Problem-solving skill development through STEM learning approaches

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***Abstract*—This research to practice full paper presents problem solving skill development through STEM learning approaches. There is a rapid growing interest in STEM (science, technology, engineering and mathematics) education. One reason for this ever growing interest is to develop the skills in pupils, which are required by the industry 4.0 (Artificial intelligence, big data, Internet of things) in an era of global digitization. One such skill is problem-solving skill. In this article, we present a brief overview of related studies and conceptions in the past related to STEM education, why STEM education is needed? What is problem-solving skill development in context of STEM education? This article aims to highlight that how STEM education can develop problem-solving skills in learners at primary education level through thinking, and creating solutions for real life problems.**

***Index Terms*—STEM education, problem-solving skill development, problem-based learning, global digitization, K-12 education, primary education, design-based learning, scientific method-based learning**

I. Introduction

With the advancements in new technologies (Artificial intelligence, big data, Internet of things etc.) and global digitization, the need for the availability of skilful human workforce is growing abruptly. To fill the gap between the technological advancements in industries and the required skilled workforce, a proactive approach in education sector is needed. Fields of engineering, and applied sciences are merging. Therefore, STEM (Science, technology, engineering and mathematics) education has an important role to play in that scenario. To meet the challenges of future industrial requirements, the educational settings are required to embrace approaches which deliver design engineering based scientific thinking to the learners. So that, from the early education, the pupils learn to critically think and solve the problems of daily life. Standards for technological and engineering literacy [1] provide a road map for the role of technology and engineering in STEM education which paves a way to the development of problem-solving skill development [1]. The structure of this article is as follows. First, the definition of STEM is discussed and the need of STEM education from the Primary level of education is explained. Second, we shed light on the problem-solving skill development through STEM education. Third, this article discusses how different approaches in STEM education develop critical thinking and problem-solving skills in young learners. For that purpose, we have given two different problems from daily life to solve, to the kids of grade 2-6 and applied STEM approaches to solve that. Finally, we make conclusions upon our findings and provide recommendations for the future research work.

II. Related work

In this section, the related research work is presented. There are similar studies done by utilising STEM approaches like problem-based, project-based, or scientific based learning to nurture professional skills in learners.

In the study [21], author applied problem-based learning approach in STEM teaching about bamboo toothpick houses. Students in this study learnt successfully to design and implement solution for building houses from bamboo. In another research work [22], STEM-based learning is applied to enhance collaborative problem-based competencies among the college students through the dietary plan lessons. The study includes 77 twelfth-grade students. The results of the study revealed that students improved three main competencies through this activity. First competency, "Establishing and Maintaining Shared Understanding, second competency, "Taking Appropriate Action to Solve the Problem, and the third competency, "Establishing and Maintaining Team Organization". The research work in [23] [24]presents how problem-based learning helps students in developing skills required by global digital economy.In [26] a study is conducted in a local primary school with two STEM teachers and 8 primary school students. Data is collected in the form of interviews during the STEM teaching sessions. The study concludes that STEM classes, taught with project-based learning approach facilitates students in developing problem-solving skills and critical thinking. The study [26] also revealed that students developed cooperation among themselves, positive behaviour towards learning and took more interest in classes. Another research work [27] investigated the impact of problem-based learning on learner's content knowledge and critical thinking towards STEM learning. The study suggested that problem based learning is an effective learning tool for STEM integration and problem solving skill development especially in K-

12 education. In [28], research consisted 27 students of 10th grade from a local vocational school.This research analyzed student‘s problem solving skills in current electricity STEM based learning lessons. The research study concluded that there was a remarkable improvement in student‘s problem-solving abilities because of the implementation of the problem and project-based learning in STEM-based learning. Research conducted in [29] studied the effect of the scientific approach based learning on problem-solving skills in early childhood. This research study revealed in its findings that scientific approach-based learning is a way to increase young learner‘s physical activity and mentality which leads to the problem solving abilities. Therefore, scientific inquiry based learning is another STEM education tool for nurturing problem solving skills in students [30].

It is evident from the related research work that STEM education approaches like problem- based or design-based learning and scientific enquiry-based learning are the key instructional tools which foster problem-solving skills in learners, where teacher acts as a facilitator in a student- centred learning environment.

III. What is STEM?

STEM is a multi-discipline approach of education where different disciplines of scientific education merge to develop scientific literacy among learners.Therefore, one way to define STEM education is that technology, engineering and mathematics concepts, knowledge and process understandings, “through efforts to combine some of all of the four disciplines into one class, unit or lesson that is based on connections between subjects and real world problems” [2]. International technology and engineering educators association (ITEEA) in 2015 [3] defines STEM as Integrative STEM education, which is ”the application of technological/engineering design based pedagogical approaches to intentionally teach content and practices of science and mathematics education through the content and practices of technology/engineering education. Integrative STEM Education is broadly applicable to different learning environments and study levels.

A. Why STEM is needed?

Across the world, STEM receives tremendous attention in education reform efforts. The International Council of Associations for Science Educators [4] recently urged member countries to work together to improve access to, and the quality of, STEM education in order to prepare all students for global citizenry. In the USA, the National Science Foundation (NSF) [5] has played a significant role in the STEM education movement by calling for research related to science, mathematics, engineering, and technology. the National Science Foundation (NSF) first used the term “SMET,” acronym for science, mathematics, engineering and technology education, revised into the term “STEM” acronym for science, technology, engineering and mathematics education in the early 2000s [6] .US government issued several studies on the state of STEM learning, and schools increased their STEM-focused learning. Numerous legislative actions also emerged at this time related to computer science, STEM teachers, and STEM as career and technology education (CTE) [7]. Policymakers, parents, and business communities are calling for STEM education. Therefore, STEM literacy is viewed as critical for the economic success and sustainable growth of nations. In December 2015, the Australian state and territory governments endorsed the ’National STEM School Education Strategy 2016-2026 [8]. World is moving towards global STEM literacy and STEM education has garnered great attention and acceptance. In order to achieve global citizenship and to meet the challenges posed by fast paced technological advancements. STEM education is needed to achieve global competencies. The global competence matrix of Asia‘s society, 2011 includes four types of global competencies: (1) investigating the world; (2) recognizing perspectives; (3) communicating ideas and (4) taking actions as shown in Fig 1. Through STEM educational settings educators can inculcate such competencies in young learners and make them prepare to face the future world challenges and solving real world problems [9] as shown in Fig 1. All of the above mentioned competencies require an approach of critical thinking and problem-solving skills. STEM lesson models include, students identify an issue or

Fig. 1. Asia Pacific Society Metric for Global Competencies

challenge, conduct an investigation, design a solution, test and evaluate the solution, and communicate the results [10]. Therefore major STEM education involves following learning processes: (1) Identifying an issue or challenge; (2) Conducting an investigation;(3) Designing a solution; (4) Testing; (5) Evaluating the solution; (6) Communicating the results as shown in Fig 2.

IV. Problem-solving skill

One of the skills known as ”21st century skills”, defined by Partnership for 21st century learning (P21), is the problem-solving skill [11]. Problem-solving skill development, through

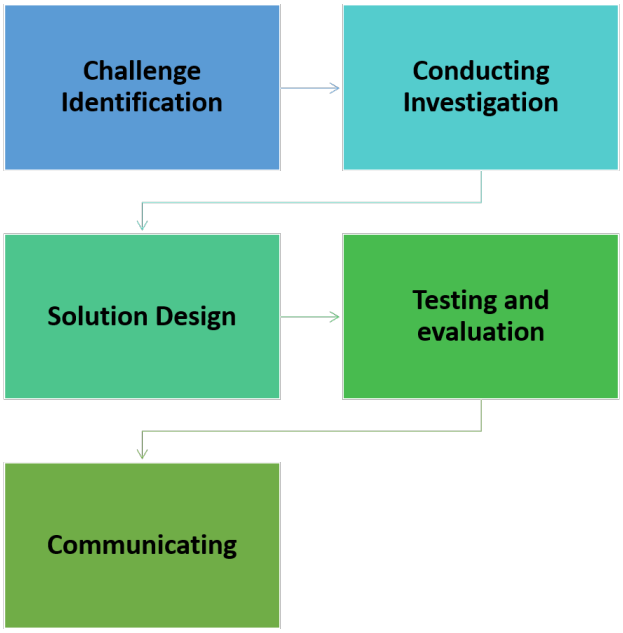

Fig. 2. STEM Learning Process

classroom instruction with real-world scenarios is always been a pedagogical challenge and an opportunity at the same time. STEM education from the primary level can inculcate this highly demanding future skill through integrating different science subjects addressing real life problems. In this way, from early childhood education, learners can acquire problem solving skill through critical thinking and problem based learning. Standards for technological and engineering literacy [12] has provided a road map for the role of technology and engineering in STEM education which paves a way to the development of problem solving skill development. In literature, problem solving skill is defined as rule acquisition and rule acquisition aligned with problem solving phases [13]. Another study suggested that routine aspect and non-routine aspect should be considered as two interacting systems. Real life problem-solving is actually the interaction between the two systems. Skills utilized in the routine aspect of the problem are defined as recurrent skills, while skills employed to solve non-routine aspect of the problem are defined as non-recurrent skills, which vary from situation to situation [14]. Recurrent skill is the ability to understand the problem and find some solution for it, while non-recurrent skill is the ability to ameliorate the existing solutions. Therefore, the interaction between recurrent and non-recurrent skills termed as a problem solving skill which is a process of problem identification, investigation, solution design, testing and evaluating, improving and communicating.

V. Applied pedagogical approach:Project oriented problem based learning

Project oriented problem-based learning (POPBL) approach is fundamental pedagogical approach applied in this research work. POPBL focuses on the problem, then analysis of the problem leading to the idea creation and designing solution for the problem and finally the implementation of the project by executing the designed activity to create the solution for the problem [20]. POPBL learning approach foster analytical and critical skills and an ability to find, argue and present innovative solutions to challenging problems in learners. POPBL is Student-centered, Problem-oriented, focuses on the learning process to address solutions. It promotes team work, social and communication skills. It also teaches learners to work in collaboration in performing actions and achieving certain goals to address challenging problems. Problem based learning enables students to efficiently and effectively analyse problem, design solution, implement and evaluate the results [24]. Therefore, POPBL is an effective approach in STEM education to engage students scientifically and allow them to think and implement their knowledge with confidence and communicate their results and actions to others.

In our research work we applied POPBL as a fundamental pedagogical approach. We planned two activities by presenting two problems to the students and facilitated them with their learning process in finding solutions for the presented problems.

A. Problem-solving skill development through STEM education

The integrated nature of STEM education takes flavours from all subjects like natural sciences, mathematics, and engineering. This integrated educational platform helps learners to develop knowledge of different fields of sciences and nurture a set of skills (critical thinking, problem-solving skill, creation and innovation etc.) commonly known as 21st century skills. Therefore, STEM education is essential for individuals to develop 21st-century skills. A study [15] has described integrated STEM education as integrative STEM education refers to ”technological/engineering design-based learning approaches that intentionally integrate content and process of science and/or mathematics education with content and process of technology and/or engineering education. Integrative STEM education may be enhanced through further integration with other school subjects, such as language arts, social studies, etc. Problem-based learning is the root methodology of integrated STEM education [16] [17].

Design-based learning: is one of the STEM education approach [18] [25] for problem-solving skill development which follows a learning process from thinking of a solution to the communication of the solution. Such kind of approach allows young thinkers to play, understand, think, and design a solution to the problem. Design-based learning or problem-based learning approach involves the identification of problem, brainstorming for the solution, designing a solution, testing and evaluating, redesigning and delivering the solution. In addition, learners learns to work in teams, interact, engage, collaborate, and communicate.

Scientific method-based learning: is another learning approach [19] which shows a real picture to the learners that

how scientists work and engage with science to solve real world challenges. Scientific method based learning involves a systematic process of seeking an answer/solution to a problem. Young kids learn to seek answers to many problems by asking questions, making hypothesis, doing experiments, making observations, critically analyzing and making conclusions to share their findings.

By applying above approaches in STEM lessons, we enrich young learners with scientific thought process, problem-solving skills, a realistic mind set considering real world problems, and eagerness to solve them.

VI. Problem-solving STEM activity with local primary school students

In this section we demonstrate design based learning and scientific method based learning STEM approaches for problem-solving skill development by presenting two different problems to primary school students of 1-6 grade. The basic aim of this demonstration is to present how young learners engage in scientific learning and how they learn to solve problems by following a scientific way of finding solutions.

A. Methodology

Two problem solving STEM activities are done with local primary school students of grade 1-6. We applied design based learning approach and scientific inquiry-based learning approach in our learning sessions. There were three sessions. In session 1 there were 12 students, in session 2 there were 8 students and in session 3 there were 15 students. So altogether 35 students participated in this activity. We divided groups as group 1 comprising of 1-2 grade students, group 2 as 3-4 grade students and group 3 as 5-6 grade students.

We collected data in terms of pictures, observations, students replies to the set of questions asked to them, and student‘s comments. We applied content analysis method to analyze the collected data.

B. STEM Acivity 1: Design-based or problem-based learning

We presented a problem, related to the environment saving to the kids from 1-6 grades in session 1,2 and 3. We applied design-based/ problem-based learning approach so that kids think and design the solution on their own.

Problem: How we can make a table from news-papers, which can hold book/books.

Motivation: Motivation to solve this problem is to save trees and avoid paper-waste by reusing it.

Materials: News-papers, tape, scissors, pencil, paper shown in Fig 3

Time of the activity: 30 min.

Questions asked in the beginning:

1. From what paper is made of?

A: Trees, wood. (a 2nd grader replied)

2. Why we need to save trees?

A: It gives us oxygen. (a 3rd grader replied)

A: It gives us food. (a 4th grader replied)

A: Because trees are animal‘s home. (a 1st grader replied)

Fig. 3. Materials for activity 1

we get shade from it. (a 1st grader replied)

3. How we can save trees?

A: By not cutting trees (a 3rd grader replied)

A: By planting more trees.(a 6th grader replied)

A: By not wasting paper. (a 5th grader replied)

4. What is global warming?

A: It means temperature of the earth is getting warm. (a 6th grader replied) A: Trees are getting less. (a 5th grader replied)

Observations: After asking few questions, we gave materials to the students and they started the activity in groups. As a result of this activity, students practiced how to think and design a solution. Many students first drew the design of the table on the paper and then started making it. We got many different designs of paper tables. Students created innovative designs. It was also observed that students got trouble in making balancing their tables but then they did rethinking and managed to solve the problems. Students worked in teams and they were eager to build something. Some kids even made more than one table. It’s important to notice here that students followed a design process and accomplish their task with a design based problem solving approach. Finally, all the groups tested their tables by placing book/books and teacher appreciated their work. We added some pictures of tables made by different students shown in Fig (4-10).

Fig. 4. Making table

Comments of the kids at the end of the activity 1:

”It was a fun.”

”I liked to do this again.”

Fig. 5. Paper table in making

Fig. 6. Paper table

Fig. 7. Paper table

Fig. 8. Paper table

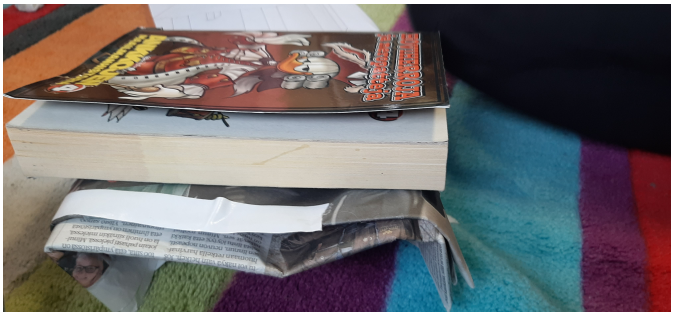

Fig. 9. Paper table

Fig. 10. Paper table

”I did it, my table is holding two books.”
”Now I want to make a chair out of paper.”
”Can we do it next time again?”
”It took us some time to think how table could be made?”

C. STEM Activity 2: Scientific method based learning

We presented a problem related to saving a medicine from spoilage, to the kids from 1-6 grades in session 1, 2 and 3. We applied Scientific method based learning approach so that kids think, experiment, observe and find the solution. We provided students with paper and pen to write down their observations.

Problem: How we can keep a medicine cold without freezer at very low temperature for some time to avoid spoilage?

Motivation: Motivation is to solve this problem by using kitchen ingredients without freezer or other cooling device. Medicine needs temperature below 0 Celsius (very low temperature).

Materials: Medicine to be saved, ice cubes, salt, sugar, thermometer, plastic bag, pen and paper for making observations as shown in Fig 12.

Time of the activity: 30 min.

Questions asked in the beginning of the activity:
1. At what temperature water freezes?
A: At +3 Calcius. (a 1st grader replied)
A: At 0 Calcius. (a 4th grader replied)
A: At 0 Calcius (a 6th grader replied)
2. What is water, liquid or solid?
A: Liquid. (a 1st grader replied)
A: Liquid. (a 2nd grader replied)
3. What is ice, liquid or solid?

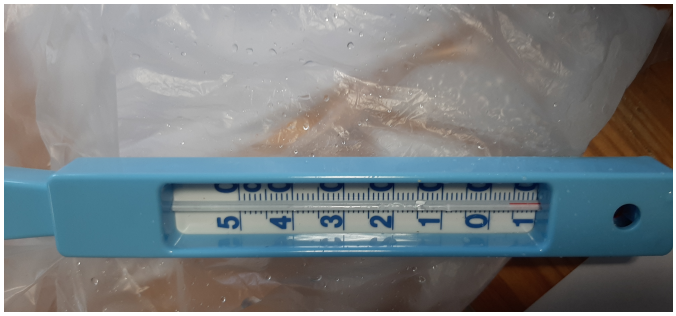

Fig. 11. Thermometer

Fig. 12. Materials for activity 2

A: Solid. (a 2nd grader replied)
A: Solid. (a 3rd grader replied)
4. What is the boiling point of water?
A: 80 Calcius (a 2nd grader replied)
A: +100 Calcius (a 4th grader replied)
A: 100 Calcius (a 5th grader replied)

Students made their hypothesis in the beginning of the experiment.

Some said (Hypothesis 1): ice and salt can make low temperature.

Some said (Hypothesis 2): Ice and sugar can make low temperature.

They took observations as;
Temperature needed by medicine = below 0 Calcius
Temperature of the ice = ?
Temperature of the ice + sugar = ?
Temperature of the ice + salt = ?

Students took observations and wrote them in table as shown in Fig 13 and Fig 15.

D. Comments of the kids at the end of the activity 2

”I want to become a scientist”.
”I love to do experiments”.
”Thinking and finding solution is fun.”

VII. Discussion

Problem-solving skill is a 21st century skill required by the future workforce. Global digitisation, industrial automation

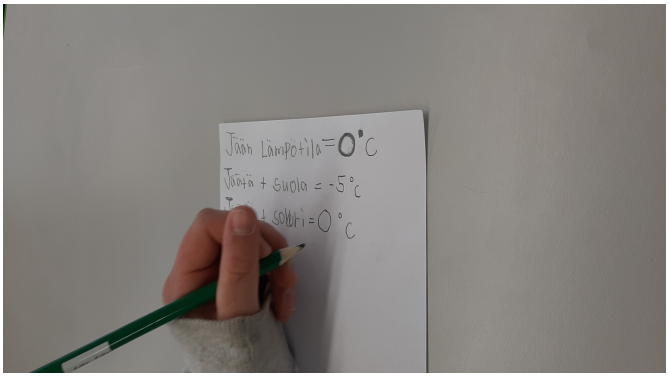

Fig. 13. Making observations

Fig. 14. Ice and salt

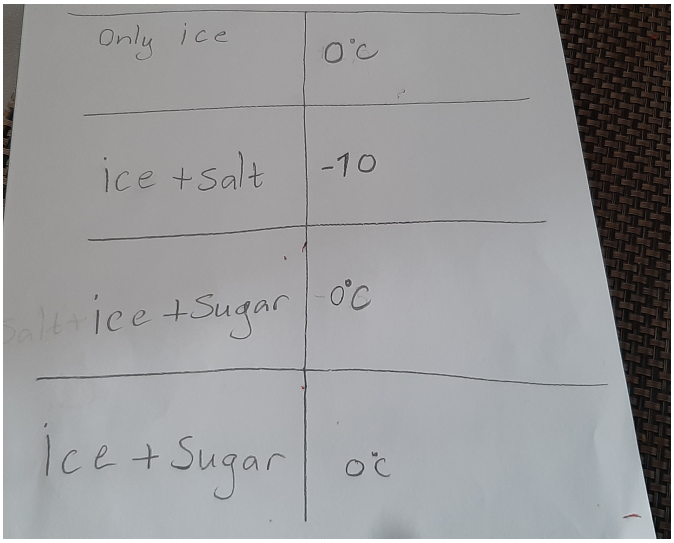

Fig. 15. Observation table

and advancement in new fanged technologies demands a skill full human resource for future. To meet the future industrial challenges and to create practical solutions to real life problems, we need critical minds with scientific knowledge. STEM education in early school days with project oriented problem based learning approach nurture skills like problem-solving skills, critical thinking and analytical thinking in learners. In addition, young learners get motivation to opt for scientific careers in future. They show interest towards STEM subjects.

Results from our STEM activities has shown that by integrating knowledge and techniques from multiple disciplines facilitates learners to develop their professional skills to competently address real world problems and challenges. Young minds learn the scientific approaches to solve problems in real life situations. Our STEM lesson sessions achieved following objectives;

-Develops interest in young learners to choose scientific careers in their future.

-Learns to work in teams and learn how to communicate, engage and interact within the teams/groups to solve a problem.

-Design thinking

-Learn to think about their surrounding and about phenomenons happening in their surroundings

-Develops critical thinking to evaluate and analyze certain outcomes, phenomenon, findings etc.

-Learns to rethink, troubleshoot and design the solution again to fix the problem and bring better solution.

-Finally, deliver the solution and communicate the results/findings to others.

Although, our study focused on the primary school education and participants of the study were young learners aged 7-12, but we can apply the same strategy within the higher education setting. Problem-based learning approach fosters practical skills in learners rather than theoretical knowledge only. Therefore, shifting from knowledge-focused teaching to competence teaching is necessary for educators to inculcate practical skills in learners for the future work force development. Engineering education, technology education and natural sciences education requires problem oriented problem based learning approach to develop 21st century workforce.

STEM education is a stepping stone in building scientific thought process, problem-solving skills, and critical thinking in young learners. Today‘s young learners are tomorrow‘s workforce. To meet the challenges of 21st century industrial revolution, STEM education focusing on problem oriented problem-based learning must be the part of the basic education to inculcate 21st century skills in future‘s workforce and to attain sustainable economical development.

VIII. Conclusion

Problem-solving skill is an important skill, which enables humans to bring ideas, innovate, create and make this world better to live. In this article we demonstrated that how STEM education nurtures problem-solving skill in young learners by applying different STEM learning approaches. In future work, we will investigate that how technology can help STEM learning and catalyzes skill development processes in young learners.

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