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Use of math software Mathematica to learn to derivate multiple variables functions online

Uso de software matemático para aprender derivar funciones de varias variables en línea

Utilização de software matemático para aprender a derivar funções de várias variáveis online

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Abstract

Technological tools, teaching materials and students' acceptance are key aspects for online education at current times. The use of computer algebra systems (CAS) may improve students' perception about online learning as it offers an interactive environment where academic achievement could increase. Math software Wolfram Mathematica under its cloud version was studied for learning second semester multivariate calculus online. A quasi-experiment was conducted with control and experimental groups. Pre-tests were carried out to evaluate the similarity of groups prior treatment and post-tests to assess scores after students learnt derivatives in multivariable calculus. Two-sample t-test was used to determine how similar the means of the control and experimental groups were for pre and post-tests' scores. Experimental group scored significantly better than control group demonstrating the positive effect this software had on multivariate calculus learning. Students from experimental group answered a survey to evaluate in more detail the experience. Results indicate that math software should be implemented in calculus courses during online education.
Key words: math software, online learning, derivatives, multivariable calculus.

Resumen

Herramientas tecnológicas, materiales didácticos y aceptación estudiantil son aspectos clave para la educación en línea actualmente. El uso de sistemas algebraico computacionales (CAS) puede mejorar la percepción de los estudiantes del aprendizaje en línea, ya que ofrece un entorno interactivo donde el rendimiento académico puede mejorar. Se estudió el software matemático Wolfram Mathematica en su versión en la nube para el aprendizaje en línea de cálculo de varias variables de segundo semestre. Se realizó un cuasi-experimento con grupos control y experimental. Se realizaron pruebas pre-tratamiento para evaluar la similitud de los grupos y pruebas posteriores para evaluar las puntuaciones después de que los estudiantes aprendieron derivadas en cálculo multivariable. Se utilizó la prueba t de dos muestras para determinar qué tan similares eran las medias de los grupos de control y experimental para los puntajes de las pruebas previas y posteriores. El grupo experimental obtuvo un puntaje significativamente mejor que el grupo de control, lo que demuestra el efecto positivo que tuvo este software en el aprendizaje del cálculo multivariable. Los estudiantes del grupo experimental respondieron una encuesta para evaluar con más detalle la experiencia. Los resultados indican que el software matemático debe implementarse en los cursos de cálculo durante la educación en línea.

Palabras clave: software matemático, aprendizaje en línea, derivadas, cálculo de varias variables

Resumo

As ferramentas tecnológicas, os materiais didácticos e a aceitação dos estudantes são hoje aspectos fundamentais da educação em linha. A utilização de sistemas algébricos de computador (CAS) pode melhorar a percepção dos estudantes sobre a aprendizagem em linha, proporcionando um ambiente interactivo onde o desempenho académico pode ser melhorado. O software matemático Wolfram Mathematica na sua versão em nuvem foi estudado para a aprendizagem on-line do cálculo multivariável do segundo semestre. Foi realizada uma quase-experimentação com grupos de controlo e experimentação. Foram realizados pré-testes para avaliar a semelhança de grupos e pós-testes para avaliar as pontuações após os estudantes terem aprendido derivados em cálculo multivariável. Foi utilizado um teste t de duas amostras para determinar quão semelhantes eram os meios dos grupos de controlo e experimentais para as pontuações de pré e pós-teste. O grupo experimental teve uma pontuação significativamente melhor do que o grupo de controlo, demonstrando o efeito positivo que este software teve na aprendizagem do cálculo multivariável. Os estudantes do grupo experimental completaram um inquérito para avaliar melhor a

experiência. Os resultados indicam que o software matemático deve ser implementado em cursos de cálculo durante o ensino em linha.
Palavras-chave: software matemático, aprendizagem em linha, derivados, cálculo multivariável

INTRODUCTION

During the 1990s, the invention of World Wide Web increased access to online learning for a wide range of disciplines (Harasim, 2000). Online courses and even academic degrees increased around the world as web sites and online community groups developed rapidly (Rajabalee & Santally, 2021). Although online education had been widely offered before, in 2020, COVID pandemic affected face-to-face education forcing to convert several courses to online learning as schools and universities were forced to close to avoid physical contact. Some schools and universities had to overcome many difficulties to implement this kind of education as ICTs had not been widely implemented prior the pandemic. Education innovation became necessary while access and engagement became key aspects. In some cases, this sudden introduction of online education introduced numerous barriers like insufficient connectivity, lack of confidence, lack of experience with technological tools, financial problems to acquire technological devices and lack of a proper physical space free of noise and distractions (Abuhammad, 2020; Mailizar et al., 2020; Zaharah et al., 2020). During the pandemic, some institutions taught solely online while others used a combination of face-to-face and online education. In some cases, institutions which had returned to physical classrooms had to convert online again depending on the number of people infected with COVID 19. In some schools and universities, the so-called new normality limited face-to-face education and some courses have stayed online or shifted to hybrid modality. This pandemic forced education to be delivered in flexible ways combining face-to-face and online learning (Lockee, 2021). Traditional learning is evolving into digital and intelligent. Education must adapt to a new normalized environment after the pandemic and be able to adapt when new emergencies happen again (Dong et al., 2022). Learning math online can be complex and some students may feel that it is best learnt with face-to-face interaction (Mukuka et al., 2021). The use of math software may improve students' perception about online learning as it offers an interactive environment and where academic achievement could increase.

Learning mathematics is compulsory for many higher education programs (Akugizibwe & Ahn, 2020). Learning math for university students is important because they are required to reason, think creatively, gather information, communicate ideas and test these ideas critically. Math taught in engineering courses usually include single variable calculus, multivariate calculus and differential equations. Some students find calculus difficult because their mathematical knowledge is not strong enough; consequently, lecturers are required to use a wide range of interactive activities to accomplish the expected learning outcomes of calculus (Carbonell et al., 2012). In multivariable calculus, several variables' functions are derived and used to determine directional derivatives, gradients, tangent and normal planes, among others. Operating multivariable functions can represent great complexity for some students as they find complicated to migrate to the two or three variable world and represent functions in 3 dimensions (Kashefi et al., 2010).
Learning derivatives can be complex and software can aid students to increase their understanding through interactive and dynamic activities while handling complex graphs (Caligaris et al., 2015). Since the 80s, when computer algebra systems (CAS) emerged, software's efficiency had been debated and studied. Rapid changes in ICT, new software and updated versions of existing software promotes to continue with this research (Sevimli, 2016). Computer-based tools can strengthen mathematical thinking an generate an appropriate environment to overcome difficulties in calculus courses (Kashefi et al., 2012). There is a wide range of software for mathematics. Computer algebra systems like Mathematica, Derive, Matlab and Maple are proprietary packages while Maxima, Octave and SageMath are free software. Dynamic geometry software (DGS) includes Geogebra, Geometer's Sketchpad and Cabri Geometry (Ayub et al., 2012; Fluck et al., 2020). In addition, Wolfram Research offers Wolfram Alpha which is a web service browser with potential to replace or complement CAS (Dimiceli et al., 2010). For statistics, computer programs like SPSS and R stand out for education, research and commercial use (Akugizibwe & Ahn, 2020). Technology offers tools to improve math understanding, making necessary to assess their effectiveness on academic achievement and students' perception (Arbain & Shukor, 2015). Mathematica software was chosen for this research because it has a cloud version and provides students an experience where coding and programming skills are developed, which is desired for undergraduate engineering students.

Mathematica software is widely used for symbolic calculation, handling data, solving math problems numerically and symbolically, modelling and simulating phenomena, among others (Ayub et al., 2012; Zotos, 2007). This computer program has been constantly changing to adapt to technological advances and currently offers desktop, cloud and mobile version. New changes have produced new research with new article and book publications. Barba-Guaman et al. (2018) demonstrated through interviews and scores' comparison how Wolfram Mathematica aids students to improve calculus interpretation. A quasi experiment with control and experimental groups was performed, but a statistical test was not performed to analyzed differences between mean scores. Results indicated that this software aided theoretical abstraction and made classes more interesting and less difficult. Baist et al. (2020)studied the effect of Mathematica on learning outcomes for a vector algebra course for control and experimental groups. Scores of pre and post tests were analyzed with normality Saphiro-Wilk and with Mann Whitney test to determine if they are significantly different between groups. They concluded that students' achievement increased with the use of Mathematica and that this software aided to improve self-regulated activities. As Jordanian universities usually lack the use of CAS for math teaching, Hiyam et al. (2019) evaluated Mathematica and Wolfram Alpha for teaching derivatives with satisfactory results as students from the experimental group scored better than control group. Means and standard deviation were analyzed with an ANCOVA analysis of covariance. This software created a dynamic environment, helped to understand theory through graphical representation and motivated students to propose innovative solutions. Hiyam et al. (2019) used the same software with a similar methodology than the one used for this study for a face-to-face single variable calculus course while the current study focuses on multivariate calculus taught online. There is evidence that math software contributes to improve learning outcomes and academic achievement; however, there is the need to determine specific software for specific math areas for online education.

This study implemented Mathematica software using its cloud version for online multivariate calculus classes to improve students' mathematical thinking trough better visualization, interactivity and problem posing. Previous research evaluated under different methodologies the benefits of using Mathematica software mainly in computer laboratories during face-to-face education; however, Mathematica's effect on academic achievement has not been evaluated under a quasi-experimental methodology for multivariate calculus for online education.

MATERIALS AND METHODS

The methodology used is a quasi-experiment with experimental and control groups. Cohen (2017) states that this method is widely used in educational research when participants cannot be randomly chosen. This methodology had been used before by some studies (Adelabu et al., 2022; Arbain & Shukor, 2015; Hiyam et al., 2019; Takači et al., 2015; Yimer & Oromia, 2022). Pre and post tests were applied to control and experimental groups to assess academic achievement and evaluate the effectiveness of using Mathematica. Literature rpeview and learning difficulties faced by students in previous years influenced the topics selected for applying Mathematica. The selected topics for second semester multivariable calculus are partial derivatives, directional derivatives and gradient. The null hypotheses related to this study are the following:ç

1. *There is no significant difference ($p>0.05$) between average grades of pre-test for control and experimental groups.*
2. *There is no significant difference ($p>0.05$) between average grades of post-test for control and experimental groups*.

The main researcher taught both courses and had previous training in Mathematica. Students at their homes accessed Mathematica as Wolfram Cloud on their computers or mobile devices. Research process and instruments used in this work are shown in Table 1. Experimental group had sessions with Wolfram Cloud while control group participated of Zoom sessions without this tool. A pre-test was applied to control and experimental groups. Experimental group had complimentary sessions with Wolfram Cloud. First, it was necessary to introduce the software to students and teach them how to access and use it. After the treatment, students of both groups participated in a post-test with similar difficulty as the pre-test. Two sample t-test was performed to determine if there is a significant difference between the two groups. After treatment, experimental group answered a survey to evaluate the perception of the contribution of the CAS to their learning process.

Table 1. *Research process and instruments*

Groups	*Pre-observation tool*	*Process*	*Post-observation tool*
Control	*Pre-test*	*Taught with traditional methodology without software*	*Post-test*
Experimental	*Pre-test*	*Taught with Mathematica software*	*Post-test, survey*

Participants

This work was performed at "Universidad Estatal Peninsula de Santa Elena", Ecuador. Undergraduate computer engineering students were selected for this study. A total of 59 students from second semester participated in this research. This research took place during online multivariate calculus. Table 2 presents number, gender and average age of students who participated in this research. For experimental group (30 students), 10 students (33%) accessed Mathematica through Wolfram Cloud using a computer and 20 students (67%) used mobile version of Wolfram Cloud.

Table 1. *Students who participated in this research*

	Number	*Female*	*Male*	*Average Age*
Control Group	*29*	*9 (31%)*	*20 (69%)*	*22*
Experimental Group	*30*	*10 (33%)*	*20 (67%)*	*23*

Data Collection

Data for analyzing academic achievement was collected by pre and post-test applied to control and experimental groups. Tests were prepared by researchers analyzing syllabus content, problems included in calculus books and Putnam exam materials. Post and pre-tests had similar difficulty. Tests had 10 multiple choice questions. Other math teachers from other careers from the same university reviewed the tests and their suggestions were included. Test's reliability was determined calculating Cronbach's Alpha coefficient which value was 0.85.

The survey to assess students' perception of using Mathematica was elaborated with 10-item using Likert scale. This questionnaire was prepared according to this research objectives and analyzing studies for other math software. A small group of students answered a pilot survey. The entire experimental group answered the survey published in the university's learning management system. Questions were written in Spanish and translated into English for this publication.

Data analysis

Results were analyzed using MINITAB v19 statistical software. Descriptive statistics were applied to detect difference in pre and post-tests' scores. A normality test was performed using Shapiro-Wilk method. Two-sample t-test was used to determine how similar the means of the control and experimental groups were for pre and post-tests' scores. Questionnaires were tabulated and analyzed under descriptive statics to determine minimum, maximum, mean and standard deviation values once Likert scale was converted to the following numerical scale:

1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree

Teaching Materials

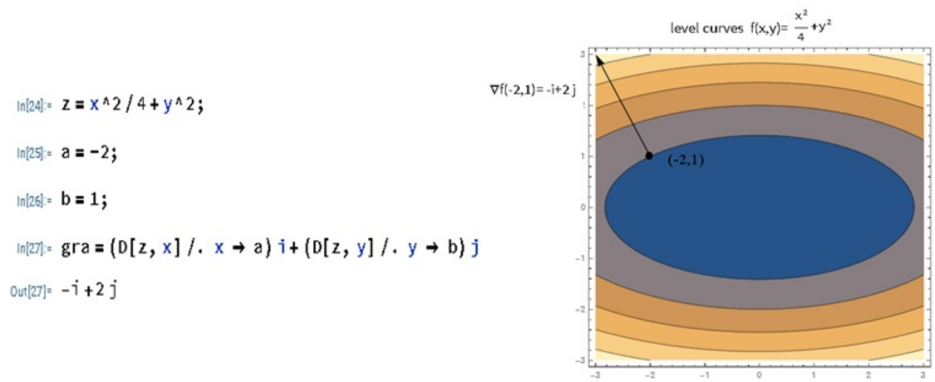
Some teaching materials used on the course were elaborated by the teacher and others were retrieved from Mathematica software help, Wolfram Demonstration Project and open course "Introduction to Calculus" offered by Wolfram U. The selected materials contributed to reach learning outcomes and involved the most important topics of multivariate calculus. Self-elaborated materials included animated power point slides and Mathematica notebooks. The following is an example of the materials elaborated by the researchers, originally written in Spanish, and later translated to English.

Multivariate calculus handles functions of more than one independent variable called functions of several variables. The gradient of a function of several variables $f(x,y)$ is the vector calculated by:

$$\nabla f(x,y) = f_x(x,y)i + f_y(x,y)j \tag{1}$$

Where $f_x(x,y)$ represents the partial derivative of $f(x,y)$ with respecto to x and $f_y(x,y)$ the partial derivative of $f(x,y)$ with respecto to y. For partial differentiation, a variable is set, and the others are considered constant. For instance, for $f(x,y)$, $\frac{\partial f}{\partial x}$ implies "x" is a variable; consequently, "y" is constant. The code presented in Fig. 1 finds the gradient of $f(x,y) = \frac{x^2}{4} + y^2$ at $(-2,1)$ calculating the partial derivatives. Using the command ContourPlot this graph is obtained.

Figure 1. Gradient of a function at a given point



RESULTS

Before applying the treatment, it is necessary to evaluate students' prior knowledge with a pre-test, so later the improvement can be evaluated for both groups. Pre-test results will also aid to determine if experimental and control groups have similar prior knowledge. Table 3 shows results of the t-test performed to pre-test grades for control and experimental groups. The null hypothesis for this test is: *H_0: There is no significant difference ($p>0.05$) between average grades of pre-test for control and experimental groups.*

Since p is greater than 0.05, the null hypothesis is accepted, and it can be stated that there is no statistically significant difference between control and experimental group, so treatment can be applied as control and experimental groups are similar.

Table 3. *Results of independent t-test on pre-test scores*

Group	*N*	*Mean*	*Std. Deviation*	*T*	*P*
Control	*29*	*1.52*	*1.88*	*-0.37*	*0.714*
Experimental	*30*	*1.70*	*1.93*		

A post-test was carried out after the experimental group learnt using Mathematica on their computers or mobile devices and control group were taught without this software. Results of the t-test applied to the scores of the post-test for both groups are displayed in Table 4. The null hypothesis for this test is:

H_0: There is no significant difference ($p>0.05$) between average grades of post-test for control and experimental groups.

As it can be observed, p value is less than 0.05, so null hypothesis is rejected, and alternative hypothesis accepted. This means that there is a significant difference between academic achievement of control and experimental groups. Comparing mean values, we notice that mean for experimental group is 2.23 higher, which implies that academic achievement of experimental group is better than control group. Therefore, it has been demonstrated that the use Mathematica during online classes has a positive effect on students' achievement. This result is consistent with works performed by Baist et al. and Hiyam et al. (2019) which concluded that Mathematica software increased academic achievement as means for control and experimental groups differ considerably.

Table 2. *Results of independent t-test on post-test scores*

Group	*N*	*Mean*	*Std. Deviation*	*T*	*P*
Control	*29*	*5.47*	*1.93*	*-3.96*	*0.000*
Experimental	*30*	*7.70*	*2.39*		

Experimental group answered a questionnaire to evaluate the use of Mathematica or Wolfram Cloud during online classes and its results are presented in Table 5. Most of the questions have an average higher than 4, where 1 corresponds to strongly disagree and 5 to strongly agree. The question with the least score is the one which states that Mathematica offers the same experience in mobile devices as computers. This may be attributed to the way menus are presented in the mobile application.

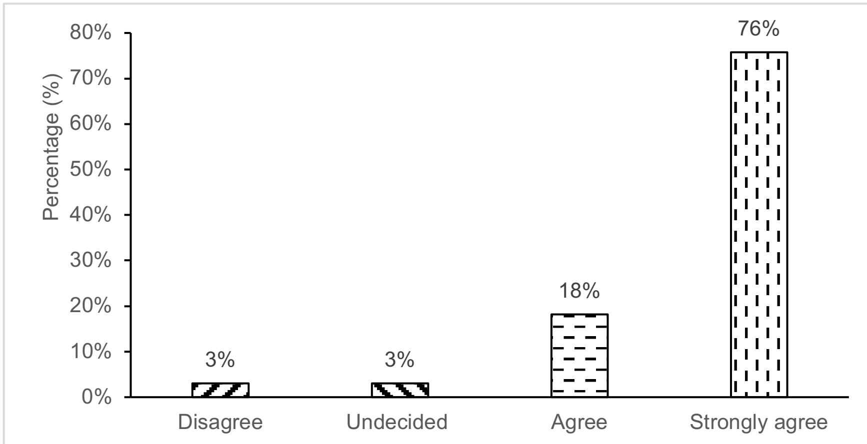
Table 3. *results of the survey for control group*

Question	*Minimum*	*Maximum*	*Mean*	*Standard Deviation*
After using Mathematica, I believe it is useful for learning calculus.	*2*	*5*	*4,424*	*0,792*
I feel confident that Mathematica has aided me to reach permanent learning.	*3*	*5*	*4,424*	*0,663*

I think that Mathematica makes calculus classes more interactive.	*3*	*5*	*4,636*	*0,603*
Mathematica has aided me for better visualization of functions	*3*	*5*	*4,727*	*0,517*
I believe that Mathematica should continue to be used for math classes during online classes	*2*	*5*	*4,667*	*0,692*
Mathematica has helped me in problem posing	*3*	*5*	*4,606*	*0,556*
I enjoyed programming math problems in Mathematica	*3*	*5*	*4,606*	*0,659*
Mathematica's mobile app allowed me to have the same experience as in the computer	*2*	*5*	*3,758*	*1.032*

When schools and universities were forced to close face-to-face education and to convert to online, there was uncertainty of how this will affect education and which tools may be used during online courses. Students replied positively when enquired about using this software to aid the transition to online learning and to improve education. Students' responses to the questionnaire showed that they liked and enjoyed using Mathematica as this software generates an interactive environment and increases their programming knowledge. Students feel confident that this software has allowed them to reach permanent learning; however, further research is required as delayed post-test were not performed. Students recommend this software for online and face-to-face classes (Table 5 and Fig. 2) as mathematics becomes more interesting, more exercises can be solved, and learning is interactive and auto-regulated.

Figure 2. The percentage of students who think Mathematica should continue to be used for online education



Every student considered Mathematica useful for learning calculus online and many enjoyed using it. Calculus classes with this computer program became more dynamic and some concepts related to derivatives easier to understand which is aligned with Mathematica's previous studies (Barba-Guaman et al., 2018; Hiyam et al., 2019). Plotting graphs helped students to understand faster partial derivatives, directional derivatives and gradients. Visual representation was useful in multivariable calculus as 3D graphs and contour plots may be difficult and time consuming to do by hand. Students using math software may increase their knowledge about ICT applied to education and programming.

CONCLUSIONS

This study used a quasi-experiment to assess the effect that Mathematica had during an online multivariate calculus course. Computers and smartphones were used to access online Mathematica as Wolfram Could. Based on the results of independent t-tests performed to students' scores, it can be stated that this software through its cloud version aided students of second semester to increase their academic achievement when compared to control group. Students' perceptions of the software gathered by surveys were positive and suggest that Mathematica should continue to be used during online learning as this software allows a meaningful learning in an interactive environment. Visual representation was particularly useful for multivariate calculus as some 3D plotting could become very difficult to be performed by hand. Students felt enthusiastic about programming for a math course as programming is essential for their engineering studies. The new normality after SARS-CoV-2 suggests that classes will not be the same anymore. Online and hybrid education will continue to be extensively implemented as some universities lack infrastructure to maintain biosecurity measures and online access to education may be more convenient for people who cannot attend in-person courses.

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