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The Effects of Integrating Technology on Students' Conceptual and Procedural Understandings in Integral Calculus

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Abstract

This paper discusses the effects of using two different learning approaches to students' understanding ofintegral calculus. Experimental and control groups were formed at random to participate in this research. Each group was divided into three sub groups which are low ability, medium ability and high ability groups. The formation of these subgroups was done according to their marks in an integral calculus pre-test given to them prior to the lessons. In general, students in the experimental group outperformed their peers in the control group in terms of their grasp of both conceptual and procedural understandings of integral calculus. By using mathematical software in learning integral calculus, the medium ability and the high ability students in the experimental group progressed better than the low ability students. On the contrary, in the control group, the maximum percentages of improvement in both conceptual and procedural understandings were from the low ability group. Since the main objective of integrating technology in the learning of integral calculus is to enhance every student's understanding, a better implementation strategy needs to be drafted in the future. One possible way is to expand the usage of the technology in other calculus topics.

Keywords: integral calculus, Maple software, conceptual understanding, and procedural understanding

1. Introduction

There is no doubt that mathematics is important in many fields, including engineering and engineering technology fields(Grove, 2012; Haripersad & Naidoo, 2008; Henderson & Broadbridge, 2007; Pearson & Miller, 2012; Mynbaev, Bo, Rashvili, & Liou-Mark, 2008). It is an ultimate gateway to engineering education and eventually into the engineering profession (Pearson & Miller, 2012).Calculus is one of the topics defined as a fundamental course in mathematics and engineering (Haripersad, 2011; Huang, 2011; Mahir, 2009). A completion of any engineering degree is highly correlated to the completion of high school calculus and a few college level calculus courses(Pearson & Miller, 2012).

Despite the well-documented importance of this subject, however, there are well-documented problems related to the learning of this subject. One of the problems discussed in the literature is students' under preparedness in this subject (Haripersad, 2011; Henderson &Broad bridge, 2007). In addition, the "surface learning" approach used in the teaching and learning of secondary mathematics has also been discussed(Selden, 2005). One of the earliest studies done by Orton (1983) has highlighted few examples in handling the difficulties in teaching integral calculus at secondary school. He highlighted that some educators reacted by avoiding to introduce this topic in school, while others reacted by introducing integral calculus as a rule. Another issue that has been discussed is about students' problems in transferring the mathematical knowledge learned to the related technical subjects in engineering or engineering technology courses (Mynbaev, et al., 2008).

In addition, even if students found calculus an enjoyable subject in school, their enjoyment does not reflect an easy pathway to succeed in tertiary calculus courses(Tall, 2010). This is an understood phenomenon as students

are expected to engage in a deep learning of concepts at the postsecondary level(Selden, 2005). Students who performed well in calculus in school still have to struggle in learning mathematical analysis at the university. What more happened to the less able students? This problem needs to be tackled at an early stage of university learning. If it is left untreated, the less able students are likely to become more confused and eventually may not complete their degrees(Tall & Razali, 1993). Furthermore, calculus, including integral calculus, is not only the prerequisite for higher mathematics subjects, but it is also crucial for all calculus-related technical subjects (Salleh & Zakaria, 2012).

The issues highlighted by students in this study are indifferent to those emphasized in the literature. In this study, engineering technology students' views were gained through an informal interview session. Two students were chosen at random to give their opinions about their experiences in learning mathematics, particularly calculus. Both of them agreed that they had previously learned all the calculus topics offered in the engineering technology mathematics syllabus for bachelor-level students at the university; however, they admitted that they failed to understand all of the topics due to various reasons and mainly because of the teaching approach. According to them, their mathematics lecturer taught the subjects by writing all the formulae on the white board and asking students to memorize them. They also mentioned that their previous lecturer gave a very minimum explanation on the application of certain formulae. Instead, they were asked to memorize steps involved in solving any mathematics problems.

Views from an engineering student were also gained in order to compare with the engineering technology students' views. When asked about her opinion in learning calculus, she automatically mentioned that it is the most difficult subject. She added that she managed to pass the subject by memorizing rules and steps. Furthermore, she claimed that she did not understand this subject because she could not visualize the ideas behind each concept. The experience shared by the engineering and engineering technology students provided insights that university calculus has problems in both the teaching and the learning aspects.

In this study, both the teaching and the learning for integral calculus were tackled through a blended approach between the existing lecture mode of teaching and the mathematical software as an aid of learning. Maple software was chosen due to its powerful properties in enhancing students' mathematics understanding. It allows not only numerical computations but also symbolic, algebraic, and graphical manipulations. These features help students to perceive calculus from different angles(Samková, 2012).The integral calculus topic was chosen based on the final semester examination analysis done at the university involved in this study. From the analysis, it was found that the integral calculus topic has a very high failure rate(Salleh & Zakaria, 2011). Therefore, this study was conducted with one major objective, which is to improve engineering technology students' understanding in integral calculus through the integration of Maple in the learning of this topic.

2. Material and Methods

A total of 50 students enrolled in Technical Mathematics 2 were selected to learn integral calculus with the help of Maple software. This group represented the experimental group. The control group, which was designed to undergo the integral calculus lessons without the help of the mathematical software, was formed by selecting another 50 students. These students were chosen from five different existing technical courses at random. The assignment of these two groups was done carefully to ensure the minimum tendency of creating an extraneous effect that would jeopardize the internal validity. These two groups were formed by choosing students from different technical courses at random. The experimental group consisted of students from two technical courses: Automated System and Maintenance Technology (ASMT) and Machine Building and Maintenance Technology (MBMT). The control group consisted of students from three different technical courses. The three courses were Air Conditioning and Refrigeration Technology (ACRT), Automotive Maintenance Technology (AMT), and Metal Fabrication Technology (MFT). These students had totally different technical subjects, and they met each other only during mathematics classes. This measure was taken in order to avoid any discussions and sharing of information about the techniques learned in mathematics classes. Therefore, the potential of creating an extraneous effect was minimized.

Due to time constraints, the lecture sessions of these two groups were done simultaneously. Obviously, there were two mathematics lecturers involved in delivering the lectures. However, the involvement of these two lecturers did not affect the treatment of the subject since the major difference between the two approaches lied in the activities conducted during the tutorial sessions. During the tutorial sessions, students were exposed to two different learning environments. In this case, there was only one lecturer involved to conduct all tutorial classes. Throughout these sessions, the experimental group was brought to the computer laboratory to complete the exercises using Maple software. On the other hand, students in the control group underwent the sessions without

any help of Maple software (see Figure 1). For the lecture, the slides for the experimental group were prepared by the lecturer involved in teaching the topic with the help from the researcher. The slides were prepared to include Maple output elements. On the contrary, the lecture slides for the control group were prepared by the lecturer involved without any elements of Maple output.

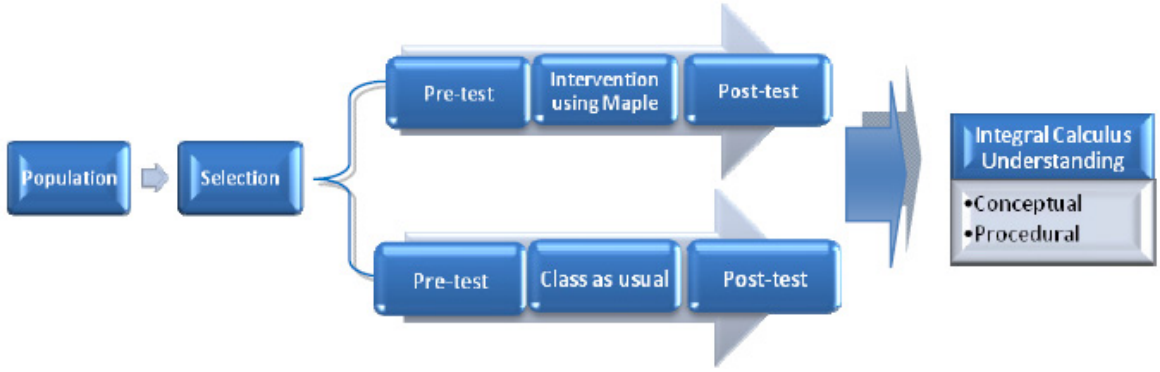


Figure 1. Study design

Prior to the intervention period, a pre-test on integral calculus was given to both groups. The objectives of giving the pre-test were to determine the basic knowledge level of integral calculus in both groups and to find out whether the previous knowledge was homogeneous among students in both groups. Based on the pre-test results, students in both the experimental and control groups were divided into three subgroups, namely low ability, medium ability, and high ability groups. Subsequently, both the experimental and the control groups underwent an intervention period of five weeks, which is equivalent to 40 hours. At the end of the fifth week, students in both groups were given a common post-test in order to determine which group was better in terms of the integral calculus conceptual and procedural understandings.

The pre-test and the post-test consisted of an Integral Calculus Test. This test was developed by the researcher and had been piloted to ensure its validity and reliability. The pilot study was conducted in the July-December 2011 session, which involved a group of 79 students who had learned integral calculus. The reliability of the test was measured using Rasch model analysis. Item reliability indices for both constructs in Integral Calculus Test, i.e., conceptual and procedural understandings, were measured high with 0.95 and 0.96, respectively. The person reliability indices for both constructs were also proven good at 0.77 and 0.86 for conceptual and procedural understandings, respectively. With these analyses, it could be concluded that the test was reliable to be used by other respondents with similar characteristics to those involved in the pilot study.

2.1 Teaching and Learning Elements in the Experimental Group

2.1.1 Teaching Elements

The approach used in the lecture emphasized the explanation of the concepts. The conceptual understanding of integral calculus is more than merely memorizing and applying rules and steps. Instead, it consists of the construction and the connection of ideas within students' mind. It is also developed by relating the existing knowledge with any new related information learnt (Hiebert & Lefevre, 1986). Therefore, in this study, the lecture slides were prepared to facilitate the development of these processes within each individual student involved, as illustrated in Figure2.

Some of the	Sample Lecture Slides	Comments

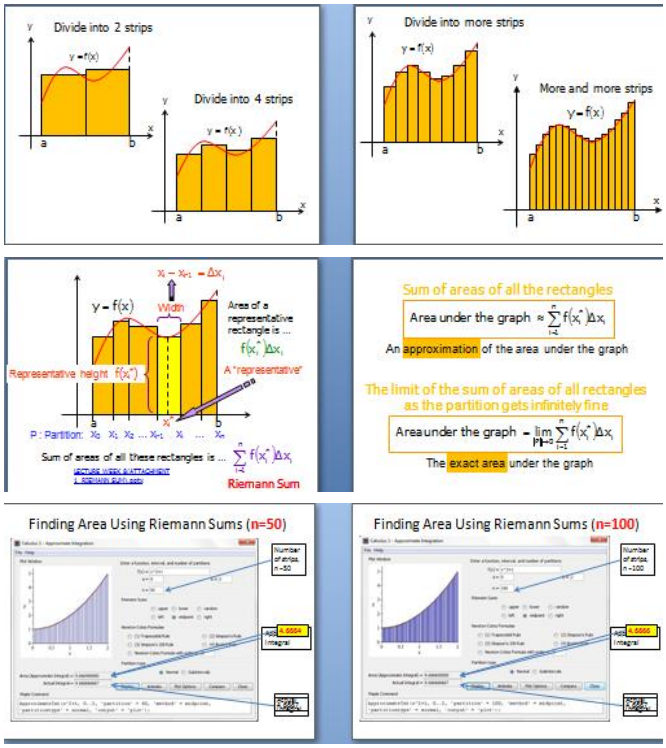
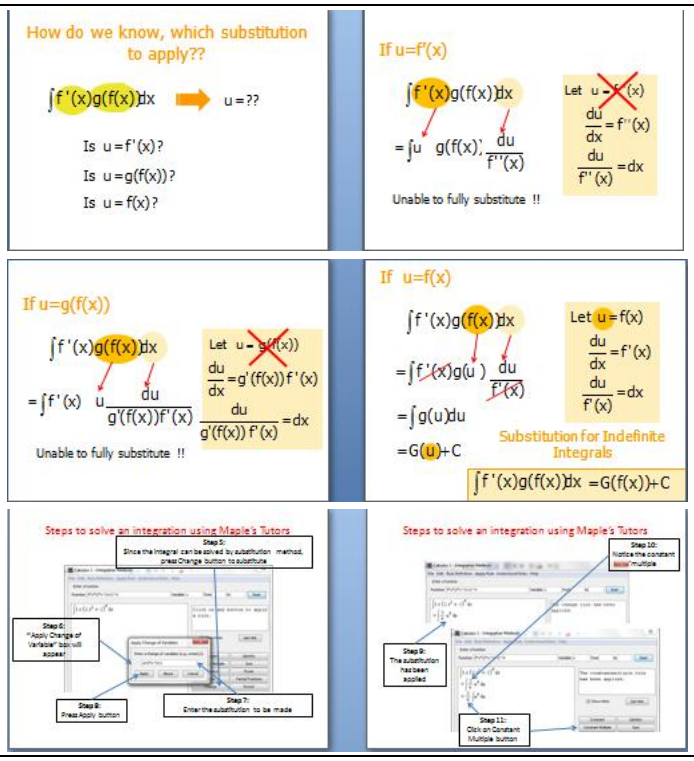
Concepts		
The introduction of integral calculus.		The integral calculus was introduced by discussing about area under the curve. Based on that, the definition of integral calculus was subsequently developed. The idea of integral calculus was also explained through the application of Maple software.
Substitution method		The concept of substitution method was explained through the relationship between integral calculus and differential calculus. Also, counter-examples were given to invoke a conflict of cognitive in students' mind. This approach was done to create disequilibrium which can enhance students' understanding. The application of Maple Tool to solve problems involving substitution technique was also introduced to help students discover the concept behind this method by themselves.

Figure2. Examples of lecture slides developed for experimental group

2.1.2 Learning Activities

In this study, the activities were developed based on Dubinsky's APOS theory. APOS (Action, Process, Object, and Schema) was chosen because this theory emphasizes on the construction of knowledge internally by each individual student himself or herself. This theory refers to the mental structures in which an individual may build in response to any given mathematical problem. The theory hypothesizes that a mathematical concept will be developed by an individual when he or she manages to convert existing physical or mental objects into an

understanding in the form of appropriate schemas(Dubinsky & McDonald, 2001; Weller, Arnon, & Dubinsky, 2011). The activities in a newly developed strategy were then implemented using a teaching cycle known as ACE. ACE is a cycle which comprises three main components: Activity using Maple software, Class discussion based on Maple outputs, and Exercises outside class hour. Some of the activities developed are shown in Figure3.

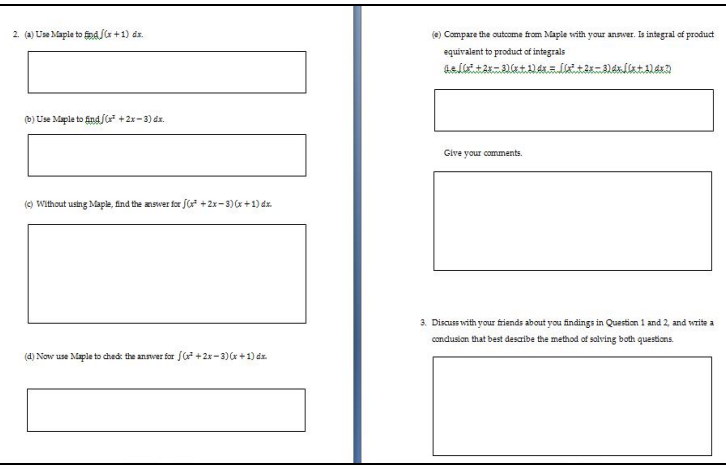
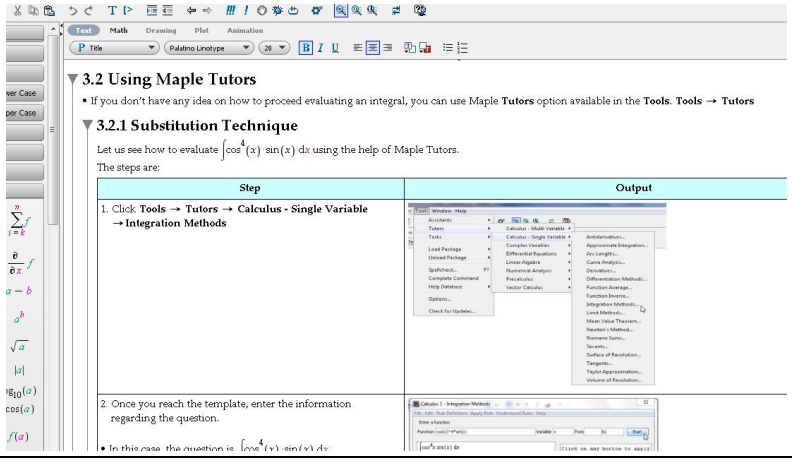
Some of the Concepts	Sample Activities in Tutorial	Comments
The introduction of integrating product of functions		Students were given an opportunity to conjecture the process of integrating product. They were also asked to evaluate the integral using Maple software in order to check their answer.
		Students were given a set of complete Integral Calculus Manual to be referred while completing their integral calculus problems with Maple software.

Figure3. Example of activities and maple manual for integral calculus developed in this study

2.2 Teaching and Learning Elements in the Control Group

The teaching approach used in the control group did not emphasize the explanation of concepts; instead, it stressed the fluency of process. Students were encouraged to memorize the steps involved to solve any integral calculus problems. They were also exposed to the patterns and types of final examination questions they would encounter. Past years' examination questions were given during the lecture, where students were asked to work on the questions individually. The solutions were discussed, and the lecturer summarized by highlighting the pattern of steps involved so that the students could memorize them. The emphasis of the fluency of process to solve problems can be observed from the slides used during lecture (see Figure 4).

Some of the	Sample Lecture Slides	Comments

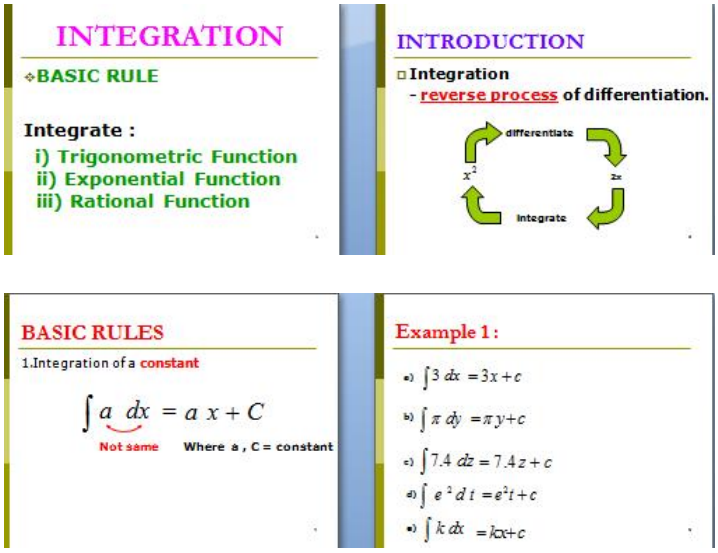
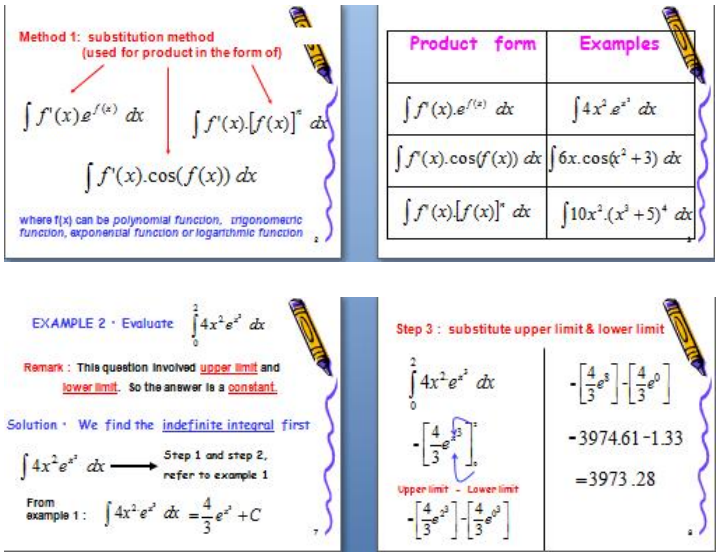
Concepts		
The introduction of integral calculus.		The integral calculus was introduced by directly discussing the process and rules.
Substitution method		The substitution method was explained through recognising the pattern of the function given. The steps of solving were emphasized so that students would recognize not only the pattern of the functions, but also the relevant steps involved in solving each pattern.

Figure 4. Examples of lecture slides for control group

The tutorial sessions for the control group were conducted in normal classrooms. During these sessions, students were given weekly tutorial questions. These tutorial questions were uploaded in the ECITIE, which is the university's online portal. Students printed out the tutorial sheets and attempted the questions prior each week's tutorial session. During the tutorial session, they discussed any problems they encountered with their friends and also with the lecturer. In this case, the discussion was done without any help from any mathematical software. The mediums involved during the tutorial sessions were pen and paper only.

3. Findings and Discussion

The statistical package PASW Statistics 18 was used to analyze the data obtained from the integral calculus test. Students in the experimental group scored a higher mean in both conceptual and procedural understanding compared to students in the control group (see Table 1).To determine whether the differences were significant differences, a statistical test was performed.

Table 1. Pre- and post-tests results for both groups

Group		Conceptual Understanding (CU) (Full Marks = 50) Post-test (Pre-test)	Procedural Understanding (PU) (Full Marks = 50) Post-test (Pre-test)
Experimental Group (n=50)	Maximum	47.92 (17.50)	41.94 (9.26)
	Minimum	0.00 (0.00)	1.61 (0.00)
	Mean	17.17 (2.25)	14.52 (1.33)
	Standard Deviation	11.47 (4.20)	11.07 (1.95)
Control Group (n=50)	Maximum	41.67 (17.50)	40.32 (7.41)
	Minimum	0.00 (0.00)	0.00 (0.00)
	Mean	7.50 (2.00)	8.61 (1.22)
	Standard Deviation	10.22 (4.20)	11.12 (2.10)

The differences in students' mean performance score after the 40 hours intervention period in conceptual understanding and procedural understanding were determined by using the Hotelling's T^2 multivariate test. This test was chosen in order to reduce the type 1 error. In addition, independent t-tests were also done in order to identify the effect of each dependent variable. Table 2 shows the outcomes of Hotelling's T^2 and the independent t-tests for both dependent variables.

Table 2. Multivariate and univariate tests results

Variables	Hotelling's T^2	*t* test	Probability, *p*	Effect size, η^2
Maple as a learning tool treatment	0.238		0.000	0.192
Conceptual Understanding		4.449	0.000	0.168
Procedural Understanding		2.660	0.009	0.067

The Hotelling's T^2value of 0.238 was significant at $p < 0.05$. Therefore, in general, there was a difference in students' mean performance score in integral calculus between those who used Maple software and those who did not use the software in learning this topic. In order to know specifically which variables were responsible for significant main effects, independent *t* tests were performed. The independent *t* tests for the conceptual and procedural understandings were found to be significant. These imply that students' performance in both groups were significantly different.

The effect size values of the intervention applied were also reported because statistical significance wasnot adequate to imply the significant effectiveness of the whole treatment (Thompson, 2002). In the PAWS Statistics 18 package, the effect size values were measured in terms of eta squared values (η^2). In this study, the effect size value for the whole treatment was 0.192. Thisη^2 value is equivalent to Cohen's *d* of 0.975 (*d*> 0.80), which is considered a large effect(Cohen, 1988). Therefore, in this study, the strategy as a whole presented a large effect on the differences between students' performance in both groups. Students' conceptual understanding was found to be one of the factors that largely contributed to the significant differences between those who used Maple software and those who did not use Maple software in the learning of integral calculus with the η^2 value of 0.168 (Cohen's $d = 0.899$). However, students' procedural understanding influenced the significant differences between the groups at a moderate level with the η^2 value of 0.067 (Cohen's $d = 0.536$).

To know exactly which group benefitted the most from the intervention, students' improvement in both types of understanding was measured. Table 3 shows how much students in both groups improved in both conceptual understanding and procedural understanding. The improvement values were reported in percentage. For the experimental group, the maximum improvement in conceptual understanding was gained by student in the medium ability group, with 80.83% improvement. The maximum percentage of improvement in the low ability group was found to be higher than the maximum percentage in the high ability group. Nevertheless, the minimum improvement value in the low ability group was zero. In terms of procedural understanding, the maximum improvement was gained by students in the high ability group, followed by the medium ability group,

and lastly, the low ability group improved the least. Similarly, for the average percentage value, the medium ability group improved better than the other two groups in conceptual understanding. Students in the high ability group improved more than the other two groups in procedural understanding.

For the control group, the maximum improvement in both the conceptual and the procedural understandings was gained by students in the low ability group. However, based on the average value, generally, students in high ability group improved more than the other two groups in both types of understanding. This study also found that students in the medium ability group did not improve at all in the conceptual understanding and improved the least in procedural understanding. Also, the minimum improvement values in both the conceptual and the procedural understandings for students in the low ability and medium ability groups were found to be negative values.

Table 3. Percentage of improvement for both groups

Group	**Conceptual Understanding (CU) Improvement (%)**			**Procedural Understanding (PU) Improvement (%)**		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Experimental Group (n=50)						
Low	57.50	0.00	25.99	63.56	2.27	20.28
Medium	80.83	5.83	43.43	73.24	2.27	41.59
High	52.50	29.83	37.78	80.17	26.37	57.75
Control Group (n=50)						
Low	79.17	-10.00	11.80	70.97	-11.11	12.58
Medium	22.50	-10.00	0.00	21.62	-11.11	11.50
High	32.50	2.50	14.17	65.83	41.46	50.66

4. Conclusion

In general, engineering technology students benefited from the integration of Maple software in learning integral calculus at the university. Both types of the understanding, i.e., integral calculus conceptual understanding and procedural understanding, were investigated in this study and were found to be successfully enhanced using the mathematical software. This study also found that students in the medium ability group benefited the most from this approach to understanding the concepts of integral calculus. In terms of the procedural understanding, the high ability group was found to benefit the most. The low ability group improved the least in both types of understanding in learning integral calculus with the help of technology with a minimum improvement value of zero in conceptual understanding. This indicates that this approach did not benefit some of the less able students in improving their integral calculus conceptual understanding. Since the main objective of the integration of the technology in integral calculus was to improve every student's integral calculus understanding, an appropriate measure needs to be figured out in the future. In the future, the implementation of this approach needs to be planned properly so that all students, including the less able students, will benefit from the strategy. One factor to be considered to improve its potential in enhancing students' understanding is to introduce a longer intervention period. Since it was not possible for the researcher to extend the duration of teaching and learning integral calculus topics, other means need to be figured out. One possible mean is to extend the use of this strategy in other calculus topics, for instance, in functions, limits and differential calculus topics. With a wider coverage and a longer intervention duration, it is hoped that the potential of this strategy will be maximized.

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