IMPORTANCE OF MODERN STEM TECHNOLOGIES FOR TRANSFORMATION OF STEM EDUCATION IN THE GRASSROOTS LEVEL: AN EXPERIMENTAL STUDY IN BHUTAN

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Abstract— *The fourth industrial revolution has necessitated the revamping of education relevant for twenty-first-century knowledge and skills. This work studies the potential of accelerating creative learning and innovation with early exposure and access to modern STEM platforms. Early access is expected to enhance understanding the significance of knowledge and skills in science technology engineering, and mathematics platforms. The derivation of understanding of the impact of early access in enhancing STEM education at the grassroots was part of the study. Students and STEM teachers were engaged in learning and experiencing the potential of STEM through hands-on experimental learning. The basic application implementation on automation, the internet of things, and artificial intelligence were used to ensure the learners gets the first-hand experience of STEM technologies. The first part of the study indicated the lack of platforms and learning tools has impacted the development of youths' curiosity about STEM despite being aware of its significance and being a daily customer. It has also adversely affected youths' ability to express their creativity and innovative ideas. On the other hand, youths through organized workshops were introduced to STEM platforms named STEMSEL and runlinc to impart an understanding of automation, IoT, and AI applications. The youth participants could experimentally design, develop and deploy (3D) the basic applications with the minimum number of lines of programming code. The student participants exhibited an increased level of understanding of the significance of STEM in the completion of workshops. Furthermore, the ability to use their creativity and converge into 3D experimentally enabled them to draw a better understanding of STEM technologies. The participants demonstrated their realization of the significance of hands-on learning tools to maximize, accelerate, and motivate themselves into learning STEM after the immersion program i.e., STEM workshops. With this study, promotion and importance of STEM education can be achieved within the region. STEM Education inculcates the hands-on experiential learning of the youths driving towards innovative workforce of the country through technology-based learning.*

Keywords--- STEM Education, Runlinc, Grassroots, Hands-on, IoT.

1. INTRODUCTION

The fundamentals of Science Technology Engineering and Mathematics (STEM) are inevitable in ensuring the digital transformation in education. The prioritization of STEM education is the growing trend in school education across the education sectors. The creative and innovative learning among aspiring youths is often driven by their exposure to STEM technologies and relevant skills. The ability to design, develop and deploy (3D) is now made easy with the readily available teaching-learning STEM technologies and platforms. The exposure to the technologies and their being able to realize their ideas into applications motivates the youths into learning STEM. Furthermore, witnessing the real-time applications of automation, IoT, and AI and the ability to develop such applications further made the understanding of STEM easier. On the other hand, it has also become inevitable and imperative to educate the youths, particularly from poor backgrounds or rural pockets, on the potential of emerging technologies as a platform to exhibit their creativity and innovation. The appropriate hands-on learning platforms are paramount in enhancing the problem-solving ability and harnessing the creativity and innovative ideas of youths. Creativity is significant in turning new and imaginative ideas into realities [1] in the era of IR4.0. It is relevant and practically possible with the utilization of modern STEM technologies in the education process. However, the reality is farfetched particularly in the least developed and developing countries [2]. It is also due to unbalanced reforms even within a country that results in some regions falling further behind in STEM literacy.

Incorporating STEM learning activities in secondary school [3] showed the enhancement of students' computational thinking skills. They concluded that STEM learning activities could be effective in the delivery of computing courses. Exposure and access to STEM technologies have become imperative to encourage youths develop interest and take up STEM subjects. A study on the strategy to encourage STEM education in [4] showed students get encouraged to choose STEM-related careers when they are exposed to STEM technologies through multiple courses; MOOCs, workshops, and the prospect of participating and competing in national and international STEM competitions. Even student with High Functioning Autism is attracted to STEM because they can interact with objects and concepts [5]. Hence, the author believed in the real linkages between High Functioning Autism and STEM participation and recommends special education resources that would benefit STEM education. The authors in [6] discussed on processes and challenges of designing introductory undergraduate STEM education courses. After the multiple iterations in four years and implementations, the authors stated that "judging by the positive experiences of most students in the program and the increasing quality of students' final assignments and projects each year, our appraisal of the course, is very positive. Collectively, the instructional team's capacity as STEM educators has strengthened and deepened over time.". This indicated the need for a proper STEM curriculum and pedagogy developed. The authors in [7] studied the shared vision of STEM education as it is recognized as an effective and sustainable approach. Fifty percent of participants indicated the usefulness of STEM-related skills in the successful design of PM 2.5 pollution in [8] and concluded the significance of design-based learning in solving real-world problems. Authors in [9] gave an overview of STEM

education in Romania and the increased demand for graduates with STEM skills. The study also showed the increased enrollment in STEM and also the increased attrition in the STEM teaching fraternity due to increased opportunities. The authors in [10] found out the significance of STEM in curriculum to ensure innovative, creative and enquiry centered learning activities. However, authors noted that STEM education is often offered separately. Hence, it is realized the need for a collaborative framework to include the STEM in existing secondary and primary education curriculum.

According to [1], the early access to technology would enable harvesting, tapping creativity and imagination of youths leading to early innovations and inventions. Dr. George Land's creativity test for NASA in 1968 still holds true to this day [11, 12]. It is even more important that underprivileged youths at the grassroots are given access to knowledge and skills on STEM technologies to bridge the digital divide. Diana [13, 14] argued that a huge volume of opportunities in STEM is lost by waiting for the introduction of STEM education until high school and university. IEEE's pre-university STEM initiatives through grants are the steps to infuse STEM learning from the early education.

STEM is the main stay in education. However, transformation is felt necessary in delivery of STEM education aligned with twenty-first century education i.e. knowledge and skills based on reality. The United Nations Educational Scientific and Cultural Organization (UNESCO) has recognized the potential of AI and IoT and identified as technological means for achieving sustainable development goals SDG5 to SDG10. One of the most important United Nations (UN) SDGs is goal 4: The Equitable and Quality Education for all where ensuring access to recent technologies is expected to play a greater role. UNICEF report [15, 16] further identified the lack of access and lack of role models as culpable reasons for low enrolment into STEM as compared to other branches of studies. The competitive advantage of automation, IoT and AI that interweaves the software and hardware have better prospect in transforming the way STEM is taught in education process.

Considering all the above parameters and their significance, this study is conducted to understand the perception of students and STEM teachers on STEM education with and without access to STEM technologies. Study is done in two phases, a preliminary study to understand the general awareness of STEM education and a experiment based case study to determine the perception change on STEM among the students after going through hands-on experience learning through 3D concept in rural Bhutan.

This work is organized as follows. In Section II the motivation for the study is followed by materials and methods used in the project are highlighted in two subsections and five sub-subsections in Section III. In Section IV results and discussions are presented in two subsections viz. findings from the preliminary survey and responses from the participants after undergoing workshops/training on STEM technology. Section V presents the conclusion and future works.

2. MOTIVATION

STEM education is priority in the education reform drive underway to which Bhutan is no exception. The measures to encourage the youths take up Science Technology Engineering, and Mathematics are initiated across the school education. The innovative teaching-learning pedagogy are devised in delivery of mathematics, physics, and chemistry lessons. The youths' understanding and exposure to ICT skills such as coding is seen as another motivational element to encourage them take up STEM. Therefore, courses in coding are introduced as early as primary education.

On the other hand, it is felt that there is a disconnect between the efforts and initiatives taken, and the way students want to learn STEM. Often the learners are reluctant to learn and be motivated unless they can visualize and see by themselves the actual applications of knowledge and skills.

Table 1. No. of Responses received from Participating Organizations

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Organization	No. of Responses
Jigme Namgyel Engineering College	64
Samtse College of Education	15
Samtse Higher Secondary School	33
Norbugang Central School, Samtse	35
Dewathang Primary School, Dewathang	3
Garpawong Middle Secondary School, Dewathang	20
Dungsam Academy, Dewathang	16
Samdrup Jongkhar Middle Secondary School	2
Kabesa Central School, Thimphu	1
Lobesa Lower Secondary School, Punakha	1
Total	**120**

Therefore, this study delves into understanding the learners' perceptive on conventional method of learning STEM i.e. classroom teaching-learning. Realizing the internet driven world that we live at the moment, potential impact of integrating automation, IoT, and AI into STEM is studied in this work. The learners' ability and motivation to embrace STEM can be driven when they can personally apply 3D and appreciate their own creativity and innovative mind. Furthermore, this study is aimed at understanding the potential of rural youths in unlocking their creativity with the access to modern STEM learning tools. The potential impact of integrating IoT-AI in STEM to enhance the STEM education is experimentally analyzed through STEM immersion programmes.

3. METHODOLOGY

3.1. Preliminary Survey

A preliminary survey consisting of fifteen questions was conducted online using a google form on teachers and students from selected schools in Samtse Dzongkhag (Samtse District) and Samdrup Jongkhar Dzongkhag (Samdrup Jongkhar District). Questionnaires were also distributed in print. However, data collection was limited to the selected schools of two Districts. The same schools were involved in experiential based studies on STEM technologies through hands-on workshops. It was carried out to understand teachers and students' awareness of STEM education. It was also to understand their opinion and perspective on STEM education in the country. The survey received participant's responses on awareness, knowledge, and skills on common educational STEM platforms. These

platforms are commonly used by students and innovators for developing basic IoT and AI applications. 190 responses were received from students of selected schools and two colleges. Table 1 provides the details of responses.

The preliminary survey question consisted of two parts. One part was to understand participants' opinions on STEM education and their awareness of modern educational STEM technology tools like Arduino Microcontroller and STEMSEL Microcontroller. The responses were recorded under opinions of Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree as individual rating presented in TABLE 2.

3.2. Case Study

Findings from the preliminary survey formed the basis for the rest of the actions. The collaborative knowledge sharing and skills transfer on modern emerging technologies through the university to school mentoring strategy was applied in the study. The study considered the access to basic STEM technology platforms a vital tool for youths to express their creativity into reality and ensure better understanding of IoT and AI. It is also to encourage the youths in rural schools in Bhutan to develop interest in STEM subjects. Therefore, workshops and training were considered a part of case study for the participating students and teachers from partner schools.

Table 2. Opinion of students and teachers of schools, JNEC and SCE

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I am aware about STEM (Science Technology Engineering and Mathematics) education.	54	81	36	9	10
STEM education is effectively delivered in schools and colleges in Bhutan	46	75	47	22	0
I know about the Internet of Things (IoT) technology	46	74	31	25	14
I have heard about Artificial Intelligence (AI) technology	67	71	24	18	10
I know how IoT technology works	46	74	31	30	14
I know the working of AI technology	26	61	51	37	13
I heard/know about Arduino Inventor's kits before.	23	36	38	61	32
I heard/know about STEMSEL inventors kits and runlinc before.	18	40	37	66	29
I know the basics of at least one of the programming language (C, C++,Python, Java, etc…).	40	72	35	29	14

3.3 Case Study Sites

To achieve the objectives, selected schools in Samtse District and Samdrup Jongkhar District were considered collaborators. Table 1 shows the list of schools considered for the pilot study as the study was focused on providing access to platforms for understanding and realizing the IoT-STEM-AI technologies to the students at the grassroots. Samtse College of Education and Jigme Namgyel Engineering College were also study site. The tables Table 1 and Table 2 presents the detail of the study site and participants from respective organizations.

3.4. Case Study Tool

Exposure to appropriate technology is important to enable the participants to express their creativity into reality. The hands-on learning platform for the students and teachers of schools and colleges was prioritized to ensure effective knowledge and skills transfer. Interactive platform STEMSEL (Science Technology Engineering Math Social Enterprise Learning) inventor's runlinc technology was considered as a main case study tool. The platform was considered to enable participants to realize their ability to understand the potential of transforming STEM education through interactive hands-on IoT and AI application development. Runlinc is an online IoT and AI application development platform interfaced with the STEMSEL microcontroller. It enables the learners to easily understand the IoT and AI concepts by interfacing the physical hardware devices to the internet thereby remotely controlling the devices for various applications [17].

3.5. Case Study Courses

Ensuring the basic understanding of IoT and AI technologies among participants was important for the study to draw a reasonable conclusion. Therefore, participants completed the basic automation, IoT applications and AI courses through the workshop session.

Table 3. Workshop, Webinars and Training conducted for the participants

Specifics	Activities	Participating Organization	No. of Participants	Date of Event
Webinar	Introduction to the project and online demonstration	Samtse College of Education, Norbugang Central School, Samtse Higher Secondary School, Garpawoong Middle Secondary School	12	
International Webinar and Workshop	Demonstration of Applications Development using STEMSEL and runlinc technology	Samtse College of Education, Norbugang Central School, Sri Lanka Technological Campus, Samtse Higher Secondary School, Jigme Namgyel Engineering College	13	20th February 2021

International Webinar and Workshop	Demonstration and Hands-on STEMSEL Applications Development	Students of Jigme Namgyel Engineering College, STEMSEL Foundation, Australia, Sri Lanka Technological Campus	35	22nd Februar y 2021
Workshop	Demonstration and Hands-on Skills Development using STEMSEL and Runlic	Samdrup Jongkhar Middle Secondary School, Garpawoong Middle Secondary School, Dungsam Academy	4	20th March 2021
Workshop	Demonstration and Hands-on Skills transfer using STEMSEL and runlic	Dungsam Academy	18	
Workshop	Demonstration and Hands-on Skills transfer using STEMSEL and runlic	Garpawoong Middle Secondary School	18	22nd May 2021

It was to enable them to understand and realize the potential of emerging technologies which has the better prospect of reaching out to learner faster and effectively compared to current scenario in STEM education. All participants implemented eight projects as courses to gain overall understanding.

Basic javascript and HTML programming languages are used in developing the applications. Runlinc is "in the internet" application development platform and does not require an independent integrated development environment (IDE). It only requires simple programming code to realize simple IoT and AI applications. For example, only two lines of code is required to create an ON and OFF button website using HTML [17].

3.6. Workshops and Training

Workshops and webinars were also an integral part of study. These forums were used for the demonstration and provide hands-on exposure to STEM tools. Workshop sessions in particular were effective platforms to train the participants practically besides enhancing their theoretical knowledge.

As part of the study, six workshops for teachers and students of selected schools in two districts. Table 3 present the details of activities executed. Besides the workshops/training the discussions on STEM promotion in schools were regular activities through webinars among the project team and international STEM enthusiasts. To further understand the impact of initiatives on participants, feedback was collected in two parts. Participants provided their opinion on STEM Education, expectation from the workshop, prior knowledge and skills in STEM fields. The same set of participants provided their feedback by answering eight questions after undergoing the workshop session. Feedback was also collected from the teachers who were part of the study and had experience in developing simple IoT and AI applications on STEMSEL runlinc technology.

Fig. 1. Students of Dungsam Academy [LEFT] and Garpawoong Middle Secondary School[RIGHT] Attending the Hands-on Workshop

Table 4. Number of participants in workshops conducted for the teachers and students

Organization	No. of Teachers	No. of Students	Remarks
Garpawoong Middle Secondary School	1	15	
Dungsam Academy	2	15	
Samdrup Jongkhar Middle Secondary School	1	0	Could not conduct a workshop for students due to COVID-19 protocols

Norbugang Central School	3	0	Could not conduct a workshop for students due to COVID-19 protocols
Samtse Higher Secondary School	3	0	Could not conduct a workshop for students due to COVID-19 protocols
Samtse College of Education	2	2	
Jigme Namgyel Engineering College	4	30	

4. RESULTS AND DISCUSSION

4.1. Preliminary Study Findings

A total of 81 school students (Classes 7- 12), 75 college students, 15 college lecturers, 1 technician, and 18 school teachers formed the responses. The large section of respondents is aware of STEM and most of them indicated that STEM education is effective in school. that the majority of students and teachers have heard about the IoT and AI technologies.

Furthermore, majority of the people didn't had the knowledge and skills on basic automation, IoT, and AI educational platforms like STEMSEL and Arduino. However, study also considered the impact of university students' response. The university students particularly of Jigme Namgyel Engineering College were introduced to the basics of IoT and AI technology who subsequently took part in the survey. On the other hand, it is encouraging to see the impact of programming languages taught in schools to promote ICT education with majority of respondents having basic knowledge/skills in at least one of the programming languages (C, C++, Python, Javascript, etc).

Further, the responses indicated that the ineffective STEM education in schools/colleges are attributed by the following factors in response to question 2.1.1.

- Teaching-Learning are more focused on theoretical knowledge
- Lack of hands-on practices/practical based learning.
- Lack of trainings and workshops to impart hands-on exposure and experience.
- Lack of resources/infrastructure.
- Need of change in curriculum.

The inference from questions 2.1.2 to 2.1.5 is drawn from Fig. 2. There is resonance among the participants on the importance of aligning the teaching-learning with the recent advances of STEM technologies. Apart from IoT-STEM-AI technologies the participants also understand the importance of staying informed about technological advancements. They also acknowledge the efforts made in imparting such knowledge and skills in school. However, the majority opined on the lack of resources and exposure to relevant technologies has limited them from advancing in exhibiting their creativity and innovative ideas into reality.

Further analysis from Fig. 2 shows that a hands-on-based teaching-learning approach otherwise an effective mechanism is not common in schools concerning P2 in Fig. 2. On the other hand, it is felt at least the awareness, basic knowledge, and skills on emerging technologies such as IoT and AI are important to ensure the relevance of STEM education. 87.89 percent of responses expressed that there is a need for change in the way STEM education is taught in schools and colleges.

The overall inference from the preliminary study was that the general mass is largely aware of development through technological advancements. However, the lack of exposure and limited resources are culpable reasons for their inability to express their creativity into reality. The youths tend to learn more when they SEE and DO the things that they learn. Therefore, developing the STEM infrastructures for early access and effective hands-on learning is vital to enhance STEM education.

4.2. Case Study Findings

The participants' prior knowledge and skills on STEM technologies were once again collected before introducing them through the workshop. However, responses were restricted to only those who underwent the workshop, hands-on exposure, and experiential learning on STEMSEL and runlinc technology. The same set of participants responded with their opinion after the completion of the workshop. It was to obtain better comparative result. It also helped in understanding the impact of hands-on experiential learning on participants' capacity to visualize the potential of emerging technologies in transforming STEM education.

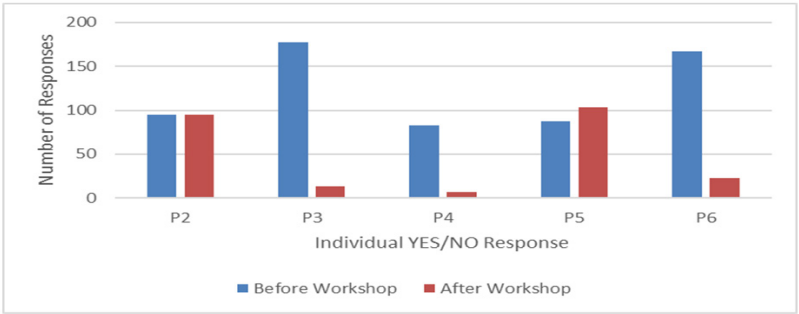

Fig. 2. Awareness of STEM technologies, opinion on the significance of STEM technologies (e.g. IoT and AI), and Status of STEM education

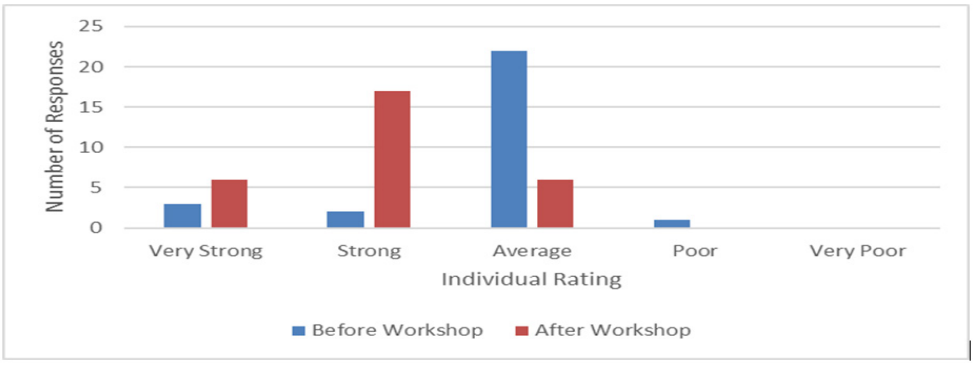

Fig. 3. Participants' rating on awareness, knowledge and skills in STEM and its potential

Fig. 4. Participants' opinion on the potential of STEM subjects in promoting creation, innovation, etc.

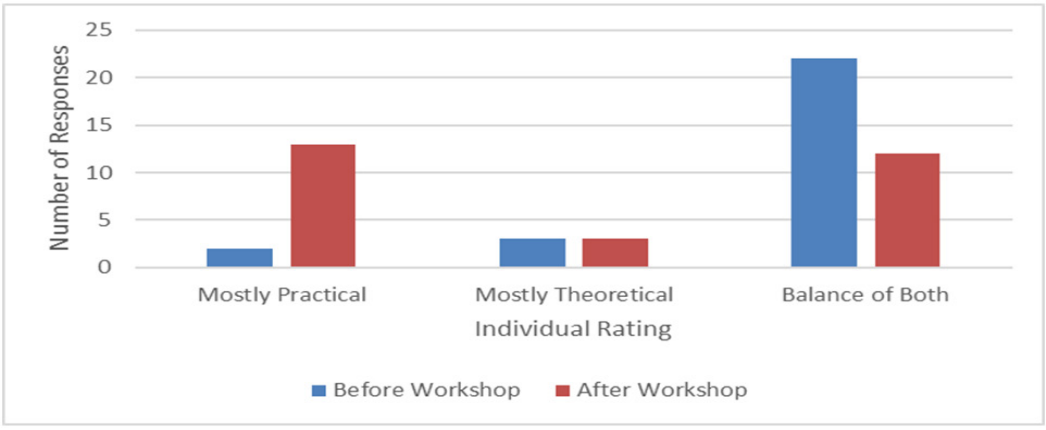

Fig. 5. Teaching-Learning strategy used to impart STEM knowledge and skills in schools/university

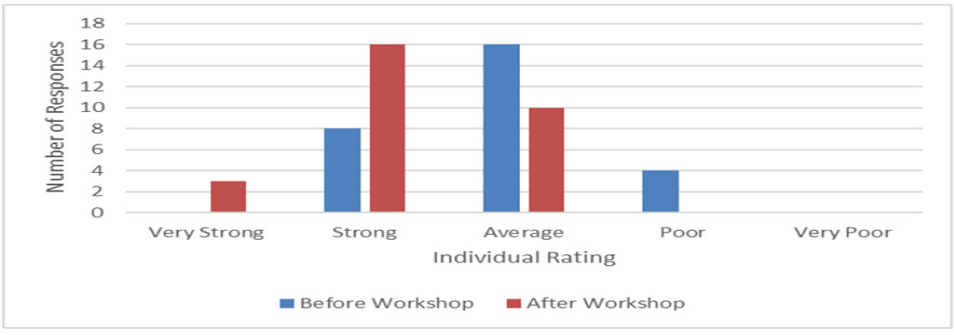

Fig. 6. Participants' rating of knowledge and skills in emerging technologies like IoT, AI, etc

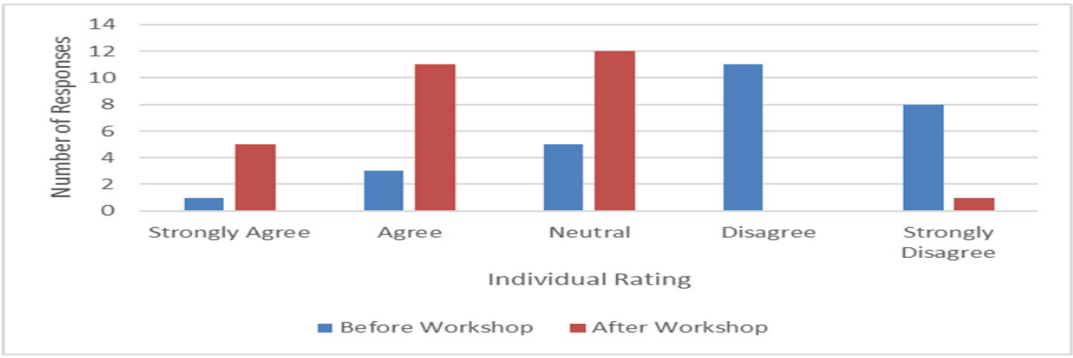

Fig. 7. Prior hands-on experience of STEM platforms and the opinion after the workshop

Fig. 8. Participants' preference of mechanism for effective learning of STEM that should lead to faster creation and innovation

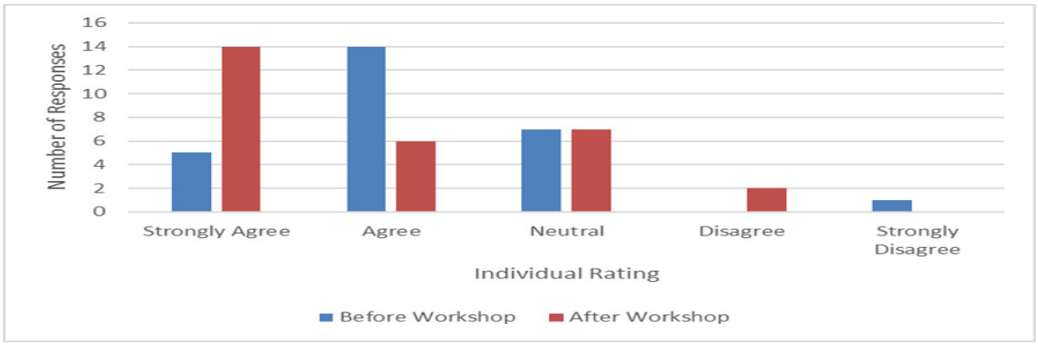

Fig. 9. Participant's view on the impact of early access to STEM technology for promotion of quality STEM education

The workshop participants were introduced to the technology evolution largely enabled by the fourth industrial revolution (IR 4.0). With 30 billion smart devices connected to the internet in 2020 and new devices getting connected to the internet every minute, every day [18, 19], participants were aware of the amount of data generated for various applications and associated opportunities. The participants also could derive better understanding of IoT concepts when all the devices connected to the internet were controlled with or without human intervention. The participants responded eight questions asked prior to workshop. The participants' responses before and after the workshop are compared through bar graph representation in figures Fig. 2 - Fig. 9.

From Fig. 2 participants' awareness, knowledge, and skills in STEM and understanding its potential flipped from a mere 17.86 percent to 82.14 percent after undergoing a workshop. It is also understood from Fig. 3 and Fig. 4 that the STEM subjects have the potential in promoting creative thinking among the youths with more emphasis on experiential learning. The level of participants' understanding of emerging technologies like IoT and AI enhanced from 28.87 percent to 67.86 percent after undergoing hands-on experiential learning through the workshop as indicated in Fig. 5. Further from Fig. 6 and 7 participants also reflected on their confidence that they would be able to translate their creativity into reality after exposure to educational STEM platforms like STEMSEL runlinc.

As per the opinion of participants in Fig. 8, the need for hands-on skills outweighs the other methods of teaching-learning to ensure maximum skills development. It is also noted from Fig. 8 that mentoring and exposure to STEM technologies are equally necessary besides the theoretical knowledge. Furthermore, participants' opinion on the impact of providing early access to such technologies drastically leaned towards strongly agree after realizing the potential from the workshop. Fig. 9 clearly shows that majority feels that there is an impact of early access of STEM technology for quality STEM education.

Participants also provided the written feedback on completion of workshop. However, only some are reflected below:

•We could understand IoT and AI concepts which was not heard before easily. I think such workshop should

continue; it will bring greatly affect the positive learning in youths.
- Such workshops can really help in making the STEM a daily language in education.
- I understood how our creativity can be easily translated into reality using modern technologies.
- The workshop session helped me learn many things including the basics of connecting wires and how physical devices can be controlled with our own creative ideas.

Teachers who were part of workshop overwhelmingly responded that they could draw a better understanding of STEM through the basics of IoT and AI technology. The workshop with demonstrations and hands-on experiential application development made them realize the potential of interactive teaching-learning to promote STEM. There is also a consensus among the teachers that providing access to interactive facilities on which students can translate their ideas into reality would encourage STEM creations and innovations among students. They also believe ensuring such facilities in schools would supplement students in learning programming languages introduced in schools as part of enhancing ICT skills. From the study, the results were encouraging. There is an increasing number of positive responses on the STEM form of learning whereby students can learn through hands-on. School students are more aware of IoT and AI.

5. CONCLUSION AND FUTURE WORK

From the preliminary survey findings, it was evident that people are aware of the importance of STEM education. People are also in general aware of the potential of STEM yet many are not assured about how STEM knowledge and skills can be translated into reality. To effectively translate STEM knowledge and skills into reality, teaching- learning of STEM need to be assisted by interactive educational STEM tools. The tools would enable the learners to translate their creativity into innovations, real-time applications where both theoretical and practical learning is enhanced simultaneously.

Opinions expressed in the preliminary findings were supplemented by the findings from the case study. The students can understand better by seeing things in reality. The concept of automation, IoT, and AI were better understood by students when they implement the applications by themselves and witness its working in real. The ability to achieve with basic knowledge of programming languages, to begin with, encouraged youths to pursue their interest in STEM. Therefore, imparting hands-on experiential-based knowledge and skills using recent IoT and AI educational tools would enhance STEM education. It was evident from the workshops that youths can create, innovate and invent if provided with the appropriate platform. The facilities can enable the youths to unlock their imagination and encourage them to pursue STEM education. It is also evident that providing early access to STEM technologies would mean faster creation and innovation. It is also evident that the youths in the rural settings are lagging behind in digital literacy. However, they can equally compete in creativity, innovation, collaboration through creation of level playing fields-thereby bridging the gap on digital divide. This study was done during the Covid-19 time on 3 schools of Samdrup Jongkhar, 3 schools of Samtse and a college in Bhutan. The study was restricted due to pandemic protocols of the country. Similar study can be done on a greater sample size from different parts of the country or in other countries in future.

A long-term study to examine the perception changes or transformation among the youths on STEM Education on introducing the hands-on experiential learning will be key. The value addition of competitive advantage of IoT and AI in imparting STEM education can be further validated. The need for STEM pedagogy for the uniform imparting of STEM education requires examination and development. The collaboration in the promotion of STEM education and its impact will be further explored in the future.

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