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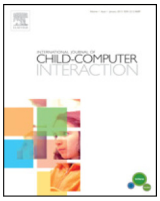

Problem-based science, a constructionist approach to science literacy in middle school

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ABSTRACT

This paper describes a four-year observation using a model designed and tested in a middle school maker space, called problem-based science (PbS). PbS was used as the primary model for a middle school science curriculum adapted by the tools and mindsets of the maker movement. PbS is learning through inventing and problem solving — while using the latest in fabrication technology, like 3D printers and laser cutters, as well as more traditional making skills, like electronics, robotics, sewing and carpentry. PbS is based on Seymour Papert's constructionism, set to a science curriculum taught full time in a makerspace or fablab. Bridging ideas in design thinking, maker education, and applied math and science, the term problem-based science was used to describe how learning would look, sound, and feel different in a makerspace, when a focus was on learner-centered curriculum. The design and testing of this curriculum took place as part of the 5th and 6th grade science courses offered at a private (non-public) school in California (USA) the fall of 2012, through the spring of 2016. Through daily formative assessment, as well as exit surveys, the patterns and benefits of learning in a self-directed learning space, designed for constructionism, were observed. This paper shares the highlights of those years. Video taped exit surveys conducted by the author, show that self-direction is both challenging and rewarding, students often felt trusted and respected, even if they did not always feel supported in a manner common in a more teacher directed classroom setting. Daily informal classroom observations revealed that using student driven, open-ended problem solving, rather than a 100% teacher led, step by step lab, lends to a more diverse pool of leadership practice in students and higher engagement in hard problems. Students typically seen as struggling in traditional classrooms, identified as experts and successful learners in this setting. Lastly, using PbS as a model for science literacy allows the youngest of learners to practice mindsets and habits typical of real scientists and inventors, fostering early identify formation in STEM fields.

0. Introduction

This study took place at the Hillbrook School, an independent school in the state of California that serves Junior Kindergarten (age 3) through 8th grade (age 13) students. In effort to make science education more inclusive, as well as relevant to a changing and unpredictable future, the school's fifth and sixth grade science curriculum was redesigned in the spring of 2012 to be 100% constructivist and constructionist based. Constructivism is Jean Piaget's learning theory of learning through experience [1]. Constructionism is a learning theory first championed by Seymour Papert, based on the making of artifacts to construct new knowledge [2]. Constructionism is commonly known in elementary through secondary learning environments as "Maker Education". The term Problem-based Science, is loosely based on the design thinking trend first coined in the Bay Area of California, by IDEO founder David Kelly. The underlying pedagogy of PbS is more deeply rooted in constructivism, however, or the belief that learners should construct their own scientific understanding through making and doing, and real life discoveries. When students make models, design tools for inquiry, or build inventions to learn science, this is constructionism or making in science. Piaget's Constructivism alone is difficult to measure or make visible. Papert's Constructionism, alternatively, is based on children making artifacts or some physical evidence of learning that makes their thinking and learning visible [3]. When you add the idea of constructionism for real world problem solving with a user in mind while designing, you get Problem-based Science.

The goal of using the PbS model was to increase science literacy, while fostering the mindset of creative problem solvers. Science literacy is defined here as using applied content knowledge, while practicing safe and ethical approaches to inquiry during the practice of constructionism, or invention literacy. PbS allows students to construct scientific literacy by behaving like a real scientist or engineer. David Perkins, author of the book Making Learning Whole: How Seven Principles of Teaching Can Transform

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Education, says this gives students "threshold experiences, that stimulate curiosity, discovery, imagination, camaraderie and creativity" [4]. The author would add to Perkins' list; joy, engagement and pride of ownership.

1. Methods

Adapting constructionism to a science course is possible when pedagogy and learning space design are reimagined concurrently. Open-ended prompts and problems instead of rote, or 100% teacher driven work was employed. Second, the design of a self-directed learning space that allows student access to creative technologies (also known as a makerspace) was employed for this study. All PbS classes were held in a room designed with tools for group work, brainstorming, self-documentation, basic wood and metal working, electronics, 3D printing, laser cutting, sewing, painting, and programming. The makerspace, known as the Hillbrook iLab, functioned as a drop in makerspace when not employed for fifth or sixth grade science, and hosted STEM (Science, Technology, Engineering, Math) related electives for seventh–eighth grade students.

During this study, teacher to student ratio was most often 1:20. To lower the ratio, volunteers/mentors would be asked to join the iLab to share their skills in electronics, programming, woodworking, sewing, etc. Volunteers ranged from parents and grandparents, to local experts, to distant experts through the use of Skype. All 5th and 6th grade science classes met for five hours (two classes were doubled back to back to create one two hour work time) per six day rotation. Total observation time allotted to the design and testing of PbS occurred over eight academic semesters, between the fall of 2012 and the spring of 2016.

To collect data on the effects of using PbS as a model in middle school, baseline surveys, in the form of paper based questionnaires, were conducted in the fall to assess student attitudes and self-identity around issues of creativity and a perceived value for fixing or making objects. Paper based exit surveys were also given to 5th and 6th graders, and video taped interviews of 5th and 6th graders were conducted by the author and science faculty of the Hillbrook school. While only small shifts in attitude were revealed by the paper surveys, more probing questions utilized during the filmed interviews, revealed evidence of increased self-efficacy around finding, addressing and designing solutions to real problems. Ideally, the interviews would be conducted by an outside researcher that the students did not have a personal relationship with, but that would require partnering with a university and or funding, which as a small private school we did not have. A complete literature review on the subjects of problem and design-based pedagogy were not possible during this study due to a lack of access to non-open source research articles. Consideration was made, regarding all major contributions to the topic of constructionism, available to the author at the time this paper was written.

1.1. The problem-based science model

The Problem-based Science (PbS) model is simple on the surface. As an applied approach to gaining literacy, learners use real problems, small and large, real tools, real materials, and sufficient time to grow as learners. Addressing problems small and large is a form of applied technology, engineering, art, math, and science (t.e.a.m.s.). We used the acronym t.e.a.m.s., rather than just STEM or STEAM, to suggest that all of the disciplines, including their tools and ideas, must work together in an antidisciplinary fashion for effective problem solving. Using this approach also signals that every learner is valued as a polymath willing and able to connect the dots of seemingly disparate ideas to design solutions. The PbS model is deeply founded on Jean Piaget's constructivism and Seymour Papert's constructionism. In effort to respect the learner, we adopted the following driving principles for the core of PbS.

1. Deep projects take time. When we spend more than a moment on an observation or task, we make deeper, more rewarding observations. Craftsmanship and research are the behavioral embodiment of this concept.
2. Learning to problem solve, to create versus consume, is a fundamental part of living a liberated existence. Exercising creativity and self-exploration is as important as learning facts, that were discovered by others. This is the core of constructivism and the true spirit of exploration. Practicing creativity builds creative confidence.
3. Autonomy is not a privilege, but the right of the human child and essential to the intellectual and spiritual fulfillment of the individual. Learning self-governance through constructive autonomy is central to self-actualization.
4. Failure is not a measure of a person, it is a natural consequence of trying something new and of learning. Failure teaches us what works and what does not. Failure is essential feedback for all learners, engineers and scientists.

1.2. "The prompt"

Because PbS allows for individualized, learner driven experiences, PbS lessons do not all look alike. Sometimes, students are presented with open-ended problems, called prompts. Prompts in PbS lessons are best likened to a game. Like most games, there are goals and rules. The goals offer the big picture, like "get the ball over the goal line", while the rules make the game purposeful (content specific), safe and fun. We call the goals of the PbS game "prompts". Once given the prompts, students solve a problem using their knowledge or passion for skills related to t.e.a.m.s.

Using prompts, rather than a fixed set of instructions, is an open-ended approach to learning that affords students choice and voice, and promotes confidence, engagement and self-esteem [5]. An example of a prompt might be "Make something that can move a 75 g steel ball from point A to B, that uses two or more forms of energy". Once given the prompt, students are given weeks to months (Driving Principle 1) to form teams based on passion and/or skill sets, brainstorm, then test and iterate on various solutions (Driving Principles 2, 4). No solution will look the same, allowing for a highly differentiated learning experience for each student or group of students. The open-endedness of prompts provides students with control over the "why, how and what" of their learning journey in a way that a learner needs and values (Driving Principle 3).

Once a learner is given time to see themselves as a creative, problem solvers, they are ready for the next phase of PbS. By the end of the school year students may be charged with finding their own problems to solve. They are prompted to do this by observing their local environment for the possible needs of others to address. This kind of problem finding can come in the shape of slow looking (observation and inquiry) or interviewing others to hear their needs (design thinking). With the PbS model, students use slow looking to find needs, followed by authentic inquiry and innovation, then we document what we learn and share our new knowledge. Using design as a platform for authentic inquiry makes sense to learners of any age.

1.3. Constructivism to constructionism in five units

PbS is one model for how to structure for constructivism that allows content standards to be addressed. The PbS curriculum is aligned with the United States Next Generation Science Standards (NGSS) with a focus on NGSS "crosscutting concepts". In addition, more twenty first century learning goals can be addressed, such as creative confidence and designing solutions for the common good. In an effort to make science literacy as authentic and rewarding

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