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Educational Video Games and Transdisciplinary Problem-based Learning

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A sixth grade student sits staring intensely in front of his laptop, fervently clicking his mouse to place sandstone blocks in the popular video game Minecraft. As the teacher moves behind him to view his screen, he tells her that after scaling his pyramid to half size, the structure was still way too big, but scaling to quarter size was too small and wouldn't "look cool." Should he scale the model to one-third size? He would have to round to a nearest whole number, but that was okay, right? The teacher asks him to explain how he would divide and round the various dimensions of the pyramid, and the student responds by quickly typing on his calculator and scribbling a few numbers on a sheet of paper, before reporting his idea.

The above scene occurred in a recent session of the Minecraft Mathematics Middle School program at The PAST Foundation, but the scene is a common one in the program, both in regards to the structure of the student-centered dialogue with the teacher as well as to the seamless application of mathematics and other subjects within the game. At The PAST Foundation, we are seeking out ways to use educational video games like Minecraft as a tool and application for learning. Specifically, we are exploring how Minecraft might be used with Transdisciplinary Problem-Based Learning (TPBL) to enhance student engagement and critical thinking through differentiation and collaboration.

The aim of this article is to depict (1) why video games can be an effective tool in education, (2) how we are using video games as an effective tool, and (3) how teachers might use Minecraft or a similar educational video game to enact student-centered learning.

Defining TPBL, Minecraft, and Video Games as Effective Educational Tools

Some argue, "but why video games? Aren't they just games?" Video games naturally teach us to play the game itself better, and affect how we process information—so what if we could take what students are already learning through a game and integrate the game's objectives with core content concepts? For example, rather than pausing an engaging scene with a pirate ship to ask the player to solve for x in the equation, the game might involve a fictional sea battle, and challenge the player to calculate the necessary elevation of the cannon needed to decimate a rival ship, given certain facts on hand. The same mathematics content is addressed, but the content is relevant to the student because it connects to a context within the game's objectives, a more tangible application.

Engagement in Relevant Content

Much of the current existing research on educational video games lacks empirical evidence (Connolly, et al., 2012; Mayer, 2015). This is an aspect of serious gaming that the PAST Foundation is addressing in our research using Minecraft with a TPBL approach. While we have yet to battle the Barbarossa Brothers off the coast of North Africa near the beginning of the sixteenth century, we use Minecraft to simultaneously address content in mathematics, science, language arts and social studies while solving a relevant problem. TPBL is just that—a method of planning and implementing such that content across multiple disciplines is intertwined during the problem solving process (Smith & Corbin, 2010-2014).

For example, in the article's opening, the problem was for students to replicate a monument within the Minecraft world as accurately as possible, with plenty of opportunities for creativity, of course. The problem was relevant to students, because a natural reward of the game is the satisfaction achieved from examining and exploring one's build. Students were eager to create something stupendous to show off to their classmates and teacher, and were provided with structured objectives to do so. These objectives included articulation of mathematical thinking and scientific processes, as well as storytelling incorporating social studies and language arts standards.

Mathematical problem-solving elements and critical thinking surface naturally in Minecraft when students address constraints while replicating or designing their own structures. During the Build Your Dream House project, middle school students incorporate multiple diagonals into their group's build—a challenge with cubic blocks in the game, but quite aesthetically rewarding in the end, with opportunities for creativity and differentiated learning in the scope of strategies for diagonal design. Students must work together to plan the location of their diagonals in their dream house, and then figure out how they will make their diagonal as "smooth" as possible using mathematics.

While solving this smoothness problem, two students recently demonstrated critical thinking as they discussed how they might divide the length and height of a diagonal by the same number to "chunk" it before further "smoothing" it block-by-block. The ease of placing and destroying blocks in the game helped them further evaluate and modify their design while sharpening their collaboration and communication skills as by-products. Students seemed to recognize that the more effectively they worked together, the more fantastic, both in size and detail, their builds could be. For example, in their final presentation, one of the two students above mentioned how working with the other student on particular diagonals helped him focus and create a more impressive build, both mathematically and aesthetically.

Engagement in the Project Design and Process

Minecraft partners well with the design process, because of its open-world setting for building almost anything else one can imagine. In the game's Creative Mode, students choose between different colored and textured blocks as well as decorative materials that might involve electrical or light-projecting functions. Minecraft boasts a large subculture evident on websites such as Minecraft Building Inc, Minecraft Forum, and on various YouTube Channels where individuals exult and teach their skills in the game. As part of the problem-solving process, students are allowed and encouraged to research online Minecraft resources to brainstorm designs and solutions for problems' constraints. We have noticed that students engaged in a relevant problem-solving process spend the majority of their time on task. Thus Minecraft as an engagement tool eliminates many behavioral issues discussed by today's teachers.

In their *American Journal of Play* article, Eichenbaun and colleagues note that time on task is directly proportional to learning outcomes, and that the inclusion of rewards and their timing can have a major impact on motivational factors (Eichenbaum, Bavelier, & Green, 2014). Minecraft Mathematics began five years ago at the PAST Innovation Lab; the project designs have evolved over the years from directly infusing content into the game, to adapting the content to better fit the intrinsic rewards already present in the game. As these adaptions occur, and our data collection continues to grow, we have noticed higher levels of student engagement, and greater academic vocabulary articulated in peer-to-peer conversations, as well as during final presentations of learning on the last day of class.

Recent computer science research shows that "learning is most effective when it is active, experiential, situated, problem-based, and provides immediate feedback" (Connolly, E. Boyle, MacArthur, Hainey & Boyle, 2012, p. 661). Through the context of Minecraft, abstract concepts are translated into applicable tasks, so that students see the concepts in action, and how they apply to tangible problems. Immediate feedback is provided to students as the teacher circles the room, applying a variety of formative assessment techniques and probing questions to evoke student thinking and articulation. To address differentiation, the teacher also challenges certain students to go deeper with content ("describe how you might build a diagonal with the opposite reciprocal slope") while supporting those who are struggling ("let's revisit rounding…how might you round here?"). Additionally, students present their progress to the class at the end of each day to show off their builds, but also to receive timely feedback and support related to the problem.

Lessons Learned from a Minecraft TPBL Example

While the Minecraft Mathematics program includes only one discipline in its title, projects presented in class incorporate all disciplines from engineering to art. One of the more developed projects at the middle school level is the aforementioned Build a Monument challenge from the article's opening:

Build a monument in Minecraft as accurately as possible. While you must use the real-life dimensions of your monument, you may be as creative as you would like!

Students are free to design the majority of the monument as they wish, but must use information researched online and present evidence for how they incorporated the information in their build. Transdisciplinary content includes mathematics around dimensions (i.e., conversions, slope, and number sense), social studies (i.e., geographical and historical contexts), and language arts (i.e., presentation and communication skills).

In addition to the main problem, a TPBL unit includes a variety of sub-problems and scaffolded steps that students traverse. For example, one of the first sub-problems in Build a Monument occurs when students determine the scale of their replication. If one block in Minecraft is equivalent to one cubic meter, how many blocks will make up the various dimensions of the monument, and will there be enough time in class or space in the game to replicate the structure on a one-to-one scale? A group of students who recently built the Eiffel Tower halved the monument's size in their build, but were still unable to complete more than the legs and first level due to the time constraint of the class. The process of designing, building and evaluating against defined criteria and constraints leads to deeper learning and lively discussions. The student in the opening scene scaling the Great Pyramid of Giza researched and converted a height of 455 feet to meters. He thought aloud about halving and quartering the size before finally deciding on dividing all dimensions by three in order to arrive at a design that he felt was possible given the time constraints, and a level of detail he wished to achieve. His thinking aloud helped him and his classmates as they all tackled problems of conversion and scale. This could have never occurred if the concepts of conversion and scale had been delivered by lecture in the abstract.

A second sub-problem of the project surfaced when the students building the Eiffel Tower were unable to make the legs of the tower consistent. Their first attempt looked more like "spider legs" than an architectural masterpiece. This provided a teachable moment: we reviewed the concept of slope, and I asked how it might relate to their builds in Minecraft. Some students were able to articulate the connection between a pixelated diagonal line, and changes in horizontal and vertical lengths (x and y coordinates, graphically). As the students continued their work, I asked them to come up with a plan for calculating the slopes of the Eiffel Tower's legs, as well as delegating sections of the build. During his group's final presentation, a student noted his appreciation for using strategies to build more efficiently.

While Build a Monument is primarily aligned to mathematics concepts, social studies and language arts applications are also incorporated as students research online, collecting information about materials used, dimensions, and historical facts. Furthermore, students are required in their final presentation, to tell the story of the monument and its significance. One student modeling part of Machu Picchu, not only shared information about the location itself, but also delved into the history of the Inca Empire, and replicated artwork he researched online within his build. While this level of historical exploration was not required, the opportunity for students to explore their interests helps emphasize the TPBL elements of the project.

Implications for the Use of Minecraft in Classrooms

Teachers interested in using Minecraft as a tool to inspire learning, especially through a TPBL framework do not need to be experts in the game itself. Although we built a few things in the game prior to designing the first course, we found that many students regularly teach each other (and the teachers!) about the game. Even today, we continue to adapt our lessons as we observe and learn from students. Minecraft projects are easily modified for younger and older grade levels through expectations for depth of research and concept articulation. Problems and building ideas might remain the same with levels of complexity changing to fit specific age groups. For example, while third and fourth graders may not know about slope in algebraic contexts, the concept can still be used for building a certain number of blocks "up" versus "over" and then connecting those directions to the x and y axes, which are viewable in the game.

Teacher organization and facilitation are vital to all problem-based learning approaches. Simply handing a project sheet to students with boxed objectives is not enough. Students are more engaged with the academic concept when facilitation and communication are regular and ongoing, as well as targeted on their builds. This type of interaction allows for improved differentiated teaching with regard to content. It provides more opportunities to ask probing questions and extract student thought processes. In this type of instructional strategy, formative assessment is constant and constructive. Students quickly gain the confidence to continuously think aloud about their designs and communicate with one another about their plans.

Therefore, implications for teaching with Minecraft encompass a student-centered approach in which the game technology is gracefully balanced with facilitation of group-worthy projects that incorporate rich content. Rather than act as the Minecraft and content expert, the teacher probes students to explain and show their thinking, building their problem-solving, critical thinking, and communication skills. Students often fail to recognize they are developing these skills due to their engagement in a hands-on experience relevant to them, which is why it is helpful to ask students about their interests. TPBL excels when the problem or issue is relevant to the student. Some students may not care about the Eiffel Tower, but without doubt there is a building or monument that does intrigue them. It may be the local airport or Machu Pichu. The importance of the exact object or place being scaled or smoothed diminishes for the purposes of the content, but increases for the importance of resonance with the students and their willingness to delve deeper in researching collateral information.

Engagement is the vehicle of learning. All concepts for all content areas can be crafted around the problem if students are engaged. Employing a tool like Minecraft that teaches multiple skills and provides a platform for hosting multiple concepts simultaneously empowers teachers and guides students in learning, teaching them important communication, problem-solving, and critical thinking skills to be used in other areas of life.

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