EXPLORING A STEM EDUCATION PEDAGOGY: TEACHERS' PERCEPTIONS OF THE BENEFITS OF AN EXTENDED INTEGRATIVE STEM LEARNING PROGRAM

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ABSTRACT

Although integrative STEM learning is gaining prominence, few research studies have been conducted to explore the development of STEM education related pedagogical practices. Such practices are needed so that students experience the way in which problems in STEM contexts are solved in real-life situations. The aim of this research was to explore the benefits of implementing a stage-based learning program that focused on the engineering design process and the development of inquiry skills concurrently. The research was qualitative in nature and the data were created from interviews with the teachers, who observed the implementation of the learning program. The perceived benefits were in relation to: the impact on students' participation and engagement, the effectiveness of the learning sequence implemented, and the opportunities for further learning.

Keywords: *STEM, engineering design process, inquiry, POGIL*

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BACKGROUND

Science, Technology, Engineering and Mathematics (STEM) education as an entity has been advocated since the early 1990s yet little progress has been made in making it mainstream in school curricula for the compulsory years of schooling. To facilitate the up-take of STEM education, recent research has explored implementation of STEM activities in classrooms (e.g., English, 2016; Fitzallen & Watson, in press; Kelley & Knowles, 2016; Moore & Smith, 2014; Ward, Lyden, Fitzallen, & León de la Barra, 2015) but the focus was often on the utility of the activities for learning content and few studies have explored the pedagogical practices that facilitate learning from integrative STEM learning activities.

Integrative STEM Education

It has become apparent that integrative STEM education can manifest in different combinations of two or more of the four disciplines (Becker & Park, 2011; English, 2016; Fraser, Earle, & Fitzallen, 2019). From a teaching perspective, this is problematic due to the pedagogy employed in the classroom being determined by the discipline expertise of the teacher or instructor (Wang, Moore, Roehrig, & Park, 2011). As a result, the engineering aspects of STEM activities are less likely to be the foci of integrative STEM learning opportunities. To compensate for that deficiency, schools take advantage of STEM outreach activities delivered by professional organisations and universities. Whilst such programs play a valuable role in broadening student experiences (Laursen, Liston, Thiry, & Graf, 2007), their one-off and transitory nature limits their effectiveness. Although often delivered by experts in the field, such programs do not offer the opportunity for students to develop the inquiry skills necessary to utilise fully new knowledge gained from such programs.

STEM Pedagogy
In general, integrative STEM learning programs relate to real-life contexts and feature the development of proto-types or models to simulate authentic problem-solving scenarios (e.g., Moore, Guzey, & Brown, 2014; Ward et al., 2015). They also involve students taking an inquiry approach that incorporates working in groups, which fosters discussion about the problems and potential solutions (Kelley & Knowles, 2016). Moore and Smith contend that STEM integration can occur from two perspectives – context integration or content integration. When related to engineering activities, context integration involves using the engineering design process (Figure 1) as a pedagogical means of developing learning about technologies through integration and application of mathematics and/or science (Ward, Lyden, & Fitzallen, 2016). Content integration involves purposefully targeting engineering and disciplinary content as learning goals. Little guidance, however, is available on the most effective pedagogical approaches needed to facilitate content integration and the learning potential offered by both aspects of STEM integration.

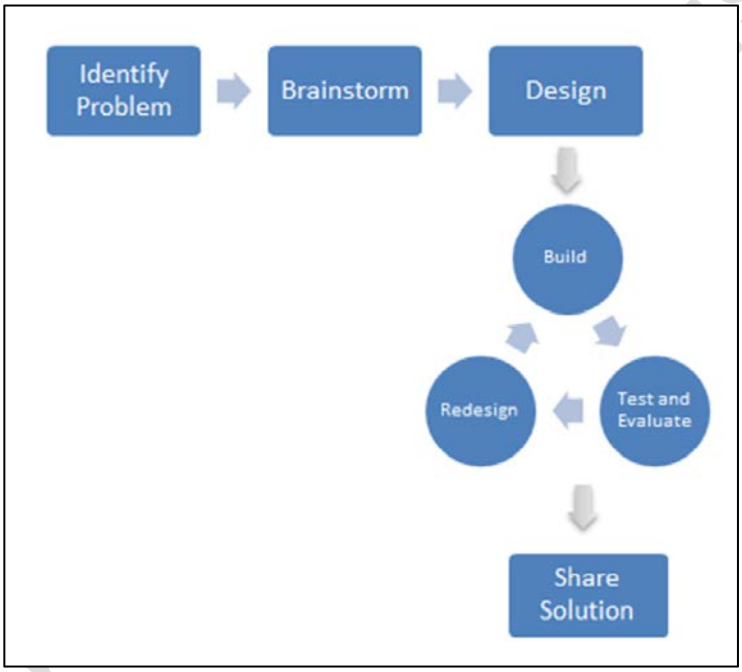

Figure 1. **Engineering design process**

A key pedagogical approach appropriate for accommodating learning about the engineering design process in conjunction with science content is process-orientated guided inquiry learning ([POGIL] Moog & Spencer, 2008). This a student-centred, constructivist pedagogy where the students are guided through content with a focus on active engagement with the learning process (Eberlein et al., 2008). It focuses not only on knowledge acquisition but also process skill development, which are achieved through the introduction, development, transfer, and consolidation of ideas according to a stage-based learning cycle. This begins with an initial exploration phase where the requisite subject knowledge is developed, followed by concept formation, where the facilitator through well-constructed questions, guides students to develop understanding of the concept. The final stage is application, which integrates naturally into context-based and team learning environments. This pedagogy was developed for and is primarily used in higher education settings. It has, however, been implemented successfully in secondary science education (Trout, Padwa, & Hanson, 2008).

THE STUDY

The research reported in this paper investigates the implementation of a five-week learning program designed to develop students' knowledge of STEM concept, as well as the requisite problem-solving and inquiry skills needed to leverage new knowledge gained to new experiences and contexts. The aim of the research was to determine the benefits of implementing a stage-based learning program that began with instructor facilitated guided learning activities and culminated in student-directed inquiry tasks. The learning program was developed in accord with the POGIL strategy (Moog & Spencer, 2008) to facilitate the application of the engineering design process as means of delivering learning about the science concepts embedded within the learning activities. The extended learning program was delivered to upper primary students by instructors with expertise in engineering fields from a School of Engineering and ICT at a regional university.

RESEARCH APPROACH

This research is qualitative and exploratory in nature. It adopts a pragmatist paradigm (Creswell, 2014) and utilises qualitative data to investigate the implementation of a staged-based integrative STEM learning program. It examines actions and situations to develop an understanding of the meaning of ideas by drawing on qualitative research methods and techniques. An emphasis is placed on developing an understanding of what works by examining solutions to problems to derive knowledge about the problems (Patton, 2002).

The Learning Program

The learning program involved the students being exposed to a staged progression of learning from guided inquiry through to student-directed activities centred on team learning. All activities in the program featured a hands-on component and the learning experiences progressively built upon each other. These experiences first aimed to support the development of understanding of electricity and related scientific concepts as well as to familiarize students with the engineering design process (Figure 1). Having established this foundation, the learning experiences aimed to facilitate students in developing the skills and confidence needed to translate scientific knowledge and design skills to solving practical problems. A summary of the workshops is provided in Table 1.

Table 1. Learning Program

Workshop	Scientific Concept Addressed	Engineering Skills Addressed	Learning Approach
1	Electricity and Circuits	Underlying scientific knowledge and experimentation	Guided Inquiry Individual
2	Electromagnetism	Application of scientific knowledge to other domains	Guided Inquiry Individual
3	Sound	Application of scientific knowledge and introduction to design parameters	Guided Inquiry Teams
4	Water Pressure	Application of the engineering design process in a real-world context	Semi Self-directed Inquiry Teams
5	Wind Turbines	Application of the engineering design process in a real-world context	Self-directed Inquiry Teams

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In the first workshop students were introduced to the concept of electricity and learned about electrical circuits. In pairs, students constructed simple circuits on solder-less electronic toy brick kits by following picture-based instruction sheets. Students were then asked to answer questions related to electricity and circuits, in general, and the circuits they had constructed. Although the majority of the session was guided by the facilitators, segments of the session provided opportunities for the students to work autonomously to investigate which materials behave as conductors and insulators.

In the second workshop, the focus was on the application of the students' acquired knowledge of electricity and electrical circuits to the concept of electromagnetism and how it can be used to generate electricity. Students explored magnets and magnetic fields using iron filing field line viewers. Students were then given kits which included all the requisite pieces to create a hand-powered light, utilising a small generator. Students were given no instructions on which components were required but were guided through the process of experimenting with component combinations until they could turn on the light. They then utilised these skills to create an electromagnet. Finally, they developed a relationship between the number of turns in a magnetic coil around an iron nail and the number of paperclips that could be attracted, based on data collected from numerous trials.

In the third workshop there was a shift from a focus on only learning about scientific concepts to developing design skills. In this workshop the students were introduced to the science of sound. They learned how sound is created, and the movement of sound waves and vibrations. They then drew on their knowledge of electromagnetism from Workshop 2 to construct simple speakers out of low cost materials. To construct a speaker, the students were offered several different construction materials for the speaker's cone. These included paper, plastic, aluminum foil, and tin cans. The activity culminated in a discussion where students were encouraged to evaluate the difference each material had on parameters like clarity and volume of the sound produced.

In the fourth workshop, the focus was on developing engineering skills and how to utilise new scientific knowledge in problem solving. The session began with the students being given some new scientific knowledge about water pressure. This was introduced in the form of a group activity, looking at bottles of water with holes down the side and how the amount of water above the whole affected the pressure of the water exiting the hole. The engineering design process (Figure 1) was then introduced formally. The students used the process in designing and implementing a water tower and distribution system capable of transporting water over the distance of a metre. Students were asked to start at the design stage and sketch out the basic details of their planned solution, including details such as the height of the initial reservoir above the ground, what size and shape the reservoir might be and how the water flow would be controlled on its' way to the end point. The test and redesign aspects of the process were emphasized to encourage the students to exercise evaluative skills when testing their design to find features that needed improvement. The final designs were tested as a group, again with the focus on developing effective strategies for identifying potential improvements for each design.

The capstone activity was a design challenge, which involved designing and building a prototype wind turbine from low cost materials and a 2.5 Volt direct current (DC) motor. The performance of the wind turbines was measured by the output power achieved when placed in front of a strong fan.

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This activity required the students to exercise both the scientific knowledge and design skills they had developed and practiced in previous sessions to design, build and test their wind turbines without specific instructions.

Participants and Implementation

The learning program was delivered in four state-funded Australian primary schools identified as either regional or as having students from low-socioeconomic backgrounds. It was run with a total of * students from Years 5 and 6, encompassing ages 10-13 years. The program involved the delivery of five workshops over a period of five school weeks, with a two-week school term break after the third workshop. The first four workshops each ran for 1.5 hours. For the final workshop, the students involved in the program from the four primary schools visited their local high-school where they had a full day of activities, including the final workshop in the program.

The learning program was facilitated by undergraduate and postgraduate engineering students, who were STEM ambassadors from a university-based STEM Education and Outreach Team. Each school was allocated one senior facilitator who attended all the sessions with that school. Supporting the senior facilitator in delivering each session was one or two junior team members, who may or may not have attended all the sessions at the school. Changing the STEM ambassadors across the course of the learning program allowed the students to be exposed to expertise from different fields of engineering.

Data Collection and Analysis

The data for this study were created from post-program interviews with the three classroom teachers involved in the project. Although the STEM Education and Outreach Team delivered the learning program, the regular classroom teachers were in attendance. Their role was to not only support the implementation of the activities but to also observe the students so that they could comment on the benefits of the learning program. A 45-minute semi-structured interview (Fontana & Frey, 2003) was used for collecting data from the class-room teachers. The semi-structured format allowed for the interviewer to elicit pertinent information about the unique experiences of the students. The interviews were transcribed verbatim and analysed using cluster analysis to determine the main themes that arose from the data (Creswell, 2014). Ethical approval for the project was granted by the Tasmania Social Sciences Human Research Ethics Committee. Pseudonyms are used to report the comments made by the teachers.

RESULTS

The key themes that arose from the teacher interview data were: the impact on students' participation and engagement, the effectiveness of the learning sequence implemented, and the opportunities for further learning.

Participation and Engagement

All three teachers commented that the students were highly focused during the sessions and stayed on task. They reported that behavior, interest and engagement were either as good as in the regular classroom setting, or better. Gerard reported that before the sessions began he had concerns that the students' behaviour may have been an issue because they were going to be doing activities that were outside of their usual routine. He was pleased to report that his concerns were unwarranted and attributed the high level of student engagement to the organisation and sequencing of the learning experiences. He said, "*when it's something different and something out of routine, then it [behaviour] is an issue… so the fact that this was out of their routine and there were no behavior*

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issues, just goes to show how well it was delivered…." Similarly, Felicity was impressed by the way in which her students maintained engagement with the various tasks. Christine, however, reported no change in student engagement, which was usually good.

The teachers mentioned consistently the students' high levels of excitement during the workshops. They suggested that the high level of excitement was more than just interest in the "fun resources." Christine said "*… it was excitement about learning not just about gimmicky things.*" When asked what level of excitement he saw in the students participating in the workshops, Gerard stated, "100%," and added "*… they were just up for whatever came their way.*" Felicity also commented on high excitement throughout the workshops. She said, "*They've been really excited, you know, they haven't whinged about it or anything like that, which is really good.*" The teachers all agreed that working through different activities that targeted the development of understanding of key ideas helped the students maintain interest.

The Learning Sequence

When asked to reflect on the learning program, Gerard remarked that the guided inquiry approach using the POGIL strategy supported his students to work independently. Christine was impressed with the way in which the learning sequence empowered her students to collaborated in groups. She attributed this to the way in which the students moved from working independently, in the beginning, to contributing to team goals by the end of the learning sequence. Felicity commented on improved collaboration and group work within the workshops compared to normal, "*I think a lot of the way they worked in groups to create things [was] to share ideas and sort of take turns and exhibit the sort of things which sometimes they're not the best at.*" In relation to students who had not participated in the full program, Christine commented that it was obvious that those students had not been exposed to the engineering design process and had not developed their self-directed inquiry skills that the other students who had participated in the full program had displayed. She said, "*I think they hadn't had that benefit of the previous sessions.*"

Opportunities for Further Learning

All three teachers commented on ways in which they would use the engineering design process in learning activities. Christine observed that the students' response to the design aspect of the activities was not as productive as she would have liked. She remarked that *"some of [the students'] initial designs were very basic, sort of almost stick drawings."* She then went on to say that she saw the potential for her to provide learning opportunities for the students to develop their drawing skills later. Gerard also reported that his students were keen to extend the learning experiences beyond the designated lessons. Christine's class opted to continue working on the wind turbines "*because they wanted to try changing some variables.*" In follow-up sessions, Christine reported the students applied the engineering process to make decisions about modifications needed to optimise the wind turbines' performance. She was impressed with the way in which they identified potential changes, revised plans, made modifications, and retested the devices. The motivation to extend their learning beyond the experiences offered was evident when the students conducted more research about wind turbines and presented their findings and the modified models constructed at a school assembly.

DISCUSSION AND CONCLUSION

The quest to explore how to teach STEM education and the type of learning activities that foster the STEM-based skills needed for solving problems in real-life contexts is ongoing (e.g., Fitzallen & Watson, in press). The research reported in this paper provides an example of a pedagogical approach that takes a stage-based strategy to learning that focuses on the development of content

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knowledge and inquiry skills (Eberlein et al., 2008; Moog & Spencer, 2008) through the application of the engineering design process (Ward et al., 2016). Traditionally, STEM inquiry-based learning involves working on projects that evolve of a period of time, such as design challenges involving robotics or solar panels (examples in Office of the Chief Scientist, 2016). Implementing and sustaining long term projects is not always feasible in the everyday classroom. Using different inter-related learning activities over the course of the learning sequence to support students to develop the skills to work together collaboratively proved to be beneficial, both in terms of developing the skills needed to be an “engineer” and the skills needed to collaborate within team-based work environments. This research suggests such an approach engages students effectively in the learning process. Further research is needed to explore the impact of the POGIL on students’ content knowledge and ability to transfer that knowledge through the inquiry-based learning process in other contexts.

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