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Effective Teaching in Constructivism: A Case of Teaching Discrete Mathematics for Undergraduate Students

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Abstract

Looking for an effective teaching method to ensure better learning of students is a common and longstanding phenomenon. Several learning theories evolved over the course of time. The constructivist approach to teaching learning is often found as an effective one that runs in a student-centred environment where participatory and active learning is nurtured. In this case study, the constructivist approach was employed in teaching discrete mathematics to Bachelor of Computer Science and engineering students at a non-government university in Bangladesh. The study was quasi-experimental involving a non-probability convenient sampling technique. A total of 372 students were invited to attend pre- and post-tests in online mode on each of the 6 chapters throughout the four consecutive semesters. Attending each of the tests was not a mandatory requirement of the students for the course. Collected scores from the 12 tests were statistically analysed to draw a meaningful conclusion based on the discussions over the analyses of findings. Limitations, implications, and direction to future research are also brought up. The results of this study will help the institutional authority, teachers, and students to make an effective plan by adopting constructivist teaching learning not only for mathematics education but also for other similar subjects.

Keywords: *Constructivism; Effective teaching; Learning theory; Mathematics Education, Student-centred environment.*

1. Introduction

"Ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all" is the fourth of the Sustainable Development Goals called SDG 4 (United Nations, 2015). Previously, Millennium Development Goals targeted a wide quantity reach of education through its 'Education for All' campaign by 2015. Quality education is specifically emphasized in SDG 4. Quality in education comes through technological advancement and proper utilization of Information and Communication Technology (ICT) that are utilized in the effective teaching-learning processes (Das, 2021). Technology and pedagogy are the two challenging areas to ensure quality in education for better learning of students. These challenges are expected to be handled by the classroom teachers through their expertise in using technology and effective plans for technology integration (Tripathi, 2002). Teachers have an important role in ensuring effective student learning even in a student-centred learning environment. Education level is sometimes dynamic. For higher education, an article recognized effective educational practices by five clusters stated in the Annual Report 2007 of the National Survey of Students Engagement in the USA (NSSE, 2007):

(1) Active and collaborative learning
(2) Student interactions with faculty members
(3) Level of academic challenge
(4) Enriching educational experiences and
(5) Supportive campus environment (Vaughan, 2014).

Another dynamic taken into consideration for this study is the subject matter. Effective mathematics teaching is identified as a special skill. Having sufficient command in mathematics content, teachers need to organize their classroom environment and manage student behaviour in a way that sets the standards for effective learning (Ottmar *et al.*, 2015). There are many myths about mathematics teaching-learning from the students' and others' perspectives. Many theories have developed for ensuring effective learning that actually circles back to the appropriate teaching methods involving learning facilities and environments. Some challenges associated with classroom management and creating a positive social environment are reasonable that ultimately influence the instructional decisions of the teachers to impact students' learning (Cohen, 1996). The constructivist learning theory is used here in this study as a case of teaching discrete mathematics to the students in the Bachelor of Computer Science and engineering (BCSE) program. The

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aim of this case study was to investigate the performance improvement of the students for the subject of discrete mathematics in the approach of constructivist teaching learning. Through this study, the authors intended to formulate a meaningful conclusion based on the statistical findings that will be used by discrete mathematics teachers and students for effective learning in future.

The literature review section of this article summarises relevant texts on learning theories and effective student learning in the context of teaching discrete mathematics in higher education. The section next to the literature review is about the research methodology and data sample. That follows the findings from the statistical tests and then the discussion, which includes the limitations of the study and a set of recommendations. Finally, the article concludes.

2. Literature Review

As this study investigates effective learning in the approach of constructivism, the previous literary evidence on learning theories and effective student learning were examined focusing on teaching discrete mathematics.

2.1 Learning theories

Among several learning theories, there are three interrelated and sometimes overlapped theories about how we learn: a) behaviourist, b) cognitive and c) constructivism. (Celikoz *et al.*, 2019). Thorndike (1905), born in 1874, developed the stimulus and response theory in which animals and men received an incentive and then responded to it. Woodworth (1918) and Hull (1943) introduced the concept of the drive to motivate behaviour. Skinner (1938), born in 1904, placed great importance on recognizing the factors in the context that was responsible for a certain response in behaviour and the selective reinforcement was given due to that behaviour. It was explained by Tolman (1932) in his book titled *Purposive Behaviour in Animals and Men* how certain behaviour could be adapted according to the facts in the environment and its purpose. According to Tolman, there are three variables in the learning process: the environment, the individual and intervening. The environmental variable might be characterized the type of stimuli we receive, the individual variable by factors such as our age or previous education and the intervening as the cognitive process that intervenes between a stimulus and the response to that stimulus. Tolman is often credited as the first behaviourist to recognize a cognitive process.

Many theorists have put a greater emphasis on the cognitivism as a part of the learning process. Jean Piaget is greatly identified as a key person in course of developing the cognitive learning theory, which is also known as cognitive constructivism (Glasersfeld, 1974). According to Piaget (1964) knowledge is constructed by active learners on the basis of their existing cognitive structures. As a result, he challenged the behaviourists who exclusively focused on behaviour that could be finally measured. Piaget asserted that mental processes could be scientifically studied. He examined the mental process happens between a stimulus and the related response from which he found that the development stage of their previous learning would influence the next knowledge to be constructed (Philips, 1995). Several factors were found by him including attention, observation, perception, interpreting, organizing, memory categorizing and forming generalizations in the learning process.

Other constructivists found the development of the learner from cultural point of view was more critical in the process of learning. The theory developed by Lev Vygotsky (1978), known as the social constructivism, states that the learner builds new knowledge based on an interaction with their peers in the society.

Lastly, there is a third group of theorists known as radical constructivism for which Ernest (1994) is best known. Ernest found that a new knowledge is constructed based on some existing knowledge to help actively participate in the respective environment.

This study has coarsely adopted a constructivist approach towards learning theory in the sense that the students are viewed as responsible for evaluating their own current knowledge level in the process of actively constructing new knowledge having influenced by their previous knowledge and experiences including their subject related and mathematical background. Students are the focus of education in constructivist learning approaches and are expected to actively take part in learning. Technology has a significant role in constructivism, especially, when the students communicate new learning. Appropriate use of technology in teaching-learning provides a higher order learning environment to the students that attracts their attention, increases their motivation, and helps re-use the previously stored information (Asiksoy and Ozdamli, 2017). Recalling own existing knowledge, communicating with others, regenerating the knowledge, and sharing again are the repetitive steps in the way of learning. In the constructivist approach of teaching-learning, most people learn precisely in this same way (Bransford *et al.*, 2000).

2.2 Effective students' learning

Effective learning is a wide term in education. Many different parameters are involved in effective learning. Students' active participation under the constructivist approach is the key to ensuring effective learning where flipped classroom teaching is one of its successful implementation methods. The subject matter with necessary study materials is shared with the students before attending their classes. Students come prepared and participate in active learning that ensures significantly higher scores during students' performance evaluations. A flipped classroom structure allowed teachers and students focusing on the activities to cultivate creativity, think critically, solve problems by discovery, and communicate effectively during the class (Loyens *et al.*, 2008).

Constructivism involving technological advancement has made a paradigm shift in teaching-learning. This grand change has been in education from a didactic model of instruction to a constructivist model that emphasises more on active learning (Jong *et al.*, 2008). This paper discusses a pedagogical, or andragogical to be more precise, intervention designed to give undergraduate-level students an active role in their learning process. It is assumed that students' evaluation of their existing knowledge on a specific subject topic can enhance the effectiveness of the teaching discrete mathematics. Technology-enhanced teaching-learning plays a significant role in ensuring effective learning. In particular, the e-learning model used in constructivism (Reiser, 2001) recognizes the responsibility of learners in managing their own learning process. Effective communication among students and teachers is often crucial. Moreover, the necessary information is not supposedly be just transferred by the teacher to the student rather it is student-centred. Along with the physical and social environment, the technological interaction is actively configured by/for the students (Fosnot and Perry, 2005).

One holistic approach to the use of ICT in education was described by Ra, Chin, and Lim (2016) that consisted of 10 macro and micro level specifications of the national system of education. In the context of three South Asian countries including Bangladesh the suggested model was modified with 7 dimensions (Asian Development Bank, 2017): (i) national ICT in education vision, policies, and strategies, (ii) ICT infrastructure (information technology backbone and connectivity), (iii) professional development of teachers and education leaders, (iv) modernization of curriculum and teaching and learning resources, (v) improvements in the learning environment, (vi) improvements in assessment and examination, and (vii) improvements in education management information system (EMIS). This includes evaluation and research to inform evidence-based planning and resource allocation. This paper accepts that integrating technology into education was intended to create a meaningful educational experience for better learning of students through a transformative process with the potential to increase performance (Goh *et al.*, 2020). The intended focus of this paper is teaching mathematics in general and discrete mathematics in particular to BCSE students.

Many research articles identified various students' myths about mathematics learning at different levels of education. Interestingly, in undergraduate engineering programs, one article recognized that the students see mathematics as a very useful and an essential tool for the engineering profession only when it is used judiciously and sceptically. According to the same article, the students responded with their thoughts that they were unable to perform without mathematics. However, they recognized mathematics as subjective and fallible; not dominating but integrated with socio-economic, and other relevant matters in the context. As a language, Mathematics is mandatory for analysis and design by the engineers to justify the solutions obtained by other means (Gainsburg, 2015).

This paper aimed at utilizing the substances from relevant works of literature on constructivism learning theory, technological enhancement in students' learning, and effective learning of mathematics in the higher education setting. The next section describes the methodology and data collection of the study.

3. Methodology and Data

The methodology and data of the research are stated in the following sub-sections.

3.1 Research design

Under the quasi-experimental method, the one-group pre-test post-test research design is used for this study. The two scores, one obtained before the formal lecture in the classroom and the other after the classes taken for the same students studying BCSE, were taken into consideration. One experienced teacher conducted 37 to 40 classes, in face-to-face mode, for each section of students in every semester. The minimum number of classes to be conducted in a semester was 36. The design is theoretically recognized to have a number of internal validity concerns including history, maturation, testing, and instrumentation (Wiersma, 1995). However, it was used in the study as the design is well-accepted in educational research and suitable for the context of similar ones. Scores were compared on a one-to-one basis and analysed with their differences by using appropriate statistical tools. Statistical findings from central tendencies, t-tests, and correlation analyses by the groups on gender, semester, and chapter were discussed for formulating meaningful interpretations. For statistical analysis two software applications named SPSS and JASP were used.

3.2 Sample and data collection

The non-probability convenience sample was used in this study (Wiersma, 1995). The author decided to select the sections of students who were studying the course named discrete mathematics, as a mandatory requirement of completing their BCSE program, in the Summer 2021, Fall 2021, Spring 2022, and Summer 2022 semesters at a non-government university in Bangladesh. All students studying the course were invited to attend the pre-test and post-test on previously announced days. Each test was taken in online mode by using Google Form and the scores were collected online and automatically compiled by Google sheet. Each test was taken on a specific subject matter identified as a certain chapter in the course. There were six chapters considered in this study. The average time gap between the post-test and pre-test in the same chapter was ten days during which classes were formally taken in the environment of active students' participation. A total of 372 students were invited for attending each of the 12 tests taken on the 6 chapters. The chapters were: (1) Propositional Logic (2) Algorithm (3) Encryption (4) Combinatorics (5) Relational Algebra and (6) Graph Theory. Attending every test was not a mandatory requirement for the students in the course. They attended the tests as they voluntarily agreed to respond to the invitation. Table 1 shows the numerical details in the process of collecting data.

The numbers in Table 1 are the total respondents of two genders – male and female – from the four semesters mentioned earlier. The valid cases were considered for the same students who attended both pre-test and post-test by chapters.

Table 1: Summary of Data Collection

The number of students who responded in pre-tests and post-tests by chapters																	
Chapter 1			Chapter 2			Chapter 3			Chapter 4			Chapter 5			Chapter 6		
Pre	**Pst**	**Vld**	**Pre**	**Pst**	**Vld**	**Pre**	**Pst**	**Vld**	**Pre**	**Pst**	**Vld**	**Pre**	**Pst**	**Vld**	**Pre**	**Pst**	**Vld**
288	314	270	361	316	316	304	231	211	222	218	196	209	213	189	198	200	176

Note: 'Pre' means the no. of students who attended the pre-test, 'Pst' means the no. of students who attended the post-test, and 'Vld' means the no. of responses found valid in terms of both pre-test and post-test scores without any missing in either of the two tests.

Each test was taken on 10 marks with 10 questions of a mixture of the types, such as multiple-choice questions, true-false, fill-in-the-blank, short answer, and calculated answer. Every pre-test was set on the foundational knowledge of the subject topic. Most of the questions were lower-order questions in terms of the cognitive domain of Blooms Taxonomy. On the other hand, each post-test was set with very formal and in-depth questions covering at least middle order learning in the cognitive domain of Bloom's Taxonomy (Krathwohl, 2002).

3.3 Hypotheses

The following null hypotheses were made on the context:

H_01: There is no difference in students' scores between the pre-test and post-test.

$H_{0}2$: There is no difference in percentage increments between the scores obtained by the male and female students.

$H_{0}3$: There is no difference in chapter-wise paired scores between the pre-test and post-test.

$H_{0}4$: There is no influence on students' scores among chapters comparing pre- and post-scores.

4. Finding and Analysis

The descriptive statistical results on the whole set of data are shown in Table 2. The scores obtained by the students in the pre-tests and post-tests are used here along with the pair-wise percentage increment of the scores. The same data are also used for making the density plot distributions as shown in Fig. 1. The first two plots indicate inconsistent performance levels in the pre-test, which becomes a consistently growing trend in that of the post-test. The third plot shows the percentage increment in scores from -87% to 400% with one outlier of 900%. Negative increments are more frequent than the positive changes in post-test scores compared to pre-test scores. The paired samples t-test results were calculated to compare students' scores between the pre-test and post-test. The t-test result was significant, $t\ (1357) = -5.486,\ p < .001$. Thus, the null hypothesis *$H_{0}1$* was rejected.

The independent samples t-test results were calculated to compare students' percentage increments of the scores between males and females. The t-test was not significant, $t\ (1357) = 1.124,\ p = .261$. Thus, the null hypothesis *$H_{0}2$* was retained. Further, it was found that gender-wise pre-test and post-test scores are significantly and positively correlated in both male and female students. However, the results were weak in strength. The Pearson Correlation Analysis results were $r = .261$ for male (n=828) and $r = .271$ for female (n=530) at the 2-tailed significance level 0.01.

Table 2: Descriptive Statistics on the Data

	Pre-Score	**Post Score**	**%Increment**
Valid	1358	1358	1358
Mean	7.469	7.858	14.134
Std. Error of Mean	0.056	0.061	1.560
Std. Deviation	2.046	2.255	57.489
Minimum	1.000	1.000	-87.500
Maximum	10.000	10.000	900.000

Note: 'PreScore' is the variable used for the scores obtained in the pre-test, 'PostScore' means the scores obtained in the post-test, and '%increment' means the percentage increment of the scores from the pre-test to the post-test.

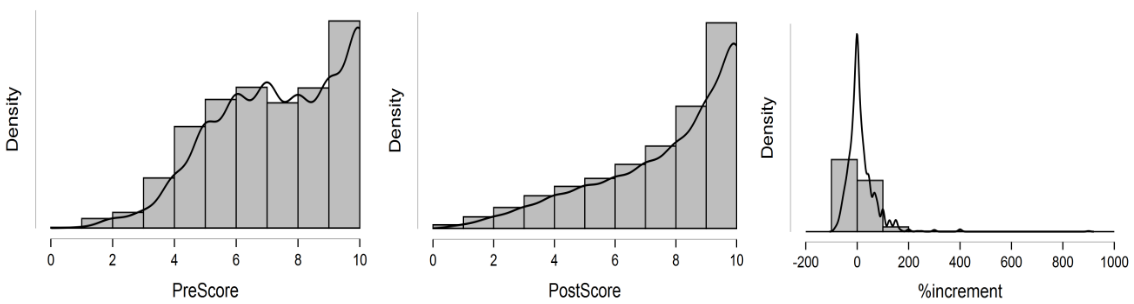

Fig.1: Density Plot Distribution of Pre-Score, Post Score, and %increment

Table 3: Significant Results of Chapter-wise Paired Samples t-Tests

Semester	Compared Pair	t	df
1	PreS1C1 - PostS1C1	4.039	61
	PreS1C3 - PostS1C3	-7.600	60
	PreS1C4 - PostS1C4	-5.053	63
	PreS1C5 - PostS1C5	-3.848	64
	PreS1C6 - PostS1C6	-3.180	66
2	PreS2C1 - PostS2C1	2.537	21
3	PreS3C4 - PostS3C4	-2.764	34
	PreS3C5 - PostS3C5	3.943	35
4	PreS4C1 - PostS4C1	-3.072	70
	PreS4C3 - PostS4C3	-2.642	80

Table 3 shows the chapter-wise paired samples t-tests results by semesters compared with the pre-test and post-test scores, which are found only significant at the 2-tailed significance level 0.01. The results shown in Table 3 confirm significant differences between the mean scores from pre-tests and post-tests on chapters 1, 3, 4, 5, and 6 in semester 1, chapter 1 in semester 2, chapters 4 and 5 in semester 3, and chapters 1 and 3 in semester 4. This rejected the hypothesis H_03.

Finally, the Pearson Correlation Analysis was done for identifying any influence of the pre-test scores on the percentage increments of students' performances. Table 4 shows the correlations results. All of the correlation coefficients, shown in Table 4, indicate negative relationships. Thus, hypothesis H_04 was rejected. In addition, many of them were strong.

5. Discussion, Limitation, and Implication

The descriptive results on the data indicated that the overall changes in pre-test and post-test scores were different. Interestingly most of the increments were negative. This was because of the different difficulty levels of the two tests as mentioned earlier. The pre-test scores came from the existing understanding level of the students on the chapter before formal teaching learning activities. In the constructivist approach, students actively participate in learning and this type of test helps them understand their own strengths. Specifically in mathematics teaching, a similar suggestion stated that incorporating a constructivist approach ensured better learning in contrast to direct teaching (Confrey *et al.*, 1990). In this study also, it was observed that the students were in the process of active learning and improved their subject knowledge in the respective chapters. Post-test scores did not increase in the same measurement scale, which ultimately made the negative increments. As a result, the first hypothesis H_01 was rejected. Therefore, the post-test scores were significantly different from the pre-test scores of the students. The consistent growth trend in the post-test scores confirmed the changes in the students' concepts on the subject achieved through the constructivist approach to teaching-learning.

As the second hypothesis H_02 was retained, it was found that percentage increments in students' performance were not significantly different between the two genders of the students: male and female. However, the comparison between the pre-test and post-test scores of the students separated by their gender showed that there were significant influences on the scores. In both gender groups, post-test scores were weakly and positively influenced by the scores in pre-tests. The authors could not uncover any previous research findings based on gender-wise performances in the constructivist teaching approach.

Paired samples t-test results confirmed the rejection of the third hypothesis H_03. That means the post-test scores were significantly different from the pre-test scores when pairwise compared by the chapters. In three semesters, out of four, the Propositional Logic (chapter 1) scores were significantly different. In two semesters, the Encryption (chapter 3) scores were different. In the other two semesters, the Combinatorics and Relational Algebra (chapters 4 and 5) scores were significantly different. In one semester, the Graph Theory (chapter 6) scores were significantly different. Scores of the remaining chapter Algorithm (chapter 2) were not significantly different in any of the four semesters. Without this exception, it is observed that in general the integration of students' activities in the learning process confirms better learning. In a previous study, students having an integrated view were motivated to make their own style of learning mathematics as they were not forced, as in their thoughts, to blindly follow the teacher (Gainsburg, 2015).

According to the findings from Pearson correlation analysis, almost all chapter-wise percentage increments were influenced by the respective pre-test scores. The only exception was Relational Algebra (chapter 5) in semester 3 for which the increment was not influenced by the pre-test. All negative correlation values came because of negative percentage increment values. In this case, the actual relationship between the increment and pre-test scores was direct. That means the influence of the scores in the pre-test was directly proportional to the percentage increment. Better pre-test scores in a subject topic led to better increment in the same and vice versa. The relationships were mostly moderate as the correlation coefficients were mostly around .5. The values of more than .75 indicated a strong relationship (Wiersma, 1995). As a result, the fourth hypothesis $H_0 4$ was rejected. Therefore, the percentage increments were positively influenced by the respective pre-test scores at moderate up to strong relationships.

Table 4: Correlation Results of Pre-Test Scores on Percentage Increments

Pre-Score	Result	Semester 1 %Increment	Semester 2 %Increment	Semester 3 %Increment	Semester 4 %Increment
PreS3C1	Pearson's r	-.683**	-.806**	-.703**	-.690**
	n	62	22	36	71
PreS3C2	Pearson's r	-.498**	-.455*	-.479**	-.451**
	n	71	28	44	87
PreS3C3	Pearson's r	-.733**	-.688**	-.636**	-.499**
	n	61	27	41	81
PreS3C4	Pearson's r	-.787**	-.576**	-.873**	-.512**
	n	64	23	35	72
PreS3C5	Pearson's r	-.737**	-.705**	-.018	-.690**
	n	65	23	36	65
PreS3C6	Pearson's r	-.805**	-.624**	-.507**	-.709**
	n	67	19	33	56

** Correlation is significant at the 0.01 level (2-tailed)

5.1 Limitations

The first limitation of this study was the standardization of the two tests by their difficulty levels. As the difference in the tests was obvious in the teaching plan, some curbing method for the scores could be planned for measuring the two test scores at the same measurement scale. Secondly, the scope of the study could be widened by incorporating more courses that could ensure more students' involvement in the learning process with the constructivist approach.

5.2 Practical implications

The authors of this study have finally formulated the set of recommendations for the concerned persons in the field of higher education teaching:

- The institutional authority should encourage the teachers and students to adopt the constructivist approach in higher education.
- Teachers should create a learning environment by incorporating various tools appropriate for constructivist teaching so that better learning is ensured.
- Students must be willing to adopt active learning through interactive teaching and method of self-performance assessment.

5.3 Direction to future research

This research is believed to be a strong base for proceeding with further research not only on the same course or subject. Research initiatives on other subjects can extensively benefit from this case study. Research on the same subject focus can be conducted with experimental design approach by employing a control group. However, the next research initiatives could be improved with the mentioned limitations taken into consideration.

6. Conclusion

This study employed the constructivist approach of teaching and learning in the case of teaching discrete mathematics to undergraduate-level students. Learning Management System (LMS) and necessary technological tools were used in the interactive and student-centred learning environment. The case study, conducted for 372 university students in Bangladesh, investigated the students' performance improvements in the mentioned teaching approach. The results found from this study can be supportive to improvement of the plan of teaching the same or similar subjects in higher education. Thence, this study can contribute to the related literature for further research and to the stakeholders for improving teaching and learning practices.

Author contributions

The study conceptualization, methodology, preparing instrument, data collection, data presentation and draft preparation of the article were performed by R. D. Das. Besides conceptualization and methodology, K. S. Uddin performed the software, data analysis, validation and editing the paper.

Conflict of interest

The authors declare no conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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