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USING SPREADSHEET TO TEACH LIMIT AMONG COLLEGE STUDENTS

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Abstract

The commandment of $\varepsilon - N$ definition is essential in order to learn the concept of limit. In Malaysia, students will only learn this definition in the tertiary level due to its complicated structure. Although technology component was introduced in secondary schools in year 2006, $\varepsilon - N$ definition was still not part of the syllabus as if learning of this definition was still impossible to secondary students. Furthermore, because of incorrect notions of limit perceived at the secondary level, students find learning $\varepsilon - N$ definition to be difficult in the tertiary level. These have motivated the researcher to create a technology-aided module that is able to remediate these difficulties. The potential of spreadsheet in enhancing understanding about limit is addressed in this study. A spreadsheet module about limit learning was designed, and its effectiveness was tested in a pre-test-and-post-test quasi experiment as compared to the traditional paper-and-pencil method. Through data analysis, it was found that participants in the study gained a significant improvement in understanding the concept, implying that spreadsheet-aided environment made learning $\varepsilon - N$ definition possible even in the secondary level.

Keywords: $\varepsilon - N$ definition, limit of sequence, mental image, spreadsheet.

Introduction

Limit is a fundamental and the most important concept in understanding calculus (Ferrini-Mundy & Lauten, 1993). The formal definition of limit must be fully understood in order to perceive the notion of limit. Also commonly known as $\varepsilon - N$ definition, limit is defined formally as,

> "We call a sequence $\{a_n\}$ to be convergent to a real number A if for any positive number ε, there is a natural number N such that $|a_n - A| < \varepsilon$ for all $n \geq N$" (Apostol, 1981, p. 70).

In Malaysia, limit is taught in both secondary schools and universities. In secondary curriculum, the concept of limit is not explicitly mentioned in the syllabus of additional mathematics (CDC, 2002, 2006, in press). However, in order to explain differentiation without discussing the fundamental understanding about limit, teachers commonly teach the symbol of limit and show how to compute limit algebraically by defining limit with words used for daily routine such as "approaching to", "growing larger and larger", "moving to infinity" and etc.. However, these do not convey the genuine mathematical meaning of limit (Cornu, 1991), and hence students in the secondary schools often perceive limit, from repetitive skill-and-drill exercises on evaluation of limit, as a dynamic entities such as "approaches to infinity" and "when x grows larger" which is only a subset of the actual meaning.

The use of technology in teaching and learning limit has been documented since in the early 90's. Li & Tall (1993) presented the effect of BASIC programming in constructing the notion of limit in the transition stage from the informal definition i.e. limit as a non-ending dynamic process to the formal definition i.e. $\varepsilon - N$ definition. In a study by Monaghan, Sun & Tall (1994), they explored that DERIVE, a type of computer algebra system, enabled students to focus the object aspect of limits through reducing interference by the problematic notions. Lastly, Bukova-Güzel & Cantürk Günhan (2010) reported the use of Flash in understanding limit meaningfully by relating mathematics and real world, visualization, and comprehending the importance of mathematics. However, lack of access to these softwares due to the cost and availability, and their complexity, such as requiring high level of proficiency in programming did not gain attraction among teachers.

It seems that a tool which is efficient, ubiquitous, convenience and requiring low programming skills, meets a high demands in mathematics classroom. Researches about the potentials of spreadsheet in mathematics education could be traced in the past almost 30 years. Abramovich & Cho (2007), Arad (1986) and Daher (2011) reported the positive effects of spreadsheet in problem solving skills such as posing problems in a range of contexts, using heuristics in problem solving, and adopting a variety of problem solving strategies. On the other hand, spreadsheet was reported to support generalisation (Wilson, Ainley & Bills, 2004) because students' attention was shifted to focus on calculation and the use of notation, and to support algebraic expression (Wilson, Ainley & Bills, 2005) due to the mediating functions of spreadsheet such as varying the cell values, dragging effect, and column-and-row naming effect. Lastly, Calder, Brown, Hanley & Darby (2006) discovered that the visual and tabular representation of spreadsheet enhanced conjecture formation..

Due to its unique features which are feasible for teaching and learning, the use of spreadsheet in classrooms is quite common. However, there are scarce researches on the potential of spreadsheet in teaching and learning limit. In 1994, Furina explored the effect of spreadsheet on students' concept image of limit. The result of this study showed that spreadsheet changes students' scheme in learning limits as the numerical proof by the spreadsheet might conflict students' expected result obtained from the algebraic manipulation. This study sheds light on adding the effectiveness of spreadsheet in teaching and learning $\varepsilon - N$ definition into the current literatures.

Purpose and Research Questions

The purpose of this study was to explore the effectiveness of spreadsheet towards students' understanding about limit. In particular, the following research questions were addressed:

(1) Is there any significant difference in understanding limit between students who are using spreadsheet and those who are not using in the pre-test?
(2) Is there any significant difference in understanding limit between students who are using spreadsheet and those who are not using in the post-test?
(3) Is there any significant difference in understanding limit among students who are not using spreadsheet in the pre-test and the post-test?
(4) Is there any significant difference in understanding limit among students who are using spreadsheet in the pre-test and the post-test?

Pedagogical Features of Spreadsheet

According to Neuwirth & Arganbright (2004), spreadsheet offered many features which were feasible in creating a conducive environment for learning. Several features are described here together with examples.

Arrays

Table groups all the values in different attribute, and each values within the same attribute are differentiated by primary keys. It gives a thorough visualization to the relationship between values by displaying the full data. Spreadsheet is basically made up of two-dimensional array consisting of infinitely many rows and columns. Therefore, a gigantic table can be formed easily by user.

Charts

Spreadsheet enables users to display their data in various diagrams such as column graph, bar graph, line graph, pie chart, scatter plot, area chart, doughnut chart, and etc. In this study, scatter plot will be used extensively to display the pattern of change of the values in the table.

Formulae

User can type anything in a cell such as numbers, a string of alphabets, and even formula. Calculation using formulae which consists of basic operations such as addition, multiplication, exponentiation and so on in cells is a unique feature of spreadsheet.

Functions

Being used as a calculating machine in various fields such as statistics, finance, engineering, banking and so on, spreadsheet contains a lot of built-in functions for convenience use. The list of functions can be obtained by typing "function" in the search engine of Microsoft Excel Help. Among examples of the function in spreadsheet, which were also used in this study, are "ABS" and "IF". "ABS" is used to return the cell as the absolute value of the selected cells whereas "IF" is used to return the cell as the value given by a condition.

Fill handle

Fill handle is another unique feature that is convenient when we need to generate a sequence of number in a row or a column following a certain pattern. Fill handle is the small black square in the lower-right corner of a cell. The pointer of the mouse changes to a black cross when it is pointed to the fill handle. Pressing and dragging this fill handle enables filling up across a row or a column. For example, a sequence of number of 1, 2, …. , 10 can be generated in a column by dragging the fill handle of a cell containing the value 1. Of course, this effortless action allows generation up to 100 or 1000 number.

Cell reference

Cell reference is a feature of spreadsheet which enables linking a formula or function in a cell with one or more foreign cells. The purpose of doing cell references is immediate modification of a cell upon altering the content of reference cell.

Methodology

Population and Sample

This study was carried out in a private college in Malaysia. Due to logistic factors, this study involved two intact classes of the college which consisted of a total of 64 participants.

Limit Understanding Test

The research questions of this study were about "understanding about limit". Roh (2008) reported three types of mental images of limit possessed by learners i.e. limit as asymptotes (Group *A*), limit as cluster points (Group *L*), and limit as true limit points (Group *L*). Only Group *L* was said to have the true understanding about limit. The instrument used in this study, namely *Limit Understanding Test* was adapted after reviewing the works of Williams (1991) and Roh (2005, 2007, 2008, in press), and it was to group the participants according to the mental image of limit of sequence by measuring the probability of having Group *A*, Group *C* and Group *L* mental image.

Limit Understanding Test comprised 2 parts i.e. part 1 and part 2. Part 1 comprised 2 close-ended items and was designed to capture the mental definition of limit. In this part, some definitions of limit, reflecting the mental image of Group *A*, Group *C* or Group *L*, were provided and the participants could choose more than one statements that best suited their definition. 1 point was awarded for Group *A*, Group *C* and / or Group *L* for each item if a participant chose the definitions corresponding to the mental image. Then, for the measurement of the true understanding about limit in this study, the probability of the participant having Group *L* mental image was calculated. On the other hand, part 2 comprised 9 open-ended items and was designed to capture the computation of limit. In this part, participants were required to evaluate the limits of different types of sequences such as monotone bounded sequences, unbounded sequences, constant sequences, oscillating convergent sequences and oscillating divergent sequences. Similar to Part 1, 1 point was awarded for Group *A*, Group *C* and / or Group *L* for each item if a participant gave explanations and final answers corresponding to the mental image. Then, the probability of the participant having Group *L* mental image was calculated

The cross validation of *Limit Understanding Test* was done by the supervisor of the author, who had a lot of experience in quantitative researches, and three senior lecturers from the college, who had at least 20 years of experience in teaching mathematics. Generally, they gave positive feedback to the instrument in terms of content, arrangement of questions and accessibility of understanding.

Spreadsheet Module

Spreadsheet was proposed as an intervention to remediate the difficulty in learning limit in this study. The spreadsheet module used in this study consisted of 11 worksheets, each addressing different learning outcome(s) which was to create a concrete environment for participants to interpret the abstract structure of the formal definition. In general, the design of the module centred on the formal definition of the limit to learn the concept from various perspectives such as (a) the relationship between limit and cluster points and asymptotes; (b) convergence and divergence of a sequence; (c) uniqueness of the limit; and (d) distributivity of the operations involving limit. Inductive discovery, which involves generalisation through examples, was adopted as the main pedagogical instruction in the module. The contents of each module are summarised in Table 1.

The spreadsheet module was inter-rated by three senior lecturers from the college having at least 20 years of experience in teaching mathematics for suitability to the participants. Generally, they gave positive feedback in terms of content, instructions in the worksheets, levels of difficulty and variety of the questions in the worksheets.

Research Design

In order to answer the research questions, a pre-test-and-post-test quasi experimental design was employed to compare the effectiveness of spreadsheet and traditional methods in understanding about limit. Based on the pre-test result, the participants were randomly and equally assigned into two different modules being spreadsheet module (i.e. the experimental group) and traditional module (i.e. the control group). After the 8-week period of treatment, 2 days in each week and 30 minutes in each day, their understandings about limit were retested. The pre-test results between both groups, the post-test results between both groups, the pre-test and post-test results within the experimental group, and the pre-test and post-test results within the control group were compared, analysed and interpreted.

Data Analysis

As mentioned, the probability of a participant having Group *L* mental image was used as the score of understanding of limit in this study. SPSS Version 21 was used as the main statistical tool for data analysis. In answering research questions (1) and (2), the scores between pre-tests of both experimental and control groups and between post-tests of both experimental and control groups were analysed using the independent t-test to compare the difference in understanding from both group before and after the intervention. On the other hand in answering research questions

(3) and (4), the scores between pre-test and post-test of the experimental group and between pre-test and post-test of the control group were analysed using the paired t-tests, to see whether there was any improvement in the understanding after the intervention was performed with exclusion of all the factors like increasing maturation in an assessment.

Results

Subject Pre-test and Post-test

Table 2 displays the total numbers of participants in Group *A*, *C* and *L* in the pre-test and post-test from each part.

The pre-test result revealed that majority of the participants were in Group *C* (approximately 66 %), Group *L* was the minority (approximately 9 %) and the remaining was in Group *A*. This indicates that most of the participants had very little understanding about limit. Of 64 participants in the beginning of the studies, only 54 completed the research. From Table 2, there seems to be increment in Group *L* i.e. from initially 9 % to 44 %, and decrements in both Groups *A* and *C* i.e. from initially 25 % and 66 % to 19 % and 37 % respectively. This shows that there was an increment in the understanding about limit in the pre-test and post-test.

Scores of Understanding Pre-test and Post-test Analysis

Table 3 shows comparison of the means and standard deviations of scores of understanding about limit i.e. Group *L* of each group in pre-test and post-test.

It can be seen from Table 3 that the mean scores of understanding about limit in both group from pre-test to post-test in each part increased. However, the improvement in the experimental group seemed to be higher than the one in the control group. With reference to part 1, the mean increment in the experimental group was 566 % (i.e. more than 5 fold) as compared to the mean increment in the control group which was only 38 %. With reference to part 2, the mean increment in the experimental group was 80 % as compared to the mean increment in the control group which is only 2 %. Independent groups t-test and paired samples t-test would be performed to see whether these mean differences were significant.

Independent t-test for Equality of Means

Table 4 shows the independent t-test for equality of means of both the experimental and the control groups.

Is there any significant difference in understanding limit between students who are using spreadsheet and those who are not using in the pre-test? The overall results in all parts indicate that there was no significant difference in the understanding about limit between students in the experimental group (Part 1: mean = 8.44 & SD = 13.584; Part 2: mean = 28.50 & SD = 12.255) and those in the control group (Part 1: mean = 12.25 & SD = 18.507; Part 2: mean = 26.94 & SD = 17.029) in the pre-test, Part 1: $t(62) = -9.39$; Part 2: $t(62) = 0.421$, $p > .05$.

Is there any significant difference in understanding limit between students who are using spreadsheet and those who are not using in the post-test? The overall result shows that there was significant difference in the understanding about limit between the experimental group (Part 1: mean = 56.23 & SD = 23.086; Part 2: mean = 51.23 & SD = 17.032) and the control group (Part 1: mean = 16.86 & SD =

28.674; Part 2: mean = 27.43 & SD = 16.446) in the post-test, Part 1: $t(52) = 5.531$; Part 2: $t(52) = 5.224$, $p < .05$. The mean scores indicate that students in the spreadsheet classroom had significantly improved their understanding about limit than those in the traditional classroom in the post-test.

Paired Sample t-test for Equality of Means

Table 5 shows the paired sample t-test for equality of means in both the experimental and the control groups.

Is there any significant difference in understanding limit among students who are not using spreadsheet in the pre-test and the post-test? The overall results in all parts indicate that there was no significant difference in the understanding about limit of students in the control group in the pre-test (Part 1: mean = 12.25 & SD = 18.507; Part 2: mean = 26.94 & SD = 17.029) and the post-test (Part 1: mean = 16.86 & SD = 28.674; Part 2: 27.43 & SD = 16.446), Part 1: $t(27) = -0.929$; Part 2: $t(27) = 1.825$, $p > .05$.

Is there any significant difference in understanding limit among students who are using spreadsheet in the pre-test and the post-test? The overall results in all parts indicate that there was significant difference in the understanding about limit in the experimental group between the pre-test (Part 1: mean = 8.44 & SD = 13.584; Part 2: mean = 28.50 & SD = 12.255) and the post-test (Part 1: mean = 56.23 & SD = 23.086; Part 2: mean = 51.23 & SD = 17.032), Part 1: $t(25) = -11.869$; Part 2: $t(25) = -6.452$, $p < .05$. The mean scores indicate that students in the spreadsheet classroom had significantly higher understanding about limit in the post-test than in the pre-test.

Discussion and Conclusion

The key results of the study are summarised in the following points:

(1) there was no significant difference in the understanding about limit between students in the spreadsheet classroom and those in the traditional classroom in the pre-test,
(2) students in the spreadsheet classroom had significantly higher understanding about limit than those in the traditional classroom in the post-test,
(3) there was no significant difference in the understanding about limit of students in the traditional classroom in the pre-test and the post-test, and
(4) students in the spreadsheet classroom had significantly higher understanding about limit in the post-test than in the pre-test.

The results show that spreadsheet module and traditional module gave a significant difference in the understanding about limit. Student seemed to improve more when learning in spreadsheet environment compared to the traditional environment. The module was designed grounded on the theory of constructivism in such a way that students would understand limit thorough experimentation and inductive discovery. Through a set of instructions or questions as the scaffold and minimum direct information (direct telling), students carried out hands-on activities, from which they constructed knowledge about limit that is meaningful to them.

Furthermore, this research supported the results of the positive pedagogical impacts of spreadsheet in previous studies. Spreadsheet seemed to be able to enhance students' formation of the correct mental image for internalising the formal definition of limit (Furina, 1994) by improving their algebraic thinking (Wilson, Ainley & Bills, 2005), reversed thinking (Roh, 2005, 2007, in press) and array visualisation (Calder, Brown, Hanley & Darby, 2006; Calder, 2008). Also, students demonstrated various abilities within the spreadsheet environment which are feasible and conducive to learn the formal definition of limit meaningfully, such as posing and solving problems (Arad, 1986; Abramovich & Cho, 2007; Daher, 2011), generalising and making conjectures (Wilson, Ainley & Bills, 2004; Calder, Brown, Hanley & Darby, 2006), and reasoning (Hoag, 2008).

As a conclusion remark, spreadsheet indeed gives a difference in teaching and learning, if used in a proper manner. Although traditional paper-and-pencil has its own advantage in teaching and learning, spreadsheet is able to overcome various physical limitations of this pedagogy which inhibit the higher order thinking. Hence, it is recommended that spreadsheet could be an alternative teaching and learning devises in the classrooms.

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Table 1
Content of Spreadsheet Module

Worksheet	Learning outcome
1	Judge the validity of limits with reference to the formal definition.
2	Identify the significance and relationship of ε and N in the formal definition.
3	Prove the implication that if the limit of a sequence exists and is known, then the limit is the horizontal line clustered by infinitely many points.
4	Predict the limit of a sequence geometrically.
5	Prove the implication that if there exists no horizontal line of clustered points, then the limit does not exist.
6	Disprove the implication that if $y = A$ is a horizontal line of clustered points, then the limit of the sequence is A.
7	Prove the distributivity of sum of limits.
8	Prove the distributivity of scalar product of limits.
9	Prove the distributivity of difference of limits.
10	Prove the distributivity of product of limits.
11	Prove the distributivity of quotient of limits.

Table 2
Numbers of participants in Group A, C and L in the Pre-test and Post-test

	Pre-test					Post-test				
Part	A	C	L	U	n	A	C	L	U	n
1	14	36	6	8	64	6	16	18	14	54
2	16	42	6	0	64	10	20	24	0	54

Note. A = Group A; C = Group C; L = Group L; U = Undefined group; n = total number.

Table 3
Means and Standard Deviations of Scores of Understanding about Limit and of Experimental and Control Groups in the Pre-test and Post-test

		Pre-test			Post-test		
Group	Part	n	Mean	SD	n	Mean	SD
Experimental	1	32	8.44	13.584	26	56.23	23.086
	2	32	28.50	12.255	26	51.23	17.032
Control	1	32	12.25	18.507	28	16.86	28.674
	2	32	26.94	17.029	28	27.43	16.446

Note. n = total number; SD = standard deviation. The above scores were adjusted relative to a maximum score of 100 in each part of the instrument.

Table 4
The Independent t-test for Equality of Means of the Experimental and Control Groups

	t-test for Equality of Means	
Part	Pre-test	Post-test

	t	DF	Sig.	t	DF	Sig.
1	-9.39	62	0.351	5.531	52	0.000
2	0.421	62	0.675	5.224	52	0.000

Note. t = statistical t value; DF = degree of freedom; Sig. = level of significance.

Table 5

The Paired Sample t-test for Equality of Means of the Experimental and Control Groups

Group	Part	Paired Samples Test		
		t	DF	Sig.
Experimental	1	-11.869	25	0.000
	2	-6.452	25	0.000
Control	1	-0.929	27	0.361
	2	1.825	27	0.079

Note. t = statistical t value; DF = degree of freedom; Sig. = level of significance.