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An Empirical Study on Learning by Making as a STEM Pedagogy: The Case of Iot Module in Gyalpozhing College of Information Technology (GCIT)

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"When the sun sets every evening, we go to sleep in the comfort that it will rise in the morning and things will be the same. Do not however let the light of education ever go out. For if it should become dark, even for a moment, we will find that generations of our children will suffer its effects and the light on a bright future for our nation will take decades to shine again."
"Therefore, our generation has the sacred responsibility of radically rethinking our education system and transforming curriculum, infrastructure, classroom spaces, and examination structures. Educationists and experts have identified what twenty-first century competencies mean for children everywhere. By developing their abilities for critical thinking, creative thinking, and learning to be life-long learners, we have to prepare them to be inquisitive, to be problem-solvers, to be interactive and collaborative, using information and media literacy as well as technological skills. We must prioritize self-discovery and exploration, and involve learners in the creation of knowledge rather than making them mere consumers of it. We must make STEM subjects part of their everyday language.

Keywords: National Science Foundation (NSF), STEM.

1. Introduction

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again."[1]

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"On education, His Majesty has underlined the importance of ensuring that our education system is relevant to the needs of our nation; ensuring our teachers and students are equipped with the right tools - right books, curriculum, right direction; building an education system that nurtures people with the right skills and knowledge."[3]

The above excerpts are just few instances that speak a volume about His Majesty's heart and passion toward education. Time and again, he has emphasized the pivotal role education plays in building and transforming a nation. This very truth cannot be emphasized further. No wonder one of the 17 SDGs [4] of UN (a.k.a. Global Goals) set in 2015, which Bhutan too adopted, is to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all by 2030. In Bhutan, this is echoed in a number of national goals that unequivocally are in congruence with the set SDGs. For instance, the nation's 12th Five Year Plan (FYP) covering the periods 1st July 2018 to 30th June 2023 spells this out succinctly in a number of places. [5]

His Majesty's statement, "We must make STEM subjects part of their everyday language" reverberates louder, especially at this juncture where the nation is entering into a major reform in the education sector. The buzzword STEM stands for Science, Technology, Engineering and Mathematics. Originally called SMET [1] STEM education was originally an initiative by America's National Science Foundation (NSF) that aimed at providing students with critical thinking skills that would make them creative problem solvers and ultimately more marketable in the workforce [2]. Ever since the coining of the acronym in 1990s, various attempts have been made to define it. For instance, according to [1], STEM education includes approaches that explore teaching and learning among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects. According to [3], STEM education has evolved into a meta-discipline, an integrated effort that removes the traditional barriers between these subjects, and instead focuses on innovation and the applied process of designing solutions to complex contextual problems using current tools and technologies. Although a singular one-size-fits-all definition is non-existent to date, some agreeable threads can be pulled out from the fabric of disparate attempts. First, its boundary is no longer confined to "S"' and "M"', the more dominant and recognizable strands of the acronym for many. The

[1] His Majesty the King's Speech at the 3rd Convocation of the Royal University of Bhutan, February 2009
[2] His Majesty the King's Speech at the 113th National Day in Punakha Dzong, 17th December 2020
[3] Section 2.5 of the 12thFive Year Plan: available at https://www.gnhc.gov.bt
[4] Sustainable Development Goals of UN: https://sdgs.un.org
[5] See section 7 of part II and part X of the 12th Five Year Plan for example.

21st century mandates the integration of the remaining strands, more specifically the "T" strand as it pertains to our work. Second, the "T"' has long been misconstrued to be synonymous with "computer"' which is just one tool in the arsenal of tools technology encompasses. The "T" of STEM, therefore, ought to be seen from a broader perspective.

The global focus on STEM education has picked up momentum in the recent past. It is increasingly recognized globally as fundamental to national development and productivity, economic competitiveness and societal wellbeing [4]. As His Majesty articulated well in the Royal Kasho, the current century we are in is qualitatively and quantitatively different from the past one. "It is defined by the accelerated rate of change in all aspects of our lives because of rapid technological advancements and globalization. The future will be more wired and digital, driven by sophisticated technologies in towns and villages alike, as well as in homes and in workplaces." Revisiting STEM curricula in order to equip students with the 21st century skills is the call of the hour. Among these timely skills are the so-called the "four C's": creativity and innovation, critical thinking and problem solving, communication, and collaboration as well as other skills such as the effective use of technology, career and life skills, cultural awareness, and information management [5]. His Majesty has uttered these core skills in the Royal Kasho. One instrumental focal point with respect to STEM curriculum is the instructional method or pedagogy.

The Oxford dictionary defines pedagogy as the method and practice of teaching, especially as an academic subject or theoretical concept. It is simply a study of instructional methods which in turn influences the effectiveness of learning. As an art or science of teaching, pedagogy houses a number of techniques/styles that vary in their approach and effectiveness. Some of them are teacher-centered / "traditional" in which the teacher is the sole central figure in the classroom, while some are student-centered in which leadership is shared and teachers act as catalysts of learning. More recently, innovative and timely pedagogies have surfaced that are reflective of the century's dynamism. Just like a nation that fights today's battles in yesterday's weaponries is bound to be doomed, educating the 21st century STEM students using just traditional methods and education tools is simply futile. This is especially the case in educational institutions like GCIT where the dynamic of technology is ever at play. The global technological ecosystem has witnessed a plethora of game-changer paradigms such as Internet of Things (IoT) and Artificial Intelligence among many others. While the inclusion of such timely technologies in its curriculum is a commendable move, due emphasis ought to be given to the instructional methods as well that orient student towards acquiring the 21st century skills. It is with this posit that this research endeavors to study one of the relatively younger methods, Learning by Making, in one of the most recent and timely modules of the college, Internet of Things (APC203).

2. Problem Statement and Scope

Improving the STEM literacy of a nation promises a multitude of benefits in many spheres of the country such as socio-economic development, intra-personal and inter-personal skill developments, and many more. To reap the benefits, however, some hurdles have to be cleared. The education system must be cognizant of the evolving global landscape. His Majesty once said, "I have studied our own official statistics, which show these [weaknesses in core STEM

subjects] in great detail – you should look at them too- but for today, what we need to do is ask ourselves the question – 'does our education system reflect our changing opportunities and challenges?' Contemplate this question." [6]

Contemplating on the aforementioned question opens the gate for further probes. Some of them include: Do our current instructional methods reflect the changing time? How effective are they in developing the 21st century skills and global competitiveness of our students? Are we tapping into the potential of recent and innovative teaching methodologies that maximize learning? We believe it is high time we start revisiting our instructional approaches.

The veteran teacher-centered teaching methodologies have been in use for generations. They still continue to dominate in many classroom settings across all education levels. Some characteristic features of this mode include: the teacher is the epicenter of knowledge, students are passive consumers, assessments are summative in many cases, and it is content-driven/textbook-centered. Although the approach has a number of strengths, it is severely constrained in meeting the demands of the hour on its own: producing problem-solving minds equipped with the 4 Cs and other 21st century skills. This is especially the case in STEM subjects where rote-learning is less effective. It is with this strong conviction we embarked on an empirical study of a student-centered instructional approach named Learning by Making in this research.

The scope of the research includes the following:

- The empirical study is limited to GCIT college. More specifically, it focuses on the Internet of Things module (APC203) of BSc in Computer Science program of GCIT which is being offered in the current semester (Spring 2021) for second year students.
- Although there are a number of student-centered instructional methods that are ideal for the century, this research seeks to experiment Learning by Making as a potential pedagogy.
- Since the module has both theoretical and hands-on components, the study emphasizes more on the hands-on sessions that the pedagogy can easily be experimented in.

3. Objectives and Significances

3.1 Objectives

The research seeks to achieve the subsequent core objectives:

1. To experiment the Learning by Making pedagogy in the chosen classroom setting.
2. To observe and empirically assess the effectiveness of the pedagogy from the students' perspectives.
3. To investigate the pedagogy as a potential candidate for more modules and pinpoint any hindrances (if any) at an early stage.

[6] An excerpt from His Majesty the King's Speech at the 3rd Convocation of RUB, February 2009

The paper hypothesize that Learning by Making is an ideal STEM instructional approach suitable for the 21st century skills that encourages the development of creativity, critical thinking, communication, and collaboration.

3.2 Significances

We deem that the significances of this research are manifold. Some of them include:

- It could help tutors in integrating the pedagogy in their respective modules where feasible.
- As we are on the cusp of a major education reform, the outcome of the research could be a useful input for stakeholders such as curriculum designers, strategists, and other key players of the reform.
- It could serve as a stepping stone for further research to flourish in the topic at hand.

4. Research Methodology

Research category

This is a predominantly qualitative empirical study where observation and actual experiences play pivotal roles.

Sampling method

The sampling method is purposive sampling method. All the students taking the module constitute the sample group in this research.

Data collection

The research has employed both primary and secondary data sources to collect relevant data. Tools such as observations, interviews, questionnaire, document analysis (books, articles/journals) are used.

In the college, it was purposefully selected the Internet of Things (APC203) module's class. The observations of the module tutor's implementation of the pedagogy and the student's response to it were made. A number of non-participatory classroom observations were made by the research members before and after individual interviews. The observation allowed for gathering primary data without directly interacting with its participants thus it enabled unbiased observation to take place concurrently throughout the semester. The module tutor's observation were also recorded as a part of classroom observations. The data from classroom observations and observation notes were triangulated with the interview data.

Structured interview was used to gain in-depth information about students' perception of the effectiveness of the Learning by Making pedagogy. Six interviews, lasting between 30-40 minutes, were conducted to elicit each participant's experiences, feelings and convictions about the aims set for this research.

The interview data were transcribed and analyzed manually using thematic content analysis. The data analysis included the process such as transcription, reading the texts, labelling the text, searching for the themes, re-arranging the themes and then creating a coherent narrative

including the quotes from the interviewees. To test the reliability of the analysis, all the researchers examined and coded the interview transcripts jointly to avoid misinterpretation of the data and therefore, the apparent categories of the findings were identified.

Data analysis and presentation

It predominantly uses qualitative research analysis techniques to derive meaning from the observed/collected empirical data. Tools such as graphs and tables are used for informative data/result presentation.

5. Preliminary Findings and Discussions

5.1. Analysis of Interviews

In conceptualizing Learning by Making as a STEM pedagogy, the questions were set based on two factors targeted to find its effectiveness.

Quality of the Learning by Making pedagogy

In this study, the majority of the participants felt that learning by making pedagogy as different and interesting compared to the conventional teaching pedagogy. For example, one of the interviewees said: "Yes, it is different in way that you actually do things by yourself. In conventional learning, the tutors would be telling us about how things are done but in Learning by Making, you do them by yourself. So, when you do things yourself, I think you remember more. Ah, and it help me to understand more."

Another interviewee reiterated the same opinion as follows: "Yes, in Learning by Making, it was easier to remember stuff, and when we are physically engaged in making those we are somewhat forced. So, it was much challenging but interesting as we can make our own programs depending on questions. All the output will be different for each individual as they have their own answer to their question".

In its support, a similar pattern was found from the classroom observation data where the module tutor was observed engaging students in the learning by assigning students to do projects/creative activities on their own. For example, a tutor started the session by activating the students' prior knowledge, and initiated brainstorming and discussion exercises which were reported to be effective learning strategies by the students.

Impact of Learning by Making pedagogy in developing students' soft skills

In this study, most of the interviewees shared that the implementation of Learning by Making pedagogy helped develop their critical thinking skills. One interviewee summed up the concept of critical thinking skills as follows: "I think it's because of this project, we are always enhancing our critical thinking skills because the things that I want to make is something new and people can't find it in Google or anywhere. So, we have to first make the framework for our project, when we implement and write codes, there are lots of things that need to be very critical and we are learning by making, so naturally, it helps us to be critical"

Five students directly conveyed that the module included practical components which demanded the students to vigorously work on projects demanding them to critically think.

One of the interviewees stated: "I would say that we have a practical on how to use the LED and buzzer sensor but we are given with the code. They have the code in Pi-Top [a programmable computing tool], after running the code, we are modifying the code and adding another sensor so, it will help us on the critical thinking part. They have simple codes to run but we are using our programming skills and then we are changing the loop, adding the conditionals and making something new out of that code which actually requires us to thinking critically"

Although all of the interviewees agreed that the pedagogy helped them to develop communication skills however, most of the interviewees stated that they use their native language to communicate in their partners when assigned with the group work. One stated as follows: "Every time I learn Pi-Top or IoT, I have to be with my partner so, we always communicate and try to find the problem and the solution to our project, so it is enhancing our communication skills. The same interviewee added: "we use Sharchop, Dzongkha and sometimes English. I don't think we are more focused on English communication in group projects, however we are able to communicate, feel comfortable and learn more".

Nevertheless, another interviewee stated: "Sir gave us one topic each to every group and he makes us present this topic to other groups. So we always present our topic to other groups, there we have to communicate in English and I think that's helping me to improve English communication"

The interview data supported that the pedagogy helped students to enhance collaboratively as they were assigned with group projects and other peer activities. Supporting these, the classroom observation data showed that most of the classes were dominated by student-centered activities, where they were exposed to hands-on project activities and students given the liberty to open up.

Interviewees expressed that the mini projects assigned to them have provided greater space for exploration and creativity. For example, one interviewee said "That aloo application that we made, I think that also helped. More to that every activities helped in building our creativity. Sir didn't give us much clue, so we have to create our own application."

Nevertheless, few interviewees felt that the lesson had not helped them to be creative. As one of the interviewees shared, "I would say that, no for me. The code is already there and we are all doing the same of thing and we already had the same type of technology in Bhutan. We are doing the same thing, I haven't added new programming to make this module new and creative because I am weak in the programming part. I couldn't make a vast difference. For me, we had the project and I was making a security system, it made me feel like I had not made something new out of it"

The statements so far signpost that most of the students are benefitted nevertheless, few glitches to avoid for the better implementation of the pedagogy was also highlighted by the interviewees. Interviewees also reported that they experienced the shortage of project sensors and malfunctioning of the devices added stress and loss of interest in their project to an extent. Some shared that they experienced stress when the instructions were not clear.

One stated, "It is easier to contact our sir when we get stuck but sometimes there are other groups who have problems and sir not able to give proper time and then the class ends. So we

are left there a bit. Sometimes we are not being able to apply the code". Most of the interviewees shared that their weakness in coding had challenged their performance as all the projects were associated with programming. Nevertheless, interviewees indicated their preference for the module tutor who was open, supportive and approachable. They shared their satisfaction towards the pedagogy.

5.2 Analysis of Survey Data

Question	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I learn better through Learning by Making Pedagogy	2.8%	2.8%	11.1%	33.3%	50.0%
Learning by Making is engaging	-	-	5.6%	38.9%	55.6%
The expriences from Learning by Making stay longer than by-hearted information	-	2.8%	8.3%	38.9%	50.0%
The Learning by Making pedagogy helps perform activities on a regular basis	-	2.8%	13.9%	52.8%	30.6%
I feel comfortable with my peers faster when I am teamed up in the Learning by Making pedagogy	-	5.6%	11.1%	38.9%	44.4%
The Learning by Making pedagogy focuses on active experimentaion (hands-on activities)	-	-	5.6%	38.9%	55.6%
This pedagogy can be applied in other practical modules	-	2.8%	8.3%	41.7%	47.2%

Table 1: survey data collection

Table 1 above shows the percentage scores in each question used in the survey questionnaire. The questions were framed parallel to the research objectives.

Part A

Pedagogical preference for Learning by Making is demonstrated by half of the students (50%) who reported that they strongly agree that they learn better through the Learning by Making pedagogy, 2.8% strongly disagreed with the statement. The majority of the student's inclination towards the pedagogy supports the very aim of this research. Considering the effectiveness of the pedagogy, the survey asked about concern for students' engagement in the class. 55.6% of the students strongly agreed to the pedagogy as engaging which supports that pedagogy and none of the students disagreed with the statement. To further investigate the effectiveness of the pedagogy, the subsequent survey question inquired if the pedagogy helped in making the students a life- long learners. Half (50%) strongly agreed that the experiences from Learning by Making stay longer than by-hearted information whereas 2.8% disagreed. The student's understanding of the achievement of teamwork and collaboration skills is demonstrated by statement number five in the table. The survey asked questions to investigate their engagement in the classroom. About (44.4%) of the students strongly agreed that they feel comfortable with peers faster when teamed up in the Learning by Making pedagogy, 38.9% agreed to the same and 5.6% disagreed. Another 55.6% strongly agreed that the learning by making pedagogy focuses on active experimentation, whereas 38.9% agreed and the rest 5.6% remained neutral to the statement. None disagreed with the statement. One of the key research objectives is to investigate the pedagogy as a potential candidate for more modules. The student's response highlighted that 33.3% strongly agreed that the pedagogy can be

applied in other practical modules however, 8.3% disagreed with the same. The higher percentage difference scored for the statement also shows an achievement for the targeted objective. Looking at the percentage in favor of the statements, it can be considered that the pedagogy is a success.

Part B

Part B of the questionnaire aimed to find out the impact of pedagogy on students' soft skills development.

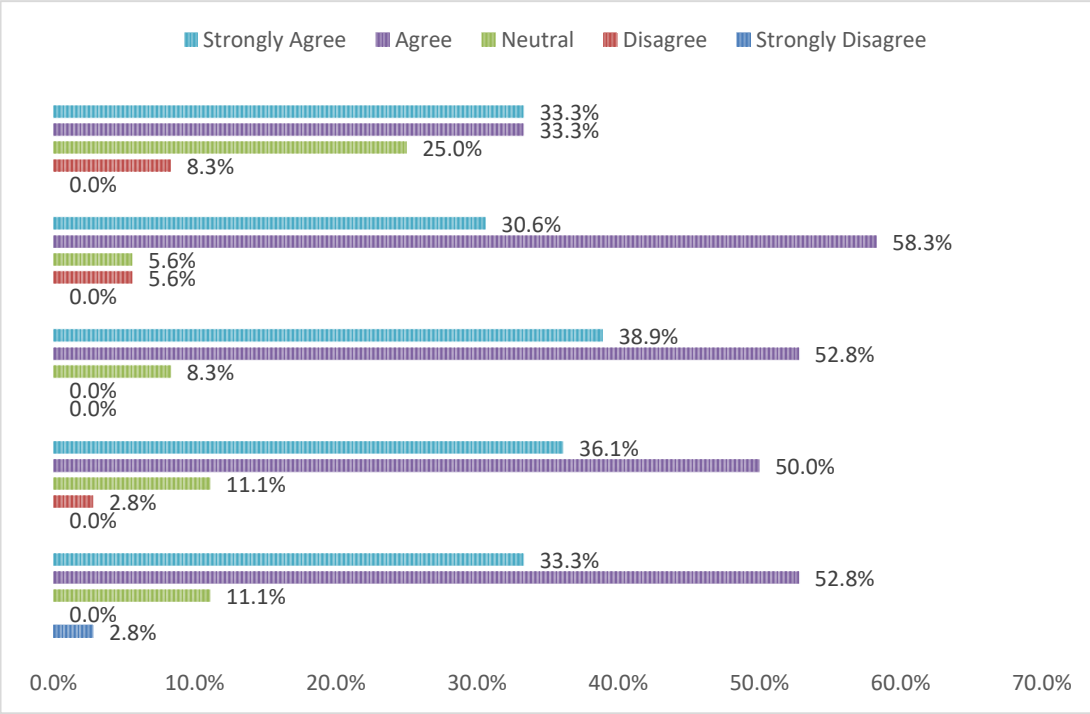

Figure 1. The figure targets to find students' development of 4C reflected in the hypothesis i.e. creativity, critical thinking, communication, and collaboration skills

The study found that the pedagogy stimulates the development of creativity, critical thinking, communication, and collaboration skills for the students. From the sample of 36 students, 50% of them have agreed and more than 30% have strongly agreed that the pedagogy encouraged them to be innovative by engaging them in creative hands-on activities (lab sessions, projects) which directly indicates that students are able to demonstrate their creativity. Similarly, more than 60% of the students indicated that the pedagogy helped them to be analytical and they showed their inclination for creativity-oriented, discovery-based lessons. The majority of the student i.e. more than 50% unveiled that the pedagogy helped them to build their communication skills through various activities such as peer activities, group work and presentation that directly correlate to the enhancement of the communication skills. The findings also manifest that more than 50% agreed on the pedagogy for providing them with team skills as most of the activities involve group works that reinforce collaboration skills. Overall, the results show a high score in favor of the hypothesis made for this research.

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