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Research Article

Teaching and learning the fundamental of calculus through Python-based coding

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The use of modern information and communication technology (ICT) tools in the teaching of mathematics and science are vigorously supported across the world, particularly in emerging countries where digital technology penetration rates are quickly increasing. The use of python programming, which has the potential to visualize abstract mathematical concepts dynamically, will assist instructors in elucidating calculus concepts that could not previously be delineated using traditional teaching methods. From this perspective, this study was conducted to ascertain the effectiveness of python-based coding on fundamental of calculus on grade eleven students in one of the higher secondary school in western Bhutan. In the study, the pre-test and post-test control group quasi-experimental design was used. The participants of the study consisted of 60 students (28 in experiment group and 32 in control group). Python-based Coding instructional units prepared by the researchers were administered to the children in the experiment group while the students in the control group received the traditional lecture strategy. CUTFC was administered to students both in the experimental and control group as pre-test and post-test. Data was collected by using CUTFC questionnaires. Results of the study showed that there is no significant difference between experimental and control group in the pre-test, whereas a significant difference in favor of the experimental group was observed in the post-test. Therefore, it was determined that the coding activities have a significant effect on students' understanding on fundamental of calculus.

Keywords: Python coding, Fundamental of calculus, Learning outcome

1. Introduction

In the fourth industrial revolution (IR 4.0), where data is transferred through the internet of things and, cloud computing to enable intelligent automation utilizing artificial intelligence (cognitive computing), ICT will have a greater influence (Balanskat & Engelhardt,2015). It is the integration of new technologies such as IOT (Internet of Things), Big Data, and AI (Artificial Intelligence) into the areas of the economy, society, science, and education in order to achieve rapid productivity improvements (Shim & Shim, 2018). All these technologies are the result of coding. Coding is the process of creating a program by listing codes (computer language), and it is used in the same sense as programming (Kim et al.,2019).In other words, making a program using a computer language is called coding, and teaching an algorithm to make a program is coding education (Kim et al., 2019).

Coding Education in Australia, United States, United Kingdom, Finland, South Korea, China, New Zealand, Singapore, and China have all prioritized it by including it in their educational curricula at all levels (Wu et al., 2019). In France, basic coding and mathematics were taught as interdisciplinary because of their shared conceptual connection (Misfeldt & Duun, 2015). Finland, China, and Singapore have changed their national standards and curricula to provide a greater emphasis on higher-order thinking, inquiry, innovation, and creativity, as well as the integration of technology in teaching and learning (Wu et al., 2019).

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The education systems of the aforementioned countries, who have consistently performed well on PISA, have embraced emerging technologies that will meaningfully and effectively educate their children with required 21st century skills for the era of IR 4.

In the era of the fourth industrialization, the cross-pollination of mathematics and coding emerged as core interests in education (Kim et al., 2018). Integration of coding with other disciplines, particularly mathematics, not only enhances students' grasp of the topic, but it also helps in the development of 21st century abilities such as computational thinking, problem solving, creative thinking, critical thinking, and decision making (Meehan, 2019). It has been experimentally demonstrated that the integration of coding unit in grade, 5th and 7th social studies significantly improved 21st century skills while also accelerating students’ enthusiasm and motivation (Von Wangenheim et al., 2017).

According to previous studies, mathematics, in general, and calculus in particular, are taught in silos, with no relation to other subjects (Kado & Dem, 2020). For decades, the predominant method of calculus teaching has been the traditional strategy of teaching in silos, focused on rote memorization of rules and symbolic manipulation. Teachers often focused more on the computational procedures rather than promoting comprehension of underlying concepts. Consequently, students developed the skills of manipulating algebraically, understanding instrumentally and memorizing the formulae instead of comprehending conceptual or relational proficiencies. This traditional approach failed to develop the conceptual understanding in calculus (Kado & Dem, 2020, 2021). Moreover, the numerous reports, such as Education in Bhutan: Findings from Bhutan’s experience in PISA for Development (Bhutan Council of School Examination and Assessment [BCSEA], 2019), National Education Assessment have shown that the majority of Bhutanese students do not meet the minimum in educational standard in all the subjects with highest variation in mathematics and science.

Unlike the traditional approach of teaching calculus in silos, the 21st century approach to teaching and learning, which includes powerful web 2.0 tools and an interdisciplinary approach using coding, provides a platform for mathematics educators to teach abstract and complex mathematics concepts innovatively. Korkmaz (2016) investigated the effect of the scratch and Lego Mindstorms Ev3-Based programming activities on academic achievement, problem-solving skills, and logical mathematical thinking skills of students by employing a semi-experimental, pre-test and post-test study of 75 students. The finding demonstrated that educational programs based on scratch, enhance students’ logical and mathematical thinking abilities as compared to the Lego Mindstorms Ev3 design and traditional teaching activities. Meehan (2019) also conducted a study based on a mixed-method approach with a group of 20 fifth grade students to examine the effects of coding integration on student engagement and academic achievement. Their findings revealed that there was a significant impact on students' engagement, and perceptions of mathematics and academic achievement are improved significantly.

It has been experimentally demonstrated that programming with Scratch Jr. software significantly enhances grade 6th students’ mathematics achievement, but no substantial improvement was revealed among second grade students (Moreno Leon et., 2016). However, the author suggested that there is still a great deal of work to be done to ascertain the effect of programming on students’ mathematics achievement. Moreover, there is less academic discourse in Bhutanese contexts. Hence, this study is set out to examine the effectiveness of coding on students’ achievement in calculus.

1.1. ICT in Bhutanese Education System

With the advent of ICSE Computer Studies in a few high schools in the late 1990s, ICT was introduced into the Bhutanese educational system. In the early 2000s, the Ministry of Health and Education began promoting ICT education. Eight high schools began offering computer application as an optional topic in class IX in 2002, and it has now extended to other high schools with computer labs (Lhendup, 2020).One of the significant achievement in ICT education in Bhutan was the institution of the Chiphen Rigphel Project, supervised by the Ministry of Information and Communications and NIIT India. The project created computer labs in 168 schools, developed an ICT literacy curriculum for all students in grades 7 through 12, and trained over 5,000 teachers in basic ICT skills (Lhendup, 2020). Subsequently, the Ministry of Education (MOE), upon the recommendation of the e-Gov Master Plan 2012, embarked on the drafting of ICT Master Plan iSherig-1 and 2 to harness the potential benefits of ICT in teaching and learning with the introduction of ICT literacy from class IV, from the 2017 academic session, with some component of coding education (Ministry of Education [MOE], 2019).

Recognizing the necessity to confront IR 4.0, as well as His Majesty's vision of producing globally competent citizens through persuasive use of emerging technology, the government emphasized integration of ICT in education in the 12th FYP. Through the flagship project, MOE initiated ICT education a mandatory subject for students in grades PP through XII, with an emphasis on coding. In order to prepare for the introduction of coding education, the MOE worked with REC and the Department of Information and Technology (DIIT) to educate 277 instructors in block and script coding with technical assistance from Leap Learners (Lhendup, 2020). The flag initiative also aims to enhance STEM education by incorporating ICT into the curriculum with the rationale to make teaching and learning mathematics and science more exciting. Thus, the interdisciplinary approach of integrating coding in mathematics and science was emphasized to enhance students' performance in STEM.

2. Research Methods

This study employed the quantitative research design in one of the higher secondary school in western Bhutan. A pretest and posttest control group quasi experimental research design was employed in this study. 60 grade eleven students who were involved in this study were divided into two groups: a control group (N=32) and an experimental group (N=28).The control group was taught using a conventional lecture method while the experimental group was taught using a python as a tool for teaching and learning fundamental of calculus.

2.1. Intervention Strategy

An experimental group was taught with python as tool for teaching and learning calculus. The concepts of the limit of a function, derivative and integral are visualized graphically using the python (see Figure 1, 2, and 3).

Figure 1

Graphical Visualization of limit of function

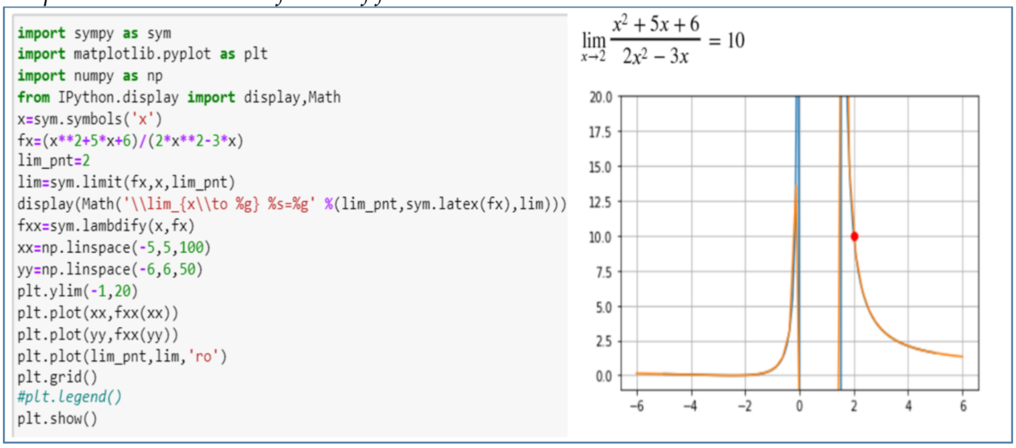


Figure 2

Graphical Visualization of Derivative

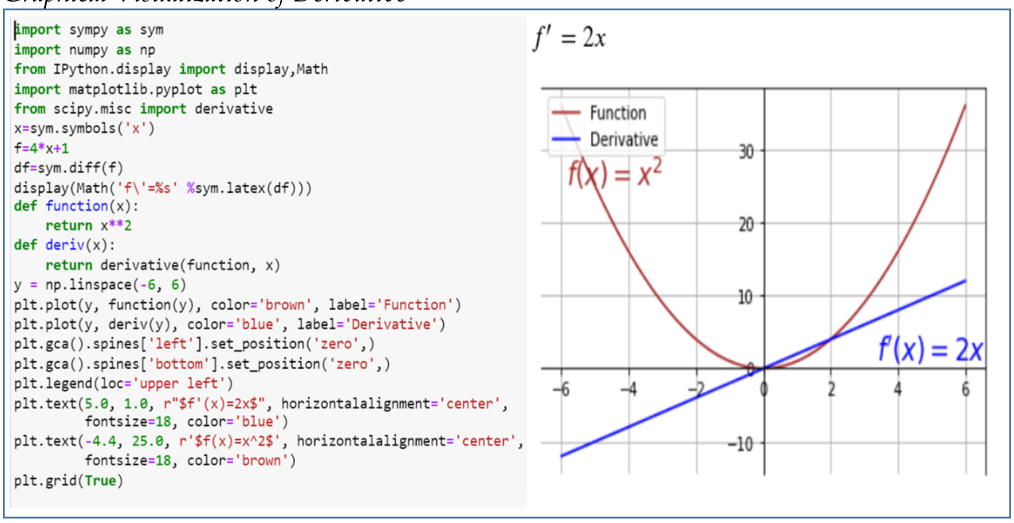
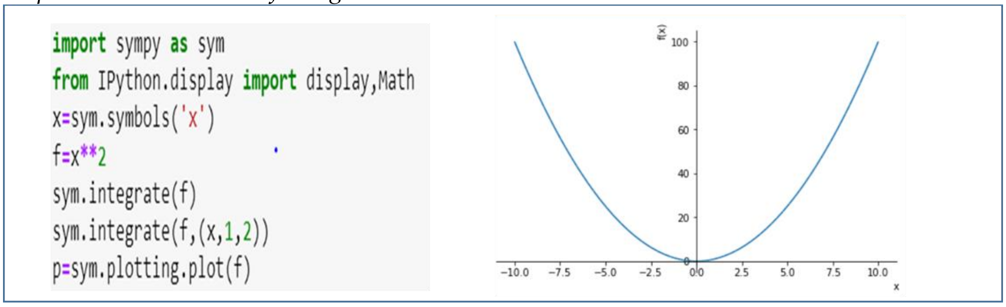


Figure 3
Graphical Visualization of Integral



2.2. Research Group

This research employed a non-probability convenience sampling approach. This method would provide the researcher the freedom to choose participants based on similar attributes (Tongco, 2007) or availability at a specific moment owing to geographical closeness and accessibility (Etikan, 2016). Since the concept of fundamental of calculus is introduced in the eleventh grade of the Bhutanese curriculum, this study involved 60 grade eleven students, studying in one of the higher secondary school in western Bhutan.

2.3. Research Instruments

Both instructional and research tools were employed in this study. The instructional tools included a lesson plan prepared using python. The conceptual understanding test on the fundamental of calculus (CUTF) was used as the main research instrument to examine the students' understanding on fundamental of calculus. The CUTF which consisted of 20 questions, modified from BHSEC Mathematics Book-I for Bhutanese Class XI students (Malhotra et al., 2011). A respondent who gave the correct answer to an item received one point, where as a null or incorrect response received zero point.

2.4. Validity and Reliability of Instruments

A content validation was done by determining the Item-Object Congruence (Rovinelli & Hambleton, 1976) and all the items having an IOC index > 0.80 were accepted during the pilot study (N=30) conducted in 2020 (Kado & Nem,2020), and later implemented to another 28 grade eleven students in one of the middle secondary schools in western Bhutan (Kado et al.,2021). The reliability coefficient (Cronbach's alpha) obtained was 0.768 indicating that the items were favorable and reliable for the implementation (Tavakol & Dennick, 2011).

2.5. Data Collection

Before data collection, the administrative and ethical procedures were strictly followed to get approval to conduct the study with participants from the school action research committee. After getting an approval, informed consent were sought from all the respondents of the study. Privacy and confidentiality were also assured and maintained. Prior to the intervention, both the experimental and control groups conducted a 60-minute pretest using the CUTFC questionnaire. After the pre-test, the experimental group was given a python-based instructional unit on the fundamentals of calculus was implemented for 220 minutes. For the control group, the same concept of fundamental of calculus was delivered using a conventional lecture method for the same duration. Both the groups were then administered with the post-test that comprised of 20 questions. The control group was taught the same concept utilizing the traditional lecture style for the same amount of time. Both the groups were administered with the post-test that consist of 20 questions.

2.6. Data Analysis

T-tests were used to assess the data gathered. To compare the learning outcomes on the idea of fundamental calculus for the experimental group that was taught using Python coding and the control group that was taught using a traditional lecture approach, the means of the pretest and posttest for both groups were computed.

3. Results

Before conducting the inferential *t-test*, the normality test were conducted using Kolmogorov-Smironov test as shown in the Table 1.The findings of Kolmogorov-Smironov analysis for the degree of normality assumptions was satisfied for both pre-posttest of EG and CG ($p > 0.05$). Additionally Levene's test for equality of variances of scores for two groups (EG& CG) were conducted as shown in Table 2.

Table 1
Komogorov-Smironov Normality Test

Groups	*N*	*Kolmogorov-Smirnov Z*	*Sig. (2-tailed)*
Pretest-EG	28	.978	.294
Posttest-EG	28	.944	.335
Pretest-CG	32	.986	.285
Posttest-CG	32	1.406	.038

Note: Significant level: >0.05—no significant, <0.05—significant

Table 2
Levene's Test for Equality of Variances

		F	*df*	*Sig.*
Pre-test	Equal variance assumed	0.151	52	0.700
	Equal variance not assumed		51.05	
	Equal variance assumed	1.116	52	0.296
Post-test	Equal variance not assumed		50.23	

Note: Significant level: >0.05—no significant, <0.05—significant

The Levene's test indicated that the assumption of homogeneity of variance for both pre-test was met as p value is greater than 0.05 ($F(1,52) = 0.151, p = 0.70$) .Moreover, the variation of post-test scores for both the groups was met as p-value is more than 0.05 ($F(1,52) = 1.116, p = 0.296$). Thus, the assumption of homogeneity of variances were met for both the groups.

3.1. Comparison of pre-test and post-test scores of Experimental and Control Group

An independent sample t-test was conducted to determine the difference in scores between the experimental and control group as shown in the Table 3.

Table 3
Independent Sample t-test

Test	*Group*	*Mean*	*Mean Difference*	*SD*	*p*	*Effect Size*
Pre-test	Control	10.20	2.38	4.00	0.026	0.006
	Experimental	12.59		3.56		
Post-test	Control	10.63	4.38	4.70	0.001	0.91
	Experimental	15.52		3.90		

An independent- samples t-test was conducted to compare the pre-test scores for EG and CG. There was so significant difference in scores for pre-test for Experimental ($M = 12.59, SD = 3.56$) and Control group, $M = 10.20, SD = 4.00$); $t(2.88) = 52, p = 0.026$ (two-tailed). The magnitude of the differences in the means ($MD = 0.391, 95\%: -3.147$ to 2.366) was very small ($\eta^2 = 0.006$). This means that the data were homogeneous and treatment could be applied to these groups to identify differences caused by the treatment.

An independent sample t-test conducted for comparison of post-test scores between experimental and control group showed significant mean difference between EG ($M = 15.52, SD = 3.9$) and CG (M $= 10.63, SD = 4.70$); $t(3.710) = 50.23, p = 0.001$ (two-tailed). The magnitude of the differences in the means (mean difference= 4.389,95% CI: 2.013 to 6.765) was very high ($\eta^2 = 0.91$). This indicates that there was a statistically significant difference in post-test scores between experimental and control group. The test scores of an experimental group were significantly higher than the test scores of the control group. Furthermore, the standard deviation of the experimental group ($SD = 3.90$) is lower than that of the control group ($SD = 4.90$), showing that students in the experimental group consistently perform better than students in the control group.

4. Discussion and Conclusion

This study was conducted to ascertain the effectiveness of the python coding on teaching the concept of fundamental of calculus for grade eleven students of one of the higher secondary school in western Bhutan. The findings of the study revealed that the mean score of posttest for the experimental group where the concept of the fundamental of calculus was taught using a python coding was comparatively higher than the mean score of the control group that was taught using a conventional strategy. This difference in the mean score establishes that the python coding had a significant effect on enhancing the learning achievements for the students on the concept of the fundamental of calculus. Thus, the statistically significant difference between the posttest scores was due to the intervention and not due to chance.

The impact of having a higher mean score for the experimental group as compared to the control group may be explained due to interdisciplinary approach of teaching calculus instead of teaching in silos. Sevimli and Unal (2022) reinforced this by stating that utilizing coding to teach mathematics through STEM education is more effective than using other engineering designs and materials. This approach helps students to understand the abstract concepts relationally, as they can easily visualize the specific concepts dynamically on screen. The use of digital educational media aids in the acquisition of a distinct understanding of mathematics (Calder, 2018; Gadanidis, 2015). On other hand, such useful interdisciplinary approach to facilitate the mathematics learning process were disadvantaged for the students in the control group that was taught using a conventional lecture method.

The traditional lecture-based chalk and teaching, which facilitates passive acquisition of knowledge, might have failed to offer some level of curiosity and stimulation to participate in the construction of knowledge as compared to python-based coding instruction. In this study, the students in experimental groups were observed learning the concepts of the fundamental of calculus dynamically using the coding, which enabled to develop the comprehensive understanding of the concepts. The use of demonstrative tools facilitate the conceptual understanding of fundamental of calculus as these tools have the potential to blend the calculus concepts with their external representation (Koskinen & Pitkaniemi, 2022). The use of digital tools and programs, when used well, positively contributed to development of problem-solving skills & learning outcomes as students engaged in common activities (Washmi et al., 2014). In short, this study established that the python based coding instruction was an effective intervention strategy for teaching the fundamental of calculus. Such positive effects of the coding on enhancing the students' understanding of the fundamental of the calculus were also reported in many previous studies such as Misfeldt and Duun (2015), Lee and Sung (2017), Lee and Choi-Koh, 2018,and Folgieri et al. (2019).

During the pretest, there was no statistically significant difference between the mean scores of the experimental and control groups, however, after the posttest, however, both the experimental and control groups showed a statistically significant difference. This findings was in keeping with the study by Iskrenovic and Momcilovic (2020) conducted with 106 third grade elementary students. The students' achievement in studying the geometry for both the groups were same at first, but after using scratch as pedagogical tools for teaching the geometry concepts, the achievement of students were observed in favor of the experimental group. A similar study by Calao et al. (2015) found that using scratch as pedagogical tool resulted in a statistically significant rise in the mathematics test score of an experimental group.

The finding of significant differences in posttest scores of an experimental and control group shares the similarity with the claims of enhancing seventh grade students understanding of prime factorization in Korea due to treatment of coding teaching and learning materials using python (Koskinen & Pitkaniemi, 2022; Shim & Shim, 2018). The achievement test and follow-up interview on students' perceptions on convergence of mathematics and coding indicated favorable results, indicating the potential application of coding in mathematics teaching and learning. This study, though focused on conceptual understanding of fundamental of calculus using the python based coding, no direst relevant study Despite searching the necessary databases for teaching and learning fundamental of calculus using the python, no direct relevant research were found.

This study, designed and developed on the fundamentals of calculus using Python coding, attempted to determine the effect of Python coding in teaching and learning the fundamentals of calculus. Based on our finding, it was established that the Python-based coding significantly enhanced the students' understanding of the fundamentals of calculus more than the conventional lecture method. The students taught in the experimental group were exposed to activities designed using Python coding and emphasized visualizing the abstract concepts dynamically instead of rote memorization of rules and formulae.

4.1. Recommendation

The findings of this study shed lights on the effectiveness of python based coding as an digital pedagogy for teaching and learning fundamental of calculus relationally rather than through rote memorization, which is a cornerstone of traditional method. Though the research evidence restricts its generalization, it is congruent with literature in suggesting positive implication of the intervention strategy. Consequently, mathematics teachers might consider implementing a python based coding in teaching and learning the fundamental of calculus.

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