Assessing Project based Learning with 3D Printing

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Abstract: A study was conducted with middle school students using a STEM transmedia book to complete engineering projects. Included in the book were optional 2D cutters and 3D printers activities that students used to solve some of the engineering projects in the book. The article explains the framework for study and possible ways to assess student achievement through a project-based transmedia STEM book.

1 BACKGROUND

Students in middle school are faced with ever-changing options for their vocational future. Their future may include vocational opportunities that do not exist today (Su, 2009). An average of 200,000 engineering jobs in the United States of America do not get filled yearly because there are only about 60,000 students graduating with an engineering degree (Hall et al., 2011). Students today can be supported for the unknown vocational future through a strong educational background in Science, Technology, Engineering, and Mathematics (STEM) (Center for the Study of Mathematics, 2012). Twenty-first century vocational skills necessitate knowing and integrating STEM subjects together (Harwell et al., 2015). The skills that will help students become vocationally successful are ones taught in a STEM curriculum that focus on teamwork, critical thinking, problem solving, and product creation and completion (Ejiwale, 2012). When STEM is fully integrated together, the connections between the individual subjects can foster real life problem solving that both deepens and broadens student understanding while increasing student interest (Harwell et al., 2015).

The Center for the Study of Mathematics and Curriculum (2012) workshop series encouraged researchers to, "...design, develop, and test a segment of curriculum that focuses on new goals for mathematics or science education or a new organization of the sequence of curriculum or uses new medium to engage students and/or structure instruction focused on traditional goals" (p. 12). Education can help encourage STEM engagement through active participation in hands on activities that get students excited about the STEM subjects (Ejiwale, 2012). The restructure to STEM benefits from a strong framework, and needs a way that teachers can assess if learning occurred.

The restructure tested by the authors was the use of a project based STEM transmedia intervention book in a middle school setting. The book has optional projects using digital fabrication with students being able to print the digitally fabricated object on a 3D printer. The book is considered an intervention as it can be completed in under twenty hours of class time. Depending on teacher choice, certain chapters can be used or not used to create a series of STEM projects that build on each other, or as individual projects that are different than the standard curriculum used in the classroom filling the teachers' desired timeframe. The book itself was designed to have each chapter as a separate project, facilitating a framework for Project Based Learning (PBL). Different forms of assessment were used to assess the different parts of the transmedia PBL implementation.

2 PROJECT BASED LEARNING

PBL encourages hands on projects that develop twenty-first century skills (Rogers et al., 2010; Johnson and Delawsky, 2013). PBL is pedagogically built upon student-centered inquiry through group collaboration (Johnson and Delawsky, 2013), and focuses more on developing solutions within a

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dynamic environment that does not have only one correct answer (Rogers et al., 2010). PBL challenges students with a main question that requires them to apply multiple knowledge bases through critical thinking and collaboration to create and present an end project solution (Schwalm and Tylek, 2012).

PBL can be adapted to many different instructional contents because it allows students to naturally pull from different contents to synthesize a solution to an authentic task (Schwalm and Tylek, 2012). PBL is adaptable to different contents and allows students to custom design their own learning path based on what they feel they need to learn to be successful. For PBL to have the necessary flexibility to be successful, the pedagogy of the educator who is implementing a PBL unit might need to experience a shift towards being a facilitator (Rogers et al., 2010) as the educator guides students to become responsible for their own learning instead of waiting for the teacher to entertain them with new knowledge (Johnson and Delawsky, 2013).

The educator, and in this study, the transmedia book, outlines the main challenge goal. Then, students begin to research and use inquiry to start solving the challenge. The educator helps to facilitate the students through their inquiry path. The final project solution is tested, presented, or otherwise shared so students can reflect and receive feedback. The transmedia book presented a challenge that students could custom engineer a filter that combined everyday materials with plastic printed pieces on a 3D printer that students digitally designed.

2.1 2D Cutters and 3D Printers

Computers can connect to specialized printers that can move beyond putting ink on paper, by cutting the paper to complete different projects that are digitally designed. A 2-Dimensional (2D) object is one that has only two measurable dimensions, such as length and width, but lacks height. A 3-Dimensional (3D) object has three measurable components, length, width, and height.

2D cutters can connect to its manufactures' software through electronic devices and allow a user to custom design how a piece of paper will be cut. A user can have a shape outline cut completely or mix types of cuts such as a perforated cut to allow the user to remove and fold a section of paper into a 3D object. The process allows for the use of precise measurements of products that can be produced multiple times in the exact same manner. The 2D cutter helps students begin to understand the concepts of measurement and geometric reasoning during the construction and deconstruction of objects as they cross between 2D and 3D forms.

3D printers connect to a manufactures' software to take a Computer Aided Design (CAD) and break it down into printer movements that allow the printer to physically create a 3D object. The 3D printer lays down layer after layer of the printer material, adding the third dimension of height to the length and width of the printed object. The CAD design of an object can be developed through different types of software that vary in complexity. Autodesk Inventor is an example of a full software package that has many features necessary to precisely make an object. Another example is tinkercad.com, a free online website that a person can use to create and export a 3D design. Once exported, the design can be imported and interpreted by a 3D printer's software and printed to make a physical object with the specifications outlined in a digital file. In this study the printed material was ABS plastic, so students digital designs became a solid printed hard plastic piece.

2.2 Transmedia

Transmedia books outline learning through the mesh of digital and physical activities (Pictus and Power, 2012) combining fiction and non-fiction writing allowing "...new intertextual engagements" (Voigts and Nicklas, 2013, p. 141). Transmedia is an example of media convergence in which different mediums add to the story (Freeman, 2014). The transmedia story *Engineers Needed: Help Tamika Save the Farm!* encouraged the reader to use QR codes to search sources, view videos, problem solve using digital fabrication with a 2D cutter and 3D printer, and create a digital platform to share their solutions with others.

Transmedia books have the potential to be student centred, self-directed, and designed to accommodate different learning styles (Parker and McDonald, 2014). Transmedia books accomplish these tasks by having different reading and skill levels embedded within the same book, through the use of different QR codes. Upon a casual glance, the books students are using would appear the same, though they can be geared towards specific students' needs. The vocabulary could also be changed to fit different levels of readers, yet use the same project constructs, allowing for members of a class to be supported at the appropriate level in a discrete way. Transmedia encourages a non-linear format focused on the readers experience (Parker and McDonald,

2014) so the way in which each learner moves through the story and utilizes technology to complete projects will be unique. The unique paths of the learners support individual student success, in addition to being able to adjust the technology students use. Students can connect to the links in the book through hand held personal devices, tablets, or computers, and use whatever adaptive software they already have on that device to help them access information.

2.3 Transmedia PBL with 3D Printing

The transmedia book offered the framework for students to move through projects that could build upon previous projects, or be used as separate independent agricultural engineering projects. There were projects that could optionally involve using digital fabrication to use a 2D cutter or a 3D printer in the development of the final project solution. Students in the study had certain project parameters defined by existing tools and previous book projects. Students had to consider these factors when developing a solution. Part of the process for solution development was understanding measurement in metric and standard formats to be able to determine and create a CAD solution that could be printed by the 3D printer to use as a pivotal project solution piece. Students could directly apply the concepts of measurement and see how incorrect math would result in a project piece that would not function, creating additional work to modify the design after the object was printed. Students had the opportunity to use different modelling software, to be fit their individual needs in the digital creation process. Students could take advanced routes or more introductory routes to design a unique project solution. In the study, a water filter frame was designed, printed, and built upon to filter water from previous chapter projects.

The 3D printing for a solution utilized technologies to bring components of math, engineering a solution, and science concept application to create a project solution to an ill-structured problem. Through the act of digital fabrication and 3D printing, students could imagine, design, and create a solution in a unique way that showed how the individual subjects are interdependent in a real world way.

3 ASSESSMENT

As the projects vary so widely in product design and printed form, the assessment of PBL projects can be daunting. Assessment of PBL can take many forms. Two forms of assessment, formative and summative should be used. Formative assessments are conducted as an on-going process in and during the context of learning that can help with evaluating complex learning tasks (Spector, 2013). Formative assessment suits PBL, as it is a performance-based assessment that moves beyond the students' ability to recall information (Boss, 2012). Technologies are being developed that can help with formative assessments; two such examples are dynamic concept mapping and stealth assessment (Spector, 2013). These technologies allow for the learner to get feedback and be redirected during the course of learning and developing potential ill-structured problem solutions (Spector, 2013).

Even if advanced technologies, such as the two examples given, are not available it is still possible for teachers to facilitate and report on student's knowledge acquisition from the way in which the project solution development occurs over time. During this study a learning management system was used to help track student project development, provide feedback, and compare student project solutions.

Different learning management systems exist that allow an educator to provide resources and expand the traditional classroom (Al-Busaidi and Al-Shihi, 2011) to provide a supportive environment that encourages active participation of the user, and an evaluation and feedback tool for educators (Gecer and Dag, 2012). The learning management system provides a framework for students to report their progress and share their knowledge in a relatively controlled space which is important for students under the age of 18. Educators can view student progress and provide formative feedback to help the projects improve, or provide summative feedback at the conclusion of a project after seeing what the students have learned.

While formative assessments meet the needs of PBL, schools in the United States must still acknowledge the summative state assessment (boss, 2012) and the need to translate formative assessments into benchmarks of summative knowledge gains that can be compared on a wider scale. Development of appropriate STEM based summative assessments should include different perspectives from teachers and curriculum specialists to identify the purpose of the assessment, the knowledge domains, and the potential burden of the assessment (Harwell et al., 2015). If an assessment requires too much time to grade, is too expensive, or takes too much class time, then the assessment will not be used for large numbers of students (Harwell, et. al, 2015).

For the STEM transmedia book, an assessment was developed from previously released eighth grade questions from The International Mathematics and Science Study (TIMSS) assessments. The released TIMSS questions are each identified with a content domain, topic area, cognitive domain, and historical mean achievement score for different countries (TIMSS 2011 Assessment). The TIMSS questions include both short answer and multiple choice test items. Depending on the teachers needs, either or both types of questions can be used in a summative assessment to gather an understanding of comparative student performance. The TIMSS may allow for both quantitative and qualitative assessments of student achievement. However, this type of assessment provides only a snapshot of students' ability to apply information to a new and relatively connected math and subject topic or thinking process.

Another option for assessment that can be both a formative and summative tool is rubrics. Rubrics can be as simple as checklists or detailed enough to assess large projects for student performance (Jeong, 2015). Rubrics can provide specific feedback and expectations to a learner to allow them revise their work based on specific benchmarks for success, which in turn allows students to perform better in the future (Lipnevich et al., 2013). Rubrics can be implemented into learning management systems, formatively and summatively. When teachers are trained, know how to use rubrics, and the rubrics are developed by experts, rubrics can add, "...reliability, validity, and transparency in classroom assessment" (Jeong, 2015, p. 13). However, it is not always possible within a classroom setting to have expertly developed rubrics with ample training to support the use of the rubrics. Furthermore, having a preset rubric that students do not help develop may make the project-based learning feeling less authentic and impact students' performance.

Studies should be conducted exploring teachers' ability to identify over-arching goals and appropriate rubric framework, with students input. Students should have the opportunity to collaborate with the teacher to define project benchmarks for success and have input into how benchmarks fit into the teacher's overall learning goals. The act of students quantifying and qualifying what success looks like before a project begins helps students know the benchmarks, and allows teacher to assess if students have a clear vision for the end performance goals. Collaborative rubric development sets the expectations and provides an on-going check for students and teachers to identify progress on a project. The same rubric may then be used at the conclusion of a project to determine if the learning and project objectives were achieved.

A rubric provides flexibility to address different parts of the transmedia project, including being able to break down individual tasks, such as a category for the research in project solution, the digital design of an object, the efficacy of the 3D printed object, and the presentation of the project solution. Each of these categories is important in the final project, and may be lost or obscured in importance when the summative assessment is represented in a single percentage score. While the performance score is important, the rubric allows an additional layer that fosters student growth within the project.

Project-based STEM transmedia expands past one media and one form of learning. Teachers should consider using different types of assessments that can provide a whole picture of the individual components that create a complex learning environment. As a teacher or researcher, it is important to understand what the options are and what is being learned to determine the best assessment tool, or combination of tools, for measuring learning goals, objectives, or behaviours in a classroom using a transmedia PBL STEM book.

The use of the transmedia book has the potential to offer benefits to students, as can be seen through these different types of assessments. Further research into STEM transmedia books with 3D printing projects through different types of assessment is encouraged, as in the study by the authors, students who experienced the transmedia book with the 3D printing project showed increased math achievement and showed a more positive perception of math (Stansell, 2016) when compared to the students who did not participate with 3D printing during the implementation period. Using a variety of focused assessments can lead to different insights for students, teachers, and researchers, after using a STEM transmedia PBL book and 3D printing in the classroom.

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