ON USING A STEAM PROJECT-BASED LEARNING MODEL FOR SECONDARY SCHOOL STUDENTS: DESIGN, DEVELOPMENT AND EVALUATION

Shivalika Sarkar
Regional Institute of Education
Shyamla Hills
Bhopal – 402 002
Email: shivalikasarkar@gmail.com

There has been much talk about using the STEAM pedagogy to promote active learning and achieve the desired competencies. However, bringing STEAM pedagogy into the classroom can be a challenging task. A STEAM pedagogical model on project-based learning for the secondary level is discussed in this paper. Through a carefully designed interdisciplinary project named "Our Sun," the elements of STEAM were brought into the high school science classroom. The model was also tested on 80 students of a school in Icchawar Block, Sehore District of Madhya Pradesh. The PBL approach is effective in providing hands-on experience to the students as well as in developing other skills like creativity, inquiry, sharing, debating of ideas within a learning community. It was found that this approach goes in line with the principles of STEAM.

Keywords: STEAM, Project-based learning, Secondary school

Introduction

STEAM stands for Science, Technology, Engineering, Arts and Mathematics, and STEAM pedagogy encompasses various activities which involve the integration of STEAM in the classroom. As we move from STEM to STEAM, the integration of arts in STEM has been done to improve student learning, creativity, and competencies. STEM was coined by the NSF (National Science Foundation) in the USA two decades ago, and since then, STEM has gained much popularity and has proved to be an effective pedagogy in enhancing student learning and achievement (Armknech, 2015). To improve and inculcate the 21st century skills among the learners, arts were added to STEM, which gave birth to STEAM. Hence STEAM education promises to inculcate among the learners the skills of problem-solving through innovation, creativity, critical thinking, communication, collaboration, and competencies required in the real world. As National Education Policy 2020 states that "no hard separations between arts and sciences, between curricular and extra-curricular activities, between vocational and academic streams, etc. in order to eliminate harmful hierarchies among, and silos between different areas of learning."

The need for STEAM education and pedagogy has now been recognised worldwide. With poor performances of students in science and maths, the last decade has seen an upsurge of interest in activities related to STEAM. In the 2009 Program for International Student Assessment (PISA), India was ranked 72nd among 73 countries. After a gap of almost a decade, India is all set to participate in PISA 2022, earlier planned for 2021. PISA 2022 will focus on mathematics, with an additional test of creative thinking. In order to improve the ranking in PISA, different state governments are planning to include STEAM pedagogy in schools. Therefore, a multidisciplinary approach needs to be followed for holistic development and lifelong learning. The effectiveness of this approach has been investigated by many researchers (Sadler, 2004; Walker and Zeidler, 2007; Land 2013; Madden, et al., 2013; Bevan, et al., 2019; Bevan, et al., 2020). Yakman (2008) describes STEAM education in two ways. First, it is an education in which the fields of science, technology, engineering, and mathematics are approached in a multidisciplinary manner in addition to their individual standards. Second, STEAM education is holistic, aiming at current fields and teaching subjecand ts (Park and Ko, 2012). Yakman (2008) describes the STEAM framework with the help of a pyramid to present STEAM education more concretely. The pyramid consists of five steps. The lowest order constitutes the subject content of the STEAM training areas in particular, and the contents described in this step form the basis of the disciplines given in the higher step. While the areas covered by STEM education are presented in the multidisciplinary step, the disciplines covered by this approach, i.e., state of the art integrated into STEM, are given in the integrative step. The top step refers to life-long learning. The subject areas covered in the first step of the pyramid are related to high school and professional education areas, the multidisciplinary step is appropriate for the secondary school level, and the integrative step for primary and secondary school education (Park and Ko, 2012).

STEAM is gaining increased popularity, but how this concept should be deployed and what model or framework to follow is still unclear to many (Colucci-Gray, et al., 2019; Conner, et al., 2017; Wilson, 2018). This paper presents a STEAM model whose effectiveness is also tested in the high school science classroom.

STEAM is an interdisciplinary approach and is in line with the constructivist principles of learning. The most popular approaches for integrating STEAM in the classroom are problem-based learning, project-based learning, and inquiry-based learning. This paper proposes an interdisciplinary project-based learning model to promote STEAM pedagogy in the high school classroom. Project-based learning (PBL) allows students to conduct investigations, collect, analyse, interpret data, draw conclusions, present their findings, and socially interact. PBL provides the joy of learning and gives opportunities to students to create, reflect, collaborate, solve a problem and share responsibility in their learning. The model was tested on 80 students, and the success of the model was assessed through text analysis and questionnaire survey.

Methodology

An interdisciplinary project was planned to promote STEAM pedagogy in the high school classroom. The project was named "our sun as a source of energy". Under this project, students had to participate in interactive activities, and they were challenged to create their artifacts—the project integrated science, technology, engineering, arts, and mathematics concepts. Many principles related to life processes, electrical circuits included in the Class X curriculum are often difficult for students to understand. When all these principles were integrated under a single project, "Our Sun" students could easily connect different phenomena. Through this project, we tried to imbibe the qualities of discovery, curiosity, and exploration among the students. Different activities of the project involved creating a hypothesis followed by experimenting, observing, classifying, and predicting. Each artifact built by different groups involved collaboration, creativity, optimism, and communication. The objectives of the research were:

- To use and apply project-based learning techniques in science classroom situations at the secondary level.
- To analyse the effect of project-based learning techniques on the students' conceptual understanding.
- To study the effectiveness of PBL in implementing STEAM principles in the high school science classroom.

In the project on 'Sun as a source of energy,' students learning was promoted through the following tasks/activities:

1. Learning by doing with the help of real objects.
2. Learning by experimentation.
3. Learning through peer group discussion.
4. Learning with the help of a mentor/ teacher.

The four experiments included in the project were 'Make Your Own Solar Oven,' 'Experiments with Solar Cells (Conversion of Solar Energy into Electrical Energy),' 'Sunlight (Solar Energy) Is Essential for Plants (Autotrophs),' and 'Showing Transpiration in Plants in the Presence of Sunlight.'

Research Design

The methodology for the project was interpretivist qualitative research based on an exploratory case study to examine school students' engagement and reflections on the PBL approach and completing specific project tasks given to them. The research employed a paper-based survey of students' engagement and scientific knowledge, self-reflection of learning followed by open-ended questions and observations to verify students' understanding of the scientific concepts and reflections in the project. The survey items were designed through a workshop of experts in the field. After each task of PBL, students completed the open-ended questions associated with each task given in the manual. After completing all the project tasks, students completed the survey.

Sample for the Study

The research was conducted at Government. Model Higher Secondary School, Icchawar Block, Sehore District. The respondents of the study were the two sections of Class X comprising 80 students, wherein the researcher conducted the project-based learning technique. Most students belonged to an economically backward class. The school did not have well-equipped labs and a computer facility. Students did not have access to technology. Due to the above points implementing PBL was a challenging task.

Tools

This research made use of the following data gathering instruments:

Student Reaction Scale

Students in the traditional classroom were presented with the content and were given few opportunities to bring their learning to life. We needed to measure whether PBL could provide enjoyment in learning, develop science concepts and processes, critical and creative thinking, learning through peers, and social skills like collaboration. For this, a survey on students' engagement and scientific knowledge was conducted to verify students' reflections about the project. Thirteen items were selected for the survey, and the school students were asked to indicate on a 5 = point scale (5 = almost always, 4 = frequently, 3= occasionally, 4 = Seldom, 5 = Never).

Self-reflection of Learning

This tool was designed to find out whether students enjoyed the whole process and to find out whether the students were engaged in the process. Finally, we wanted to know whether the student's level of interest is sufficiently high and they believe they will accomplish something of worth by doing it.

Open-ended Questions for Discussion

Each group had to answer a set of questions given in the instruction manual related to the scientific principles associated with the task, observations taken, and application of those principles to their daily lives. These questions were open-ended and helped us understand whether this approach could develop the conceptual understanding of the students in science.

Project Report Collected from Each Group

Each group was asked to submit a project report at the end with the title and duration of the project, names of the students in the group, class, description of the project, learning methodology followed, answers to the questions given along with each task in the instruction manual and learning achievement. This helped us evaluate each group's overall performance based on rubrics.

Data Collection

The class was divided into ten groups, with eight students. An interdisciplinary project from Class X Science Curriculum on the topic 'Our Sun' was assigned to imbibe the concepts of photosynthesis, electricity, our environment, and sources of energy. Four project tasks were given to each group. Data for self-reflection of the students' learning was collected through a questionnaire. A survey on students' engagement and scientific knowledge was conducted to verify students' reflections about the project. Open-ended questions were given in the instruction manual related to the scientific principles associated with the task, observations taken, and application of those principles to their daily lives. Each group had to submit their artifacts, project report and were required to make a presentation on 'Sun as a Source of Energy.' The final project was evaluated with the help of rubrics.

Intervention

The facilitator explained to the students that they had to work in teams on STEAM challenges.

The first day of PBL comprised students being divided into groups. Ten groups of eight students were formed. Students were asked to name their groups by a scientist of their choice. All students enthusiastically participated in this process and chose different scientists' names from their groups.

A group leader was selected from each group democratically. Students were also asked to prepare badges of their choice for each group. A poster competition was also announced on the theme 'Our Sun.' A brief documentary on our Sun was shown to the groups. After the documentary was finished, each group was asked to discuss themselves and reflect on the documentary. After this, an ice breaker activity was conducted to become familiar with the students. This activity comprised mulling over why a candle extinguishes when covered with glass. Students enthusiastically participated in the activity.

After this, necessary material to conduct the different activities was supplied to each group. Students were asked to perform each task within their groups and discuss the results obtained. After all the groups finished the experiment and their discussion within the group, the instructor asked one student to present their observations and reflect on the possible cause behind the observations.

The second day of PBL started with the presentation of the badges and posters by each group. Every group member was asked to wear the badge prepared within each group. The theme for poster making was again 'Our Sun.' All the posters were displayed on the wall of the classroom. Figure 1 shows a sample poster made by one of the groups.

Now it was time to start with the project-related activities. The project's first task was to make their own solar oven and test it. A kit comprising required material (pizza box, scissors, aluminum foil, clear tape, plastic wrap, black construction paper, newspapers, ruler or wooden spoon, thermometer) to make the solar oven was distributed to each group along with a lab manual comprising steps to be followed to make the solar oven and discussion questions related to each task was given. The manual comprised all the

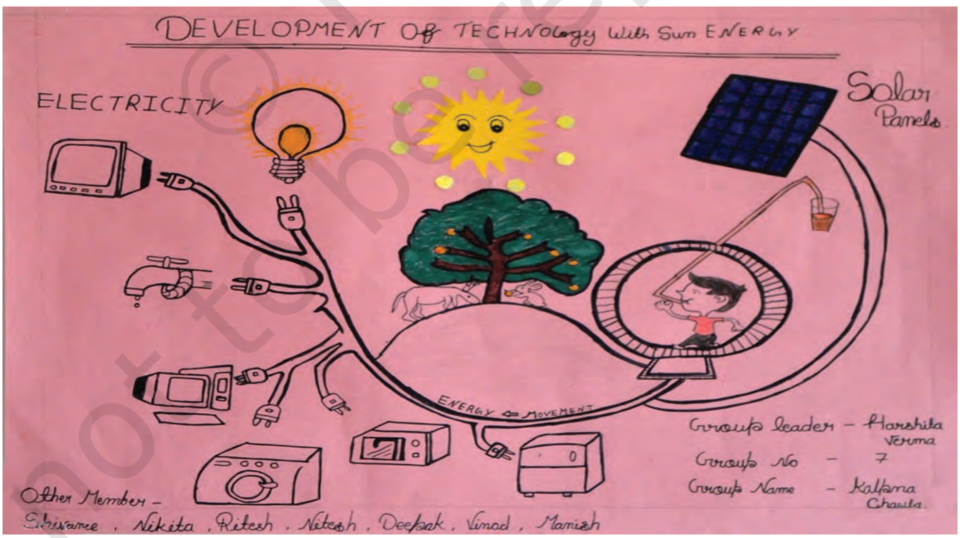

Fig. 1: A poster made by the group on the theme

tasks to be completed under the project 'Our Sun' and discussion questions that were conceptual in nature to discuss within the groups and their answers to be written neatly on a separate sheet of paper. The manual also comprised plenary questions to be discussed among groups at the completion of the task. Each group actively participated in the task, made their artifacts, and tested them (Figure 2).

Fig. 2: Students testing their own solar ovens

The next activity was making a solar-powered fan. All necessary material (solar cell, plastic-coated wire, electric motor, soldering gun, solder (rosin core), sandpaper, knife or wire stripper (optional), 6-inch (15-centimetre) diameter cardboard circle, utility knife, glue (hot or white), plastic wheel with axle hole in centre, black marking pen, stopwatch, one sheet of black construction paper, several sheets of coloured transparency film in a variety of colors, paper, and pencil or pen) was distributed to each group.

Students were asked to draw the circuit diagram connecting the solar-powered fan. Then, they checked the current and voltage rating of the solar panel provided in the kit. Students also checked the open-circuit voltage (Voc) and short circuit current (Isc) using a multimeter provided in the kit. Next, they connected the solar panel to the DC

Fig. 3: Models of solar-powered fan made by students

motor and the fan and checked how the speed of the motor changes when the solar panel is illuminated in sunlight. They also checked how the motor speed changes with the orientation of the solar panel. They also calculated the theoretical power, actual power, efficiency of the solar panel, and the effect of different colour transparencies on the output power and speed of the fan. Figure 3 shows the artifacts made by the students under this task. A discussion was then conducted among different groups on how to make a closed circuit, how solar panels can be used as a source of electrical energy, and how solar energy as a renewable source of energy can be used in any area. All the activities required integration of science, technology, engineering, and mathematics.

The next day, students had to work on a different task: examining that plants release oxygen in the presence of sunlight during photosynthesis. Again, all necessary materials (beaker, test tube, funnel (all materials should be transparent), some sprigs of hydrilla *(Vallisneria)* aquatic plants, baking soda) were distributed to each group as mentioned in the manual. Accordingly, different groups had to perform the task under different conditions, as shown in Figure 4.

Fig. 4: Different tasks assigned to different groups under project task 2

Fig. 5: Students examining their hydrilla setups

After completing their experiment, all the setups were displayed at a place, and a discussion on the observations in different setups was done. Many questions were raised, like, are there air bubbles in your setup? If yes, why if not, then why? Which setup has more air bubbles? Can we count the number of bubbles? After two hours, all the experimental units were inspected to find out the test tube, which was more than half-filled with gas bubbles. The facilitator raised the question, "let us try to identify the gas in these bubbles in the test tube." The facilitator showed the students that a lighted incense stick, when inserted in the test tube with its mouth tightly closed, lights up instantly, showing the presence of carbon dioxide gas in the test tube. This activity showed the students how gas evolution occurs in sunlight.

On day 5, two activities were completed. One was to observe transpiration in plants in the presence of sunlight, and the other was to examine the process of photosynthesis. The first activity conducted was to observe transpiration in plants in the presence of sunlight. All necessary materials were distributed to each group as mentioned in the manual. For the first activity, students went outdoor and tied transparent polythene bags to cover the leaves of some plants. Some of them tied polythene bags to cover the leaves of plants coated with Vaseline. The difference had to be observed. After finishing, students returned to their classes and discussed among themselves, and then discussion within the groups was conducted.

After completing each activity, students discussed among themselves and completed the open-ended questions given in the

Fig. 6: Leaves tied with polythene bag

Fig. 7: Water droplets visible on the polythene bags

instruction manual. Also, on completing all the activities, students had to prepare a project report, and a presentation by each group was made on the topic 'Our Sun.'

While constructing each artifact, students were using their creativity, working collaboratively to achieve a common goal, using different science concepts, analysing and plotting data, and becoming aware of the technology used.

Results

This research project was created using in mind that students understand the concept of the sun as a source of energy and its different applications. In the NCERT Science Textbook for Class X, different chapters on photosynthesis, electric circuits, our environment, and energy sources are given. Through this project, we have tried to integrate the various concepts given in these chapters in a single project entitled 'Our Sun.' The PBL students were assigned to research the essential question, "How can we utilise energy from the sun?"

We needed to know whether students enjoyed this process of learning. Table 1 gives the self-reflection of the learning of the students.

Table 1
Results of Self Reflection of Learning

I enjoyed making my own artifacts. I liked this way of learning very much. I would like to learn this way	76%
I did not understand the activities completely I needed help in completing the tasks. With teacher support, I am willing to learnthis way again.	22%
I did not like performing the activities I did not find the activities interesting I want to learn by the method I used to	2%

A survey on students' engagement and scientific knowledge was conducted to verify students' reflections about the project. Thirteen items were selected for the survey, and the school students were asked to indicate on a 5 = point scale (5 = almost always, 4 = frequently, 3 = occasionally, 4 = sleldom, 5 = never).

Table 2
Survey on Student's Engagement and Knowledge

Statement	Almost always 5	Frequently 4	Occasionally 3	Seldom 2	Never 1
Provides enjoyment in learning	79%	18%	3%	-	-
Working in a small group with a mentor helped to learn	48%	42%	8%	2%	
Easily develops science concepts and processes	80%	18%	2%	-	-
Develop critical and creative thinking	47%	39%	6%	8%	-
Promotes learning through peers and collaboration	65%	19%	16%	-	-

Provides an opportunity to correlate the subject matter in a real-life situation	22%	36%	18%	24%	-
Provides an opportunity to work in groups	40%	32%	7%	21%	-
Give freedom to plan and perform own learning in own ways	58%	28%	8%	6%	-
Helps in developing practical skills	52%	30%	8%	10%	-
Involves in life-like and purposeful activities to promote learning	55%	32%	11%	2%	-
Promotes learning by doing	63%	34%	3%	-	-
Provides a real and direct experience.	34%	43%	15%	8%	-
Helps to develop social skills and values among the students	50%	32%	7%	11%	

In this project, school students engaged in the activity in groups of ten. Each group was given all necessary components to complete the project tasks and was encouraged to use their logical reasoning and trial and error to complete a given project task. Different items of the survey are displayed in Table 2. According to the data given above, 97 per cent of the students enjoyed the PBL approach. This agreed with the item mentioning that working in a group with a mentor helped them successfully complete their tasks (90%). It is worth mentioning that 87 per cent of the students also found these activities purposeful and linked to their daily lives. The students experienced a different way of science learning through working in groups and collaborating with peers, giving them a new learning experience. This different learning experience provided the students with new perspectives on science learning. In addition, students developed their collaboration and communication skills. They learned that collaboration helped them complete the tasks in an enjoyable environment.

For the final source of data, each group had to answer a set of questions given in the instruction manual related to the scientific principles associated with the task, observations taken, and application of those principles to their daily lives. In addition, they had to submit a project report, and also each group had to make their presentation on the topic 'Our Sun.' Finally, the overall project was evaluated with the help of a survey, answers to discussion questions, self-reflection of learning, project report, and presentation made by each group with the help of rubrics. Figure 8 shows the overall performance of the different groups.

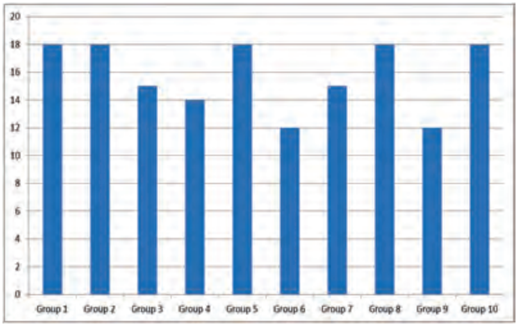

Fig. 8: Overall performance of the groups

Discussion

The learning experiences provided by PBL are relevant to the principles of National Education Policy 2020 (NEP-2020)* that envisages critical thinking, analysis based learning by meaningful experiences to the learners. Conceptual understanding became easier as students could link the concepts to their daily lives. Students experienced the benefits of working together, which stimulated their collaboration and communication skills. Students were also interested in completing the project and finding different ways to complete their tasks. This project-based learning model of integrating STEAM concepts effectively targets many content areas. The STEAM approach has overtaken the STEM approach, and research has proved its success, especially in countries like Japan and South Korea (Jin, et al., 2012; Yakman and Hyonyong, 2012). However, a challenge is how to implement the STEAM principles in the traditional classroom. In our simple PBL framework presented in the paper, we touched several content areas belonging to different science disciplines like physics, chemistry, and biology. However, teachers can start small in their first implementations and pick only a couple of content areas to target. However, as teachers and students become more PBL-savvy, STEAM can be an excellent opportunity to create a project that hits science, math, technology, and even art content.

From designing to creating the artifacts, the entire project involved many concepts of science, mathematical concepts like measurements, calculations, graphs, technology, and the use of various tools in building the artifacts. This experience will help the students build their creativity and critical thinking, which will help them find solutions to real-life problems (Chung, et al., 2017; Jho., H., Hong, D. and Song, J., 2016).

In the traditional classroom, students usually listen to a lecture or get a chance to view a demonstration done by the teacher, but in the PBL classroom, students were actively involved in all the activities discussing and collaborating with their peers. The role of the teacher was that of a mentor providing guidance whenever required.

Creating, building, testing, improving, reflecting, predicting, building higher-order skills, and positive approaches to learning were the attributes of the project activities. Students understood various processes that can be explained by the conversion of energy received from the sun. In this process, students' collaborating skills improved as they gained more experience working in groups to complete the different project tasks. Initially, students had a tough time working with groups and participating in group discussions,

*The Original reference was Draft NEP-2019 but by the time of publication of this issue, NEP-2020 was published and hence modified accordingly.

which gradually improved. After completing the project, most of the students expressed their satisfaction with STEAM integration of different concepts in a single project, evident from the results presented in Tables 1 and 2. Creating the artifacts successfully also demonstrated that they had acquired diverse skills like problem-solving, creativity, and critical thinking (Herro and Quigley, 2017; Zalaznick, 2015).

Conclusions

This study proves that project-based learning in the high school science classroom is an effective instructional approach. Specifically, PBL is valuable for promoting understanding of critical concepts in science and for learning and using scientific practices. Students expressed very positive attitudes towards doing project tasks as part of their science instruction. Many principles related to life processes, electrical circuits, are often complex for students to understand. When all these principles were integrated under a single project, 'Our Sun' students could easily connect different phenomena. By completing the project tasks and gaining the skills to record and analyse data on different tasks, students could construct their understanding of the several concepts of the high school science curriculum. From the students' viewpoint, this is a very different experience than reading about different concepts in a book, doing different activities in the classroom, watching a video about the sun, interacting with peers, discussing and presenting their viewpoints and ideas. By gathering their data and then using it to contribute to a real-life problem, students draw on various skills from other disciplines and use higher-order reasoning to accomplish the task. By engaging in this project, the students experienced a sense of gratification as they realised that their ideas were valued and actively involved in making the world a better place. The many advantages to this instructional approach include: contextualising and establishing a purpose for learning, creating a shift in the teacher's role from being an expert to being the facilitator, and developing a stronger sense of classroom community. This context made the abstract more concrete and will provide a strong foundation for the student's future study of physics, chemistry, and biology. Additionally, the 'real world' application embedded within the project was equally important for creating a purpose for the learning and keeping students engaged and motivated.

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