Utilizing MATHEMATICA Software to Improve Students' Problem Solving Skills of Derivative and its Applications

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Abstract

Traditional methods of teaching calculus (1) at most Jordanian universities are usually used. This paper attempts to introduce an innovative approach for teaching Calculus (1) using Computerized Algebra Systems (CAS). This paper examined utilizing Mathematica as a supporting tool for the teaching learning process of Calculus (1), especially for derivative and its applications. The research created computerized educational materials using Mathematica, which was used as an approach for teaching a (25) students as experimental group and another (25) students were taught traditionally as control group. The understandings of both samples were tested using problem solving test of 6 questions. The results revealed the experimental group outscored the control group significantly on the problem solving test. The use of Mathematica not just improved students' abilities to interpret graphs and make connection between the graph of a function and its derivative, but also motivate students' thinking in different ways to come up with innovative solutions for unusual and non routine problems involving the derivative and its applications. This research suggests that CAS tools should be integrated to teaching calculus (1) courses.

Keywords: Mathematica, Problem solving, Derivative, Derivative's applivations.

INTRODUCTION

The major technological advancements assisted decision makers and educators to pay greater attention on making the learner as the focus of the learning-teaching process. The use of computer algebra systems (CAS) in teaching mathematics has proved to be more effective compared to traditional teaching methods (Irving & Bell, 2004; Dhimar & Petal, 2013; Abdul Majid, huneiti, Al-Nafa & Balachander, 2012). It has become necessary to take a new educational approach to teach mathematical topics to coup with latest computer technology. CAS has the ability to easily shift teaching strategy from teacher-center class to a student- center class, which will lead to more interesting, inventive, and exploratory (Kumar & Kumaresan, 2008; Medina & Valdes, 2015).

CAS enables students to gain high level of achievement by improving their understanding of difficult mathematical subjects and ideas (Salleh & Zakaria, 2011; Ardic & Isleyan, 2018). The 2000 Standards issued by the National Council of Teachers of Mathematics (NCTM, 2000) recommended that using technology as one of the key teaching strategies. NCTM states that" It is essential that teachers and students have regular access to technologies that support and advance mathematical sense making, reasoning, problem solving, and communication. Effective teachers optimize the potential of technology to develop students' understanding, stimulate their interest, and increase their proficiency in mathematics. When teachers use technology strategically, they can provide greater access to mathematics for all students" (NCTM, 2000).

The idea of using technology in teaching and learning has also been used for accreditation of undergraduate programs such as engineering and information technology. The American Accreditation Board for Engineering and Technology (ABET) has focused on learning and teaching mathematics, and using the techniques skills and modern engineering tools (i.e. using CAS in teaching and learning).

Many universities were interested in improving their mathematics students' understanding and performance. Reform movements to the mathematical courses such as calculus suggested that CAS (such as Maple and Mathematica) are used in teaching calculus to increase students' conceptual understanding, improve students' ability in problem solving and develop positive attitudes towards mathematics and technology (Tall, Smith & Piez, 2008). Maple and Mathematica are the current market leader CAS beside MatLab, SciLab and MuPAD.

Here is a list of some of the most famous free and commercial mathematical software. Additional information on these can be found on their respective websites.

Table 1 Most Famous CAS and other mathematical software (Kumar & Kumaresan, 2008)

Software	Year of start	Utility
Mathematica*	1988	General purpose CAS
Maple*	1985	General purpose CAS
MuPAD*	1993	General purpose CAS
MatLab*	Late 1970	General purpose CAS
MathCAD*	1985	General purpose CAS
Magma*	1993	Arithmetic Geometry, Number Theory
SciLab	1994	General purpose CAS
Maxima	1998	General purpose CAS
YACAS	1999	General purpose CAS
SAGE	2005	Algebra and Geometry Experimentation
Macaulay2	1995	Commutative Algebra, Algebraic Geometry
GAP	1986	Group Theory, Discrete Math
GP/PARI	1985	Number Theory
Kash/Kant	2005	Algebraic Number Theory
Octave	1993	Numerical computations Matlab-like
Singular	1997	Commutative Algebra, Algebraic Geometry
CoCoA	1995	Polynomial Calculation
Gnuplot	1986	Plotting software Dynamic
Solver	2002	Differential Equation
R	1993	Statistics

(*) Commercial software. Remaining are free software. The above list is not complete and there may be many other mathematical software (Kumar & Kumaresan, 2008).

There are few studies that have been conducted on the use of Mathematica as a tool for first year college students. Mathematica provides a powerful interactive and dynamic working environment, which when integrated in teaching and learning results in a great improvement in the effectiveness of lecturing. Mathematica is one of the most popular CAS which has positive effect on learning theoretical and applicable mathematics. It also improves students' mathematical knowledge as it motivates the student to build their mathematical concepts (Vorob'ev, 2012; Ardic & Isleyen, 2018). Tersian and Chaparova explained that using Mathematica in teaching mathematics and engineering in universities encourages students to make suitable visualization and exploring the symbolic and numerical analysis of primary mathematical concepts (Tersian & Chaparova, 2017).

Mathematica is a symbolic mathematical computation program, called also a computer algebra program, widely used in many scientific, engineering, mathematical, and computing fields. Also widely used by researchers, educators, engineers and mathematicians. It is easy to use at the command level. It was designed by Stephen Wolfram and is developed by Wolfram Research of Champaign, Illinois in USA. The Wolfram Language is the programming language used in Mathematica.

Mathematica can manipulate the numerical and algebraically mathematical concepts and provides excellent visualization capabilities, to many mathematical concepts such as derivative, integrals, differential equations, system of linear equations, series, sets, vectors, matrices, and plotting graphs of functions or equations in 3D and 2D. By using Mathematica students save time and efforts when calculating complex mathematical problems that if done traditionally will take from them longer time with possibility of making mistakes. It motivates and helps students to develop the primary mathematical concepts and adequate skills needed in their majors.

MATHEMATICA FOR DERIVATIVE AND ITS APPLICATIONS.

The calculus course is a starting point for many undergraduate science, engineering and information technology students. The derivative and its applications are one of the primarily ideas in calculus. The derivative measures the slope of a tangent line to a curve at a point, the rate of change of one quantity changes relative to another which helps in modeling (population dynamics, speed of different objects and many more), and helps in finding the critical and inflection points of graphs' functions, and many more.

Mathematica provides students with an easy and effective dynamic access to multiple representations of derivative concept. There are three representations of the derivative, namely the formal definition of the derivative (algebraic representation), the instantaneous rate of change (numeric representation), and the slope of a tangent line (graphical representation). The ease of use and animation features of Mathematica provide students with an environment of discovery, experimentation, identifying patterns, generating and testing conjectures, and visualizing multiple representation of the derivative concept in ways that were impossible by using white board and pencil (Shatila, Habre, & Osta, 2016).

Practicing derivative problems in all of its representations contributes to mathematical reflection, making suitable decisions, organizing the numerical data, and identifying patterns and reasoning, which all considered being some of the problem solving skills. Problem solving is considered to be the most needed mathematical ability for students to challenge the daily life of decision making. Therefore students should be empowered with mathematical problem solving skills, through the development of mathematical knowledge (mathematical language skills, algebraic symbolic, numerical facts, algorithms of calculations, and solutions strategies).

STATEMENT OF THE PROBLEM

Calculus 1 at the Jordan University of science and Technology (JUST) has been taught by lecturing as in most of universities. Lecturing strategy is teacher- center method, which can't meet students' pursuit of verification, exploration and visualization. This leads students to face difficulties in derivative problem solving, by focusing at the final answer without taking solution strategy in consideration, to imitate the teacher or the textbook work only. Students tend to show their works in an inappropriate and unorganized way, taking long time in derivative problem solving, resulting in low success rate in calculus 1 which leads to high failing rates in later courses that have calculus 1 as prerequisite course.

Using technology to teach calculus 1 is almost none existing in Jordan Universities according to the experience of the researcher. Technology could improve mathematics teaching, increases students' performance and reinforces the students' problem solving skills (Hsiao, Lin, Chen &Peng, 2018; Al-Khateeb, 2018 & Radovic, Marvic & Passey, 2019). Therefore, it is necessary to change lecturing strategies to adopt technology to refocus the teaching learning process into students, creating the wanted student-centric approach, and to comply with constructivist theorem which states that for student to learn mathematics he or she must be actively involved in the construction of one's own knowledge rather than passively receiving knowledge.
This study examines how Mathematica impact students' problem solving skills of the derivative and its applications. The study addresses the following primary question: "What is the effect of utilizing Mathematica in improving the students' problem solving skills of derivative and its applications?", which yields the following research question:
Is there a difference between JUST students' means performance on the problem solving test according to teaching strategy?

PURPOSES OF THE STUDY

The purpose of this study is to develop innovative approaches for Jordanian Universities in using technology solutions through commercially available tools such as Mathematica, which provides supporting resources for both the instructor and the student.
The study suggests Mathematica as a tool for teaching approach of Calculus 1 at Jordanian Universities, which the study approves that it will enhance understanding of the derivative concept in multiple representations, supporting students and teachers solving derivative and its applications problems. Additionally, utilizing Mathematica in the teaching approach improves students' engagement and concept retention by exploring more dynamic, hands-on, learning environment.

SIGNIFICANCE OF THE STUDY

This study will help students with methods to develop high-quality static and dynamic two dimensional graphics. Moreover, the student computational efficiency will be improved and enriched with deeper understanding of calculus concepts, resulting in a noticeable improvement in problem solving skills. By interacting with Mathematica, the student benefits from the wealth of the information that the software provides for calculus teaching, especially in teaching derivative and its applications. It will help the instructor to be able to improve learning-teaching collage processes, through implementing methods which helps students to become more active leaner. Furthermore, it is possible that the tools of this study and the developed computerized education material will be used in future research outside or inside of Jordan.

REVIEW OF THE LITERATURE

Engineering mathematics lab module using Mathematica was developed by Logheswary, Nopiah, Zakaria, Aziz and Samah. The lab module consists of course outcome from three different subjects namely, vector calculus, linear algebra and differential equations. The lab module was developed to aid the teaching of engineering mathematics. The module was developed using the Rasch Model analysis in the preliminary test for vector calculus, linear algebra and differential equations. Logheswary et al., approved that Mathematica captures students' interest in learning engineering mathematics as it is less time-consuming in solving mathematical problems.
Parrot and Leong study aimed to investigate the impact of graphing calculator on students' problem solving success in solving linear equation problems. A quasi-experimental control and experimental group using the pre-test and post-test design was used to test the study's hypotheses. A sample size of 1,500 10^{th} grade students participated in this study. Experimental group received problem solving

based instruction using the graphing calculator while the other control group learned using the traditional approach. Results from the study show a significant difference in the mean scores between the two groups; the experimental group students performed better in the problem solving tasks compared to students of control group. A questionnaire that was used to obtain students' attitude toward problem solving in mathematics revealed that students who use graphing calculator have a better attitude toward problem solving in mathematics.

The purpose of Ardic and Isleyen (2018) study was to explore the effect of teaching mathematics by using CAS on the secondary education students' achievement in Turkey. The participants of the study consisted of (145) 10th grade students, distributed into control group and experimental group. The results showed that the achievement of the experimental group is higher than the achievement of the control group. Experimental group lessons had been carried out through CAS's (such as Mathematica) at high levels. The activities in experimental group have a strong effect on the students' achievement in the parabola lessons.

In reviewing the literature within the Arabic countries context, the researcher could not identify any previous work utilizing Mathematica in teaching calculus for 1st year university students. Therefore, this paper aims to improve Jordanian universities students' proficiency in problem solving skills by teaching derivative and its applications, the study was characterized from others by developing the computerized educational materials by using Mathematica, testing the students problem solving skills and achievement, and bridging a gap in the literature.

METHODOLOGY

A quasi-experimental design was used in this study to meet its nature and question, to achieve the goals of the study. The experiment was applied on Calculus 1 students at the Jordan University of Science and Technology. 50 students sample size were used. The sample was split into 2 groups; experimental and control group each of (25) students.

The experiment design consisted of computerized educational materials using Mathematica and the problem solving test. The computerized educational materials and the problem solving test was judged by experts to insure its validity. Those two instruments of the experiment design were:

1. **The Computerized Educational Materials**. Materials have been designed to motivate students towards learning derivative and its applications, support students in solving complex textbook problems and comparing it with hand solving, and explore derivative and its applications concepts through visualization, experimentation, multiple representations and seeing the connections between various calculus concepts. The use of CAS enhanced students' motivation to learning mathematics (Abdel Majid, Hunetite, al-Naafa & Balachandran, 2012), since it is become easy for students to observing of noticeable and meaningful patterns of information.

   Mathematica shift emphasis from manipulative skills to fundamental calculus ideas. It communicates mathematical ideas using a single screen that includes explanatory text, formulas, pictures, outputs and graphics by Mathematica commands. It improves students' engagement and concept retention by exploring core mathematical ideas.

   As an example, the student can use the Mathematica's command to trail derivatives of different composition functions to comprehend the rule of derivative of the composition function. Figure 1 shows the composition function of Sine(g(x)), allowing the student to observe the output from different inputs by trial.

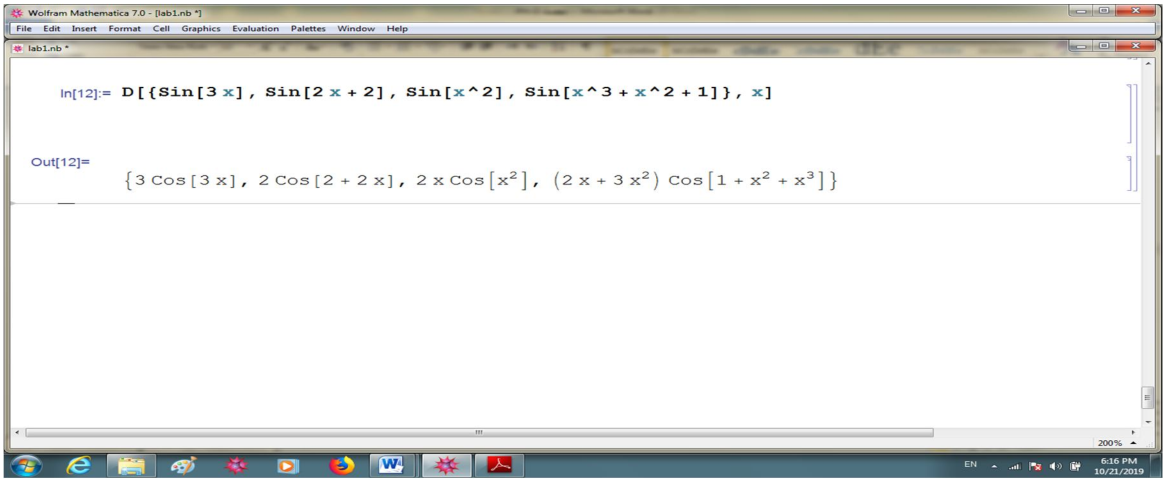

Figure 1: Mathematica generated screen for exploring patterns through experimentation.

Mathematica can also support students understanding of different mathematical concepts by presenting these concepts in visualization of static and dynamic graphs of functions or interactive environment. For example, the instructor can utilize Mathematica in the class room to teach the concepts of the slope of the tangent line at specific point by exploring easily different combinations until the slope of secant line approaching the tangent line, making it easy for the both the instructor to explain the concept and the student to understand it. This technique is demonstrated in Figure 2, which shows the tangent line iterations for a quadratic function. The same idea is also explored in Figure 3, which shows various secant lines possibilities for the same function in the same graph. Figure 4 presents the same concept, allowing the student to interactively use the curser to modify the variable (h) in the definition of the slope tangent line to comprehend the mathematical concept of the tangent line. In this way Mathematica allowed a better teaching-learning environment in the class room.

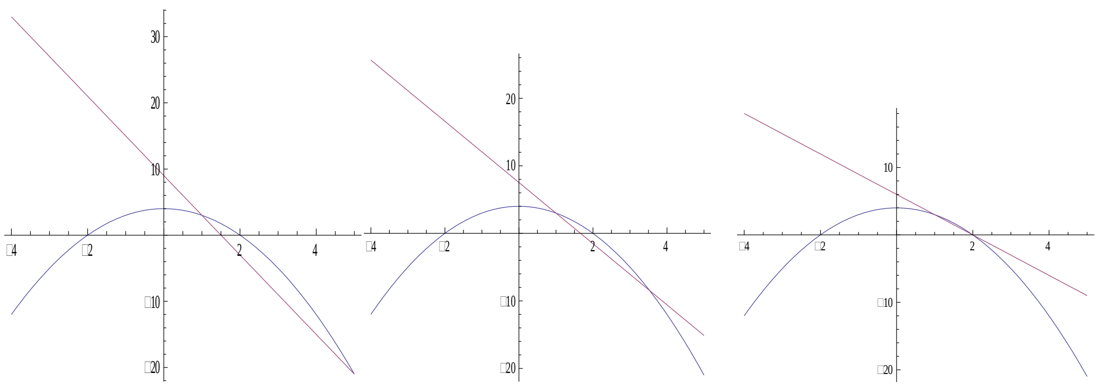

Figure 2: Mathematica generated multiple graphs to illustrate the concept of slope of the tangent line at x = 1.

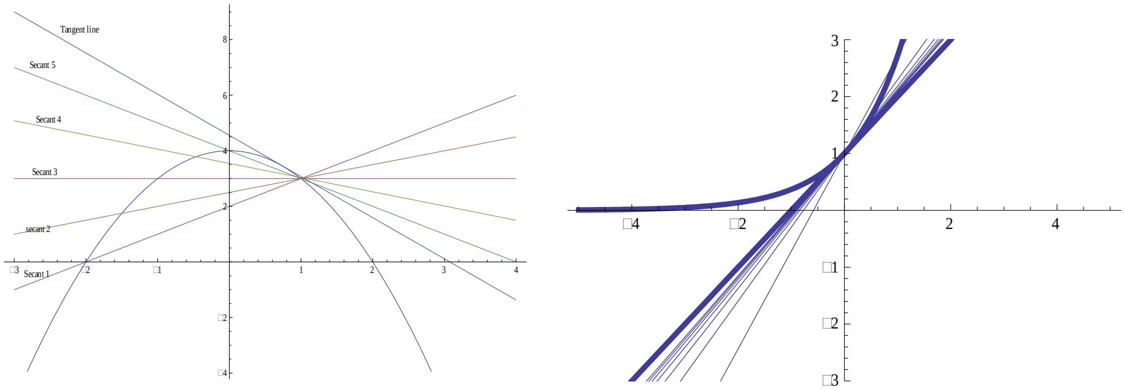

Figure 3: Mathematica generated graphs to show the secants lines approaching to tangent line at x =1 in quadratic function and at x = 0 in the exponential function.

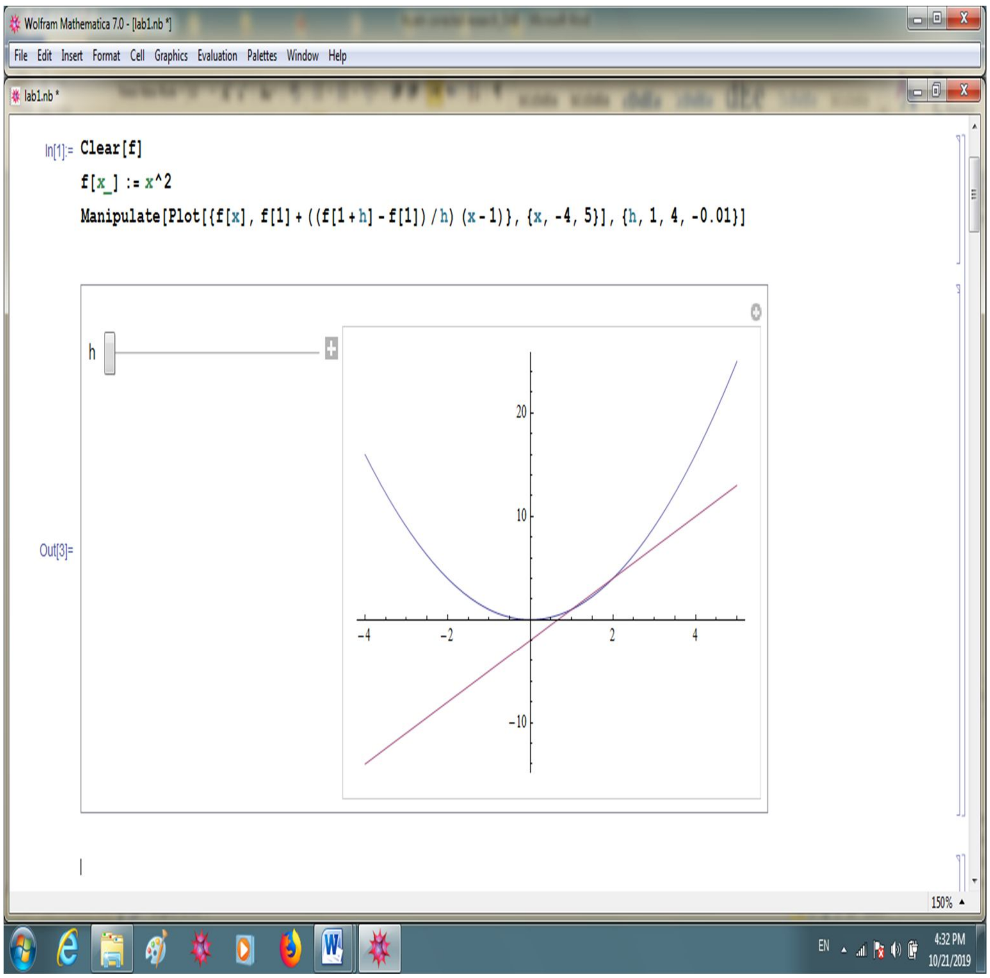

Figure 4: Mathematica generated interactive dynamic screen to illustrate the slope tangent idea by manipulating the algebraic form.

Additionally, Mathematica can enrich the learning-teaching process by showing the properties of the function graphs. For example, extrema and inflection points of function can be shown graphically on the screen as demonstrated in Figure 5.

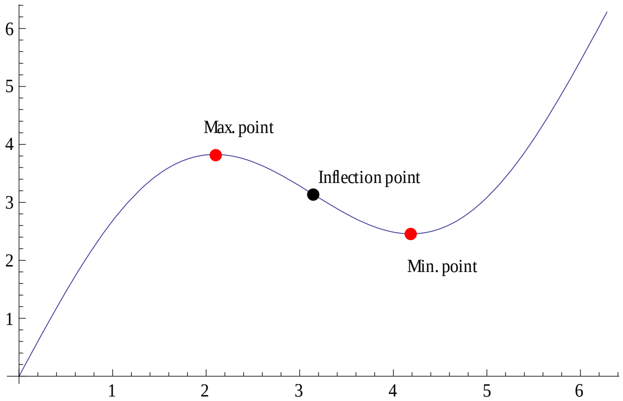

Figure 5: Mathematica generated the graph of **(f(x)=x+2sin(x))** illustrating some extrema points and inflection point (Maximum point at x = 2, Minimum point at x = 4, and Inflection point at x = 3)

Calculus 1 students in Jordanian universities are usually capable of solving the limit of a function by manipulating algebraic representation of the limit. However, the student generally finds difficulty to connect between different representations of the limit concepts. Instructor can use Mathematica to demonstrate such complex concepts to the students in the class room. For example Mathematica can find the limit algebraically as shown in Figure 6. It also can generate the limit graphically as shown in Figure 7, and numerically as shown in Figure 8.

```
Limit[(x^2 - 4) / (x - 2), x → 2]

4

Limit[(D[x^2 - 4, x]) / (D[x - 2, x]), x → 2]
4
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Figure 6: Mathematica showing limit of a function algebraically and using L’hopital rule

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Plot[(x^2 - 4) / (x - 2), {x, -4, 4}]
```

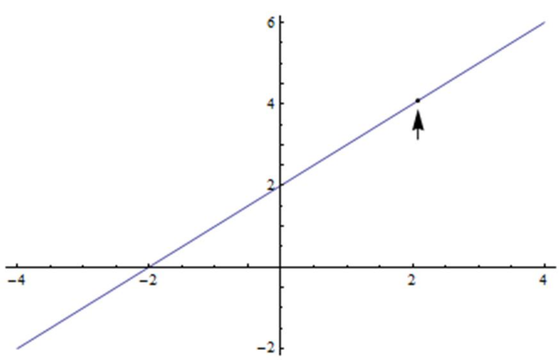


Figure 7: Mathematica showing limit of a function graphically

```
Table[f[x], {x, 1.9, 1.999999999999, .01}]
Table[f[x], {x, 2.1, 2.000000000001, -.01}]


{3.61, 3.6481, 3.6864, 3.7249, 3.7636, 3.8025, 3.8416, 3.8809, 3.9204, 3.9601}

{4.41, 4.3681, 4.3264, 4.2849, 4.2436, 4.2025, 4.1616, 4.1209, 4.0804, 4.0401}
```

Figure 8: Mathematica showing limit of a function numerically.

Traditional calculation methods performed with pencil and paper can be verified by Mathematica. However Mathematica does not provide the detailed steps of the solution for the basic level users such as the Calculus 1 students. As a support tool, students and instructors can use on line platforms such as Walfram/Alpha which is an easy to use platform providing detailed steps for any mathematical problem. As an example, Figure 9 shows detailed steps for calculating derivative of x^4 sin x

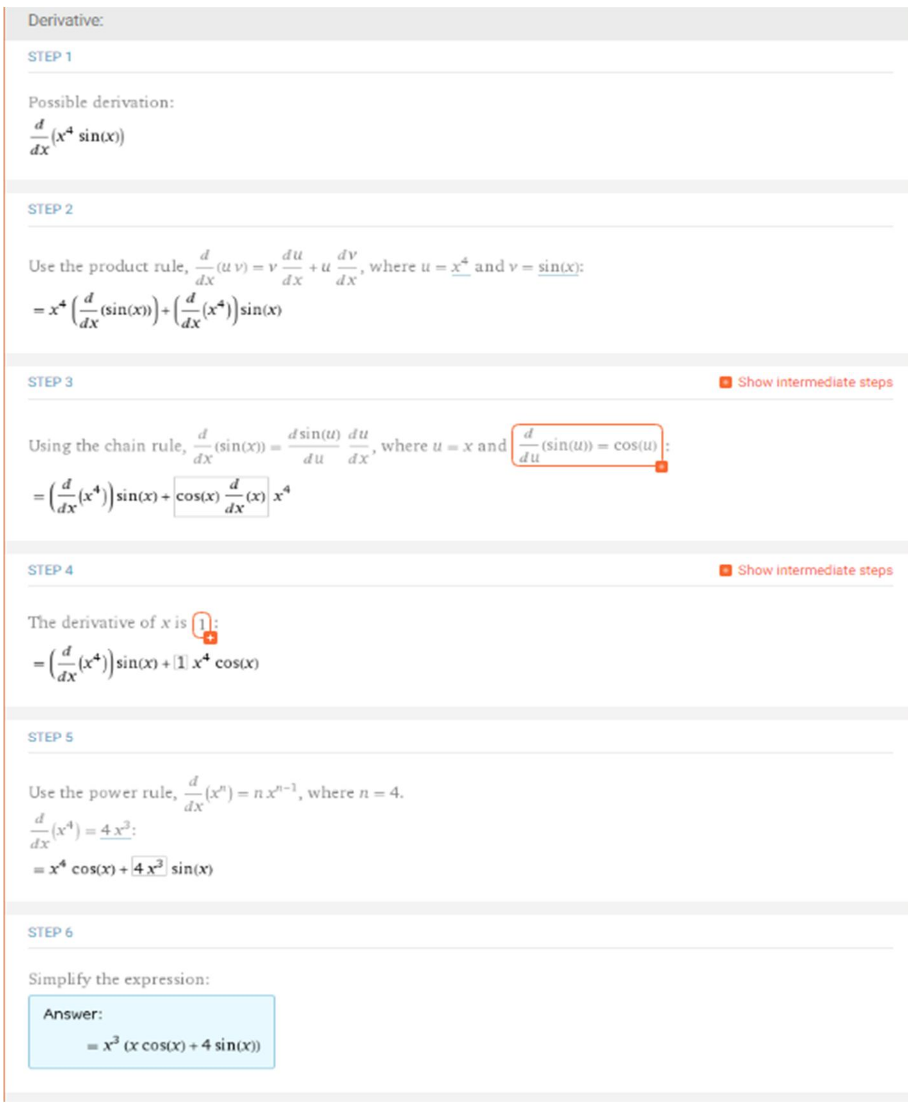


Figure 9: Detailed solution steps example from Wolfram/Alpha platform.

Once the material was developed as discussed above, teaching for the derivative and its applications was conducted for the 2 student groups, using the computerized education materials for the experimental group. The control group was taught using the traditional methods.

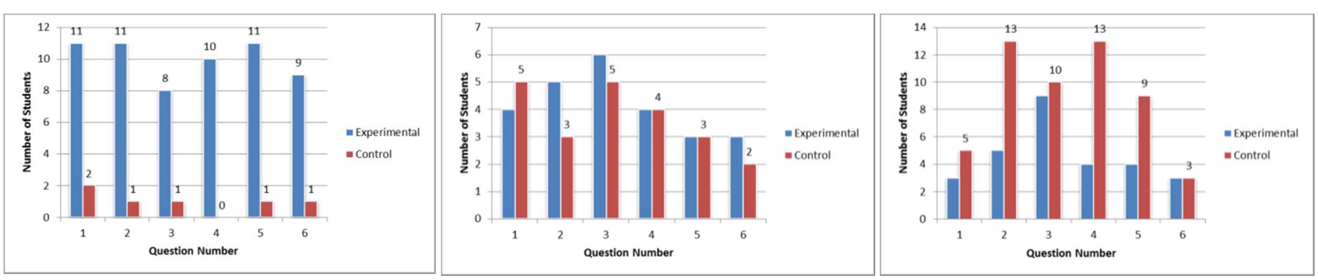
2. **Problem Solving Test**. After reviewing the available problem-solving tests about the derivative and its applications in the literature and the Calculus by Antone (textbook used in Jordan University of science and technology), a six derivative problems test exam was developed, and reviewed by experts from the university. The sample groups (experimental and control groups) were tested. The test assesses the student's ability to move back and forth between the different representations of derivative concept. Question 1 tests the student ability to obtain the graph of the derivative by using the graph of its function. Question 2 tests the student's ability to look for patterns to find the nth derivative of a function. Question 3 tests the student's knowledge in finding the limit by connecting its idea with the definition of the derivative. Question 4 tests the student's skills in finding the limit by using the L'hopital rule. Question 5 asks the student to give the appropriate reasoning for investigating for a given problem. Question 6 requests the student to use the graph of derivative of a function to get the graph for the original function.
Students in both groups had not solved in class any question similar to the ones found on the test. Once the teaching of the derivative and its applications was conducted for both groups, a one-hour problem-solving test above was performed by both groups.

FINDING AND DISCUSSION

The problem solving test was scored for the 50 students. The scoring was conducted based on the rubric form, designed by the researcher. The analysis of the results was primarily to answer the following research question:

Is there a difference between JUST students' means performance on the problem solving test according to teaching strategy?

To answer the above question, the students' answers in the problem solving test were analyzed and compared. Each question of the test has a weight of 5 points, summing to a total of 30 points for a full mark answers. An initial analysis of the student's marks was conducted. The answers of the students who scored above or equal 3 in each question was plotted to show the differences between the groups for the passing (above 50%) answers. As demonstrated in Figure 10 below, more experimental group students scored 5 or 4 out of 5 in all questions than the control group students.



Student Scored 5 points (full mark) | Students scored 4 out of 5 | Students scored 3 out of 5

Figure 10: Analysis of students' scores in problem solving tests for marks 3, 4 and 5 out of 5.

To better understand the results of the test, statistical analysis using SPSS software was conducted. The results revealed that the mean score of the experimental group is greater than the mean score of the control group, as shown in Table 1 below.

Table 1: Means and Standard Deviation of the Students' responses for problem solving test according to teaching group

Group	Mean	Std. Deviation	Sample Size (N)
Experimental group	21.6	6.0	25
Control group	14.7	4.6	25
Combined Groups	**18.1**	**6.4**	**50**

To investigate whether there is a significant difference in the mean scores related to the teaching method between the two groups, ANCOVA test was conducted. The results of the analysis revealed that there is a statistical significant difference in the means of the scores in favor of experimental group, Table 2.

Table 2: ANCOVA analysis was used to measure the mean scores for the student's responses according to method of teaching.

Source	Sum Of Squares	DF	Mean Square	F value	Sig.
Covariant (first exam)	72.7	1	72.7	2.6	0.112
Teaching Method	538.5	1	538.5	19.5	0.000
Error	1298.5	47	27.6		
Total	18466.0	50			
Corrected Total	1976.7	49			

There is a significance differences in the means of the students score in the problem solving test in favor of teaching method. This is resulted to the effectiveness of utilizing Mathematica in teachings. The corrected means and standard deviations for the scores are shown in table 3.

Table 3: Corrected means and standard errors for problem solving test according to group

Group	Mean	Std. Error
Experimental group	21.5	1.056
Control group	14.8	1.056

Table (3) shows the difference in means for both groups to the problem solving test in favor to experimental group compared to control group. The reason behind this is due to the positive effect of the computerized educational material using Mathematica.

This result is due to the computerized educational material using Mathematica, which offered rich, dynamic and interactive environment that deepened students' conceptual understanding of the derivative and its applications concepts. The researcher instilled in students' minds many key ideas of the derivative and its application concepts such as the slope of the tangent line on the graph of a function, the definition of the derivative in interactive screens, the relation between a function and its derivative graphs, the visual representations of the function and its derivative, and many more.

The use of Mathematica not just improved students' abilities to interpret graphs and make connection between the graph of a function and its derivative, but also motivate students' thinking in different ways to come up with innovative solutions for unusual and new problems involving the derivative and its applications as found in students' answers in the problem solving test from the experimental group, as shown in figure (11). It were found that students in the experimental group showed better abilities in handling unusual derivative problems than students in the control group. The experimental group student's work show more innovative, flexible and useful skills in their solutions for the problem solving test, and they were more comfortable working with different representations of the derivative concept than those of the control group.

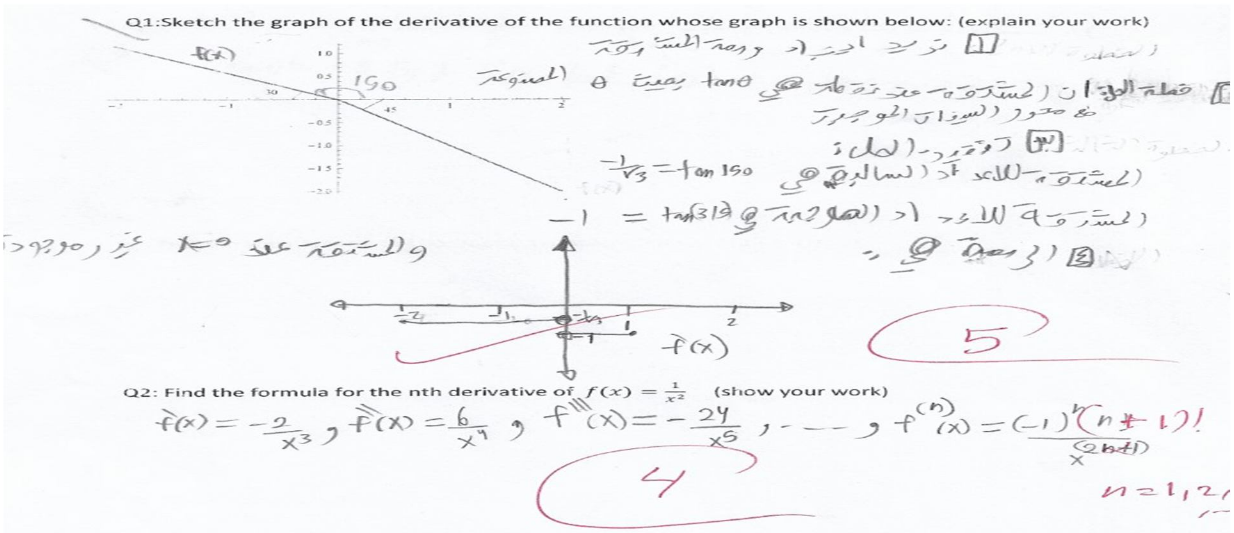


Figure 11: Sample from the experimantal group students' work for question 1 & 2.

On the other hand the students in the control group, see figure (12) as an example, revealed deficiencies in their understanding on the derivative and its applications concepts, and their thinking restricted to procedural symbolic representation, so some of them left the questions that involving graphing empty
with no attempt at all.

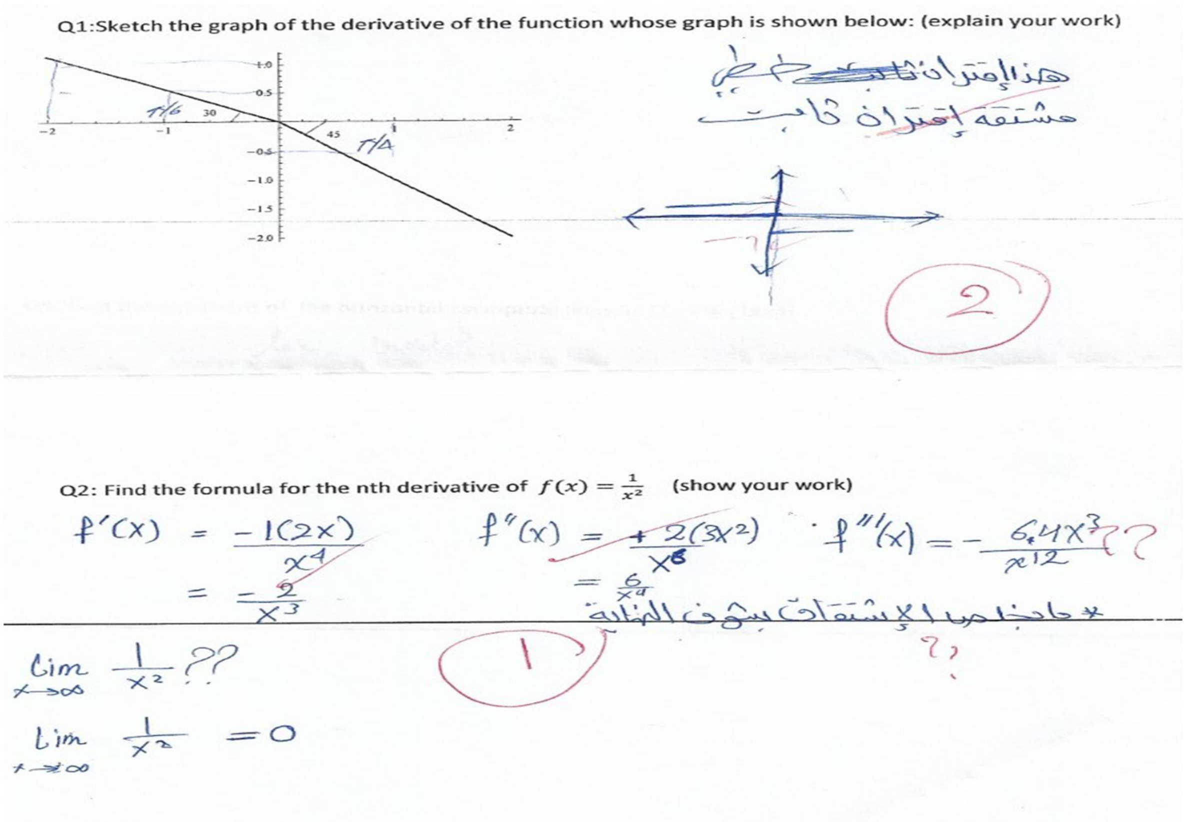


Figure 12: Sample from the control group students' work for question 1 & 2.

CONCLUSIONS

The results of this study demonstrated that the teaching method utilizing computerized educational material by using Mathematica, as in the experimental group, is more effective in developing student's problem solving skills of the derivative and its applications. This approach equips students with multiple representations of the derivative concepts which comes in handy when solving different context problems, and also motivate the students to think in critical and innovative ways. As an instructor, the researcher finds this approach easy, save time and effort, keep the students in focus, change the class-room into student-center one.

Consequently, this research advise that CAS tools should be utilized in teaching Calculus 1 for first year university students, as it allows the students to develop better understanding and helps the instructors in creating a better class environment using better course design.

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