to test whether there was any significant difference in the results.

Some researchers believe that a null hypothesis should not be rejected based only on a *statistically* significant test (Burns, 2000). So the effect size is also calculated to see whether it is *practically* significant to reject the null hypothesis. The effect size is "the *degree* to which the phenomenon is present in the population" (Burns, 2000, p. 167). It is used to determine the strength of the relationship between the independent and dependent variables that is independent of sample size. Meta-analysis of findings of quantitative research studies is based on the concept of effect size.

3. Results

It was found that there was a significant difference in the scores of both the CK and PK Tests between pupils in the experimental and control classes. Tables 3 and 4 summarise the Mann-Whitney Tests for the CK and PK Tests respectively.

Table 3. Mann-Whitney Test on Conceptual Knowledge Test

Group	n	Mean	Std Dev	Z-value	p-value	Effect Size
Experimental	32	20.7	2.95	–4.238	< 0.001	1.28
Control	33	15.9	4.42			

Table 4. Mann-Whitney Test on Procedural Knowledge Test

Group	n	Mean	Std Dev	Z-value	p-value	Effect Size
Experimental	32	20.2	3.77	–2.532	0.011	0.705
Control	33	17.4	4.23			

The effect size of 0.705 for the PK Test suggests that the experimental approach had a large effect on pupils' procedural knowledge test performance. But the effect size of 1.28 for the CK Test suggests that the effect was even bigger for the pupils' conceptual knowledge test performance.

4. Conclusion

The findings of this study, together with those from most local dissertations and studies from other countries (as reported by Barton, 2000), have very important implications for teaching and learning with IT. First, this study suggests that the use of computers to explore mathematics is a better pedagogical approach than the mere teacher-directed teaching or maybe even guided-discovery learning without the use of computers. Next, it suggests that the computer can be a useful tool for pupils to explore mathematical concepts without any loss of procedural skills. Finally, from a research perspective, the study suggests that the advantage of IT lessons in many research studies, both local and overseas, is not due to a difference in pedagogy but rather, there is something inherent in the computer that enhances pupils' exploration of mathematics. These findings suggest that there is a need for teachers to make full use of the interactive features of software, like *the Geometer's Sketchpad* (a dynamic geometry software) and *LiveMath*, to guide their pupils to explore mathematical concepts so that pupils can construct their own mathematical understanding with the cognitive tools. However more studies need to be done to substantiate these findings, as a small research study like this has its limitations.

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