FOUNDATIONAL PRINCIPLES AND PRACTICES TO CONSIDER IN ASSESSING MAKER EDUCATION

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ABSTRACT

The maker education movement is growing in the United States. In order for this movement to gain widespread acceptance it is critical that students' learning goals and progress towards those goals are clearly visible to all stakeholders. Given that traditional assessment methods may not be best suited for measuring some of the higher order skills associated with maker education, this paper explores this essential question: What are the critical principles and practices to consider when designing an effective assessment plan for maker education? Following a brief definition and history of maker education, the authors suggest that there are eight principles and five practices worthy of consideration when designing an assessment plan for students engaged with maker education experiences. An appendix containing example assessment tools is included.

Keywords: Maker Education, Maker Space, Assessment Plan, Design Thinking, Project-based Learning, Hands-on Learning, Iterative Learning, Innovation, Experimentation, Invention, Design Cycle, Fab Lab, Hacker Space, Digital Badges.

INTRODUCTION

Contemporary education has a primary task of ensuring that students gain the standardized base of knowledge they need. Increasingly, however, educators recognize the need for students to design, create, and share new ideas and solutions. The ability of students to do well in school and perform on standardized tests is not what our present economy and world needs. We need innovative thinkers and creators that seek new ways of viewing the world. We should be looking at schools to prepare their graduates to bring "important innovations, competencies, creative problem-solving methods, inventions, inquisitiveness, design thinking and experimentation" (Washor and Mojkowski, 2013, p. 202).

One can suggest that maker education, which finds its pedagogical roots in constructivism (Piaget, 1976; Vygotsky and Cole, 1978; Dewey, 1998), may be a way to help develop "young people who are problem finders, who are inquisitive, trolling their everyday world to observe, conjecture, and hypothesize, and thinking critically about real problems they encounter in their lives" (Washor and Mojkowski, 2013, p. 200).

For the maker education movement to gain widespread acceptance in public schools, it is critical that students learning goals and progress towards those goals are clearly visible. Finding a balance between structure and open-ended opportunities is critical to measuring the effectiveness of maker education opportunities (Martinez and Stager, 2013). And, because maker education is by its very nature not fully compatible with traditional assessment methods, it is critical to consider how maker education is best assessed. Following a further definition of maker education, and a brief discussion of the history of maker education, this paper directly addresses this question - "What are the critical principles and practices to consider when designing an effective assessment plan for maker education?"

1. Definition of Maker Education

Maker education, as defined in this paper, is a type of project based learning where the learner produces a physical object or artifact resulting from newly learned concepts and skills. While the experience directly addressed in this paper does involve new technologies, such as 3D printers and laser cutters, a maker education program does not need to have any specific tools or materials. "Making" in education can take many forms.

Fleming (2015, p.7) states that maker education "is about moving from consumption to creation and turning knowledge into action". Having making as a part of the educational process extends students' learning through the active process of designing and making things that fulfill some purpose. Martinez and Stager (2013, p. 2) calls it "learning by doing". Maker education both turns knowledge into action and helps create knowledge from action. It is a highly engaging and interactive way of implementing the principles of project based and hands-on learning. But project based or hands-on learning is not what maker based education is, but rather just "what it looks like" (Dougherty, 2013, p. 10). As with all project based learning, the initial challenge or prompt to the student provides a context in which learning takes place. When done well, maker education requires students to access and develop both conceptual and procedural knowledge.

While this paper primarily uses the term makerspace to describe the ideal environment in which maker education should happen, it is common to hear terms like "fab lab" ("fabrication lab") and "hackerspace" used when discussing spaces set up for making. The terms "makerspace" and "hackerspace" are essentially synonymous. Makerspaces differ from fab labs such that makerspaces are not beholden to any specific tool or technology. Fab labs typically have more digital fabrication tools, such as 3D printers, laser engravers, router tables and plasma cutters.

2. History of Maker Education

One could argue that the maker movement has been developing since the beginning of humankind. People naturally seem to be drawn to create new things. Invention and innovation are attributes of all humans. The idea of learning by doing is nothing new. The constructivist theory of education has driven the push for project based and experiential learning for years (Piaget, 1976; Vygotskiĭ and Cole, 1978; Dewey, 1998). However, the emergence of an identifiable maker movement in education is relatively recent. Sheridan et al. (2014) attribute some of this to then President Obama's "Educate to Innovate" campaign in 2009. As a result of this campaign, the U.S. saw increased focus on math and science preparation. This focus on a hands-on, experiential learning form called maker education was encouraged in large part by the explosion of the internet and the age of open source, as well as by new digital fabrication technologies. Today, makerspaces can be found everywhere, from kindergarten classrooms to public libraries.

3. Foundational Principles and Practices in Assessing Maker Education

As with any educational initiative aimed at increasing student development, assessing whether or not students are growing in the intended ways is an important part of measuring an initiative's effect. Maker education presents some challenges when it comes to finding efficient, reliable ways to measure student success and academic growth. Kohn (2012), a leading researcher in the area of grading, identifies three key ways of grading student knowledge, skills, or products which can be detrimental. While Kohn does not address maker education directly, the concerns he outlines readily transfers to this approach. The three primary negative consequences of grading that Kohn presents are diminished interest in topic, a preference for easier path to completion, and reduced quality of student thinking. When one considers the educational goals for maker education, it is imperative that whatever assessment plan is implemented does not deter students from reaching the larger educational goals of maker education.

4. Foundational Principles

A review of the professional literature suggests several foundational principles when designing maker education experiences and implementing an appropriate assessment plan.

4.1 Teach a Design Cycle

Based on the research, it is unclear if one design cycle model is better than others. What is clear is that students need to have a basic understanding of an engineering design process. The design cycle chosen should be simple, clear, and memorable. Teachers need to guard against being too rigid and treating the process like a checklist. Martinez and Stager (2013) remind teachers that no cycle is going to be perfect, and that they are "meant merely to suggest the iterative, forward-progress nature of the work to be done, and the tinkering mindset that goes along with it" (p. 51).

4.2 Focus on Process Over Product

Fleming (2015), Dweck (1999), Martinez and Stager (2013), and many others emphasize the importance of taking the spotlight off the end product and focusing on the process that allows students to get to that end product. This is especially true for young children when fostering creativity and innovation is the primary goal. Dweck (1999) and others found that being recognized for achievement on summative or final product work does not necessarily lead to increased performance when confronted with new challenges.

4.3 Involve Students in Real-World Problem Solving

Research has shown that achieving high levels of engagement, increasing graduation rates, and deepening understanding of content requires involving students in meaningful problem solving embedded into their daily classes. Providing meaning through relevant context for learning (Rumberger, 2011) directly affects the retention and success of all students, especially those who are more at risk.

4.4 Provide Teacher Freedom

School administrators and leaders need to encourage innovation and provide teacher freedom (Fleming, 2015, p. 58). Authentic innovations and inquiries cannot happen if teachers are not allowed to address learning and assessment of objectives in a variety of different ways.

4.5 Encourage Teachers to Embrace the Iterative Learning Process

Dweck (1999) reminds us, "The tasks that are best for learning are often the challenging ones that involve displaying ignorance, and risking periods of confusion or error" (p.16). Teachers should encourage and embrace the iterative learning process." Kurti et al. (2014, p. 10) found that "No amazing innovation is created on the first try. Truly paradigm-shifting technologies and devices are the outgrowth of many iterations. Thus, the path to success is paved with failures."

4.6 Encourage Teachers to Reconsider their Traditional Role in the Classroom

Instead of being the bearers of knowledge, teachers might consider themselves ethnographers or collectors of information, documentarians, recording evidence of learning, studio managers, making sure all necessary resources are available and organized, and encouragers, asking the kinds of questions that lead to further investigation and problem solving (Martinez and Stager, 2013). Teachers positioning themselves as learners must be open and responsive to new and diverse perspectives.

4.7 Provide Student Choice

One common theme in maker educations best practice is student choice. Consequently, student interests and passions are important in designing the makerspace, the tools available, and types of projects selected (Agency By Design, 2015; Doorley and Witthoft, 2012; Halverson and Sheridan, 2014; Martinez and Stager, 2013). One of the goals of maker education is increased student ownership and self-efficacy, and providing student choice encourages this (Kurti et al., 2014).

4.8 Create an Environment that Understands and Values Play

Derhally (2016) documents on how play and unstructured time have steadily declined for more than 60 years. She discusses how lack of exploration and discovery time is connected to emotional and social development issues. She also found that when students are experiencing depression or anxiety, developing high order thinking skills is extremely challenging. Schools need to consider how much time students have during the day to accommodate explorative, open-ended activity that may look like playing.

5. Foundational Practices

Although the maker movement currently has a great deal of momentum, the U.S. public school system which is assessment and accountability focused, struggles to embrace this movement. As Martinez and Stager (2013) observe, in many ways a good maker project is immune to assessment, and this puts maker education opposed to most teacher and student appraisal processes. That said, researchers suggest a number of practices helpful in assessing the effectiveness of maker education. These practices, coupled with an understanding of the principles of maker education, are worth considering.

5.1 The Prompt

Effective assessment of learning starts with the initial teacher prompt, which sets a direction and provides basic objectives. Bennet and Monahan (2014) observe that student engagement increases as they participate in defining the problem to be solved. While challenging for instructors, it is possible for students to have autonomy and control, and still have a clear direction and purpose provided by the prompt. In order to assess 21st century skills (i.e., creativity, collaboration, critical thinking, and communication) along with content specific learning targets, the prompt must be clear enough to provide direction while being open-ended enough to allow for creativity and critical thinking.

5.2 The Rubric

After a well-crafted prompt, the second component in effective assessment is a rubric or checklist. The rubric can serve two purposes. First, it allows for clarity in what students should know and be able to do by the end of the project. Second, it provides a basic structure that helps students to both learn about and experience an iterative design thinking process. Yokana (2015) is a strong advocate for the use of rubric-based assessment in maker education. She suggests a three-part rubric: process, understanding and product. Each project or prompt will probably have varying objectives. This three-part structure provides an opportunity for teachers to present the different types of objectives clearly. This can be a useful structure, but as with the prompt, the teacher must guard against being too structured or rigid, which could stifle true creativity and innovation.

Rubrics may serve students in other ways, as powerful learning tools when used for both peer and self-assessment. The rubric or even part of the rubric can act as a formative checkpoint or as a summative self or peer assessment. Examples of rubrics designed for maker education are found in Appendix A and B. An example of a more general rubric that could be applied to any maker project is found in Appendix C. Appendix D is an example of an engineering design process checklist applicable to any project that involves engineering components.

5.3 The Reflection

Reflection is a powerful self-assessment tool teachers can use for formal summative purposes. Instead of having students take a test at the end of a unit, a teacher could have the students spend time on open-ended reflection questions that provide the teacher insight on both the conceptual and procedural objectives of the project. Here is a sample set of reflection questions:

1. Describe a project you have thought about that you would like to make. You may base your project on those we have seen over the past couple of months. 2. What does it do and how does it work? 3. Why is it interesting or exciting to you? 4. If this project is based on another project, how will you make it your own? 5. How will you improve or change it? (Hlubinka et al., 2013).

When teachers are able to help students articulate their thinking, they can use that information to help coach a student to learn from mistakes and previous failures. Reflections should always include questions about thought process and group interaction. Students should always be asked to explain how they used the engineering design process to arrive at their final product. Appendix E is an example of what this reflection might look like for a balloon car project that integrates physical science, engineering, and maker education objectives.

There may also be days or even weeks when no final product emerges. In these situations, students can complete a weekly reflection and shared it with both teachers and parents to ensure communication about progress towards the end goal. Appendix F is an example of weekly reflection prompts.

5.4 Portfolio Development

One way to accomplish a "process over product" approach is to assess student portfolios. Portfolios allow students to document their thinking, give context to the products they create and provide evidence about their growth as a maker over time (Chang et al., 2015).

Chang et al. (2015), Hlubinka et al. (2013), and other researchers emphasize the value of portfolio development. According to these sources, a portfolio can be structured in many different ways, but the important thing to remember is that the portfolio belongs to the student. Chang's research also emphasizes the importance of using both digital and non-digital practices for documenting work. Encouraging students to carefully document the thinking and work being done each step of the way allows the teacher to better assess student learning. The key for assessment purposes is that the documentation provides a window into the creative process used to develop the end product. Notebooks, blogs, photos, posters, videos, and digital stories are just a few of the different forms that documentation might take (Hlubinka et al., 2013, pp. 45-46). Options like blogging or web page development provide innovative ways for students to showcase their work, but it is important that teachers remain open to the different ways students might best reflect on and share their process.

5.5 Digital Badges

Digital badges can serve to organize, communicate and display accomplishment and progress in any class, but they have a special application to a maker-based class. Digital badges, like badges used in scouting, can serve as recognition for a skill learned or task accomplished. With digital badging, students complete established requirements and then receive a digital image that can be displayed using some type of online presence. Additionally, badges can supplement report cards by clearly displaying academic understanding and accomplishments. Badges can also be used like a credential system. In maker education, students are potentially exposed to both expensive and dangerous equipment. Hlubinka et al. (2013) is very clear about the importance of identifying tools and clearly delineating why student training is necessary before each tool can be used independently. The ability to give and display badges on a digital platform allows teachers across a building and between grade levels to know who is trained in what and who should be given access to what equipment. Appendix G is an example of a collaboration badge that students work on earning early in the school year to establish what good collaboration looks like.

If teachers are using a class platform like Edmodo or Class Badges, they can create and assign badges to student accounts easily. However, implementing a badge program need not require a classroom badging platform. Mozilla's "Open Badges" initiative is a major driving force behind badges in both professional and educational settings, offering options for creating and using these open badges. The downside is that some of these open badge systems take some technical skill to utilize and can be challenging to manage for classroom use.

Conclusion

As educators, we must move away from a system that tells students about how the world works (Honey and Kanter, 2013). Research has shown that if we desire high levels of engagement, increased graduation rates, and deeper understanding of content, we must involve our students in real-world problem solving embedded into their daily classes. If we want to retain all students, including those who are more at risk of failure and or dropping out, we must provide meaning through relevant context for learning (Rumberger, 2011).

Maker education is a way to provide a relevant context for learning. It can be accomplished in small-scale or deliberately large-scale ways, ranging from dedicated teachers implementing small making components into a project, to districts investing to create high tech fab labs in their high schools. Some of the essential components in an effective maker education program include teachers who see themselves as co-learners and coaches, projects that have open ended elements that allow for student interest and inquiry, explicit instruction of design, process thinking, adequate physical space materials and supplies, available and organized in a way that inspires creativity (Fleming, 2015). In addition to each making experience in school, assessment components must provide the teacher and student alike with useful information to help shape student growth as learners and makers.

Schools in the United States have become increasingly standardized. That standardization, while important for accountability, may not be producing the kind of students our nation and world needs. Dougherty (2013) writes, “there is increasing skepticism that even those who succeed academically are not the kind of creative, innovative thinkers and doers that we need” (p. 8). As one builds a case for maker based education, an important question to address is what are the critical principles and practices to consider when designing an effective assessment plan for maker education? Without fully understanding those principles and practices, assessment, as Martinez and Stager (2013) found, can have a negative impact on the intended outcomes of a maker education program.

John Dewey's observation in the 1940's carries a truth and urgency worth returning to: “The world is moving at a tremendous rate. No one knows where. We must prepare our children not for the world of the past, not for our world, but for their world—the world of the future” (Flanagan, 1994).

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Appendix A

Tree House Master Rubric

	1	3	5
Brainstorming and Planning	Little effort was shown in researching, writing ideas, and sketching	There was evidence of some research, basic sketching and some written explanation of ideas.	Research is thorough. Sketches show detail, creativity and include measurements. Written explanation helps in understanding what final product will be like.
Craftsmanship of final product	Poorly assembled and does not match plan.	House looks like plan for the most part, but dimensions are not exact, and final product looks rushed	House looks like plan, dimensions match plan with precision. Final product is carefully assembled and includes extra features beyond walls and roof
Safety	Area is not kept organized and equipment is not used properly	Area is mainly organized, but some reminders about proper equipment use is needed	Area is organized, and equipment is used properly 100% of the time
Criteria Met	None of the criteria met	Criteria were partially met	All criteria were met

Appendix B

Name_______________________________ Period_____________

Puzzle Piece

Criteria: Create a puzzle piece that demonstrates creativity, critical thinking, group collaboration, and communication skills. Your teacher will assign you to a group of 3-4 classmates. You will have to create tabs or indents on your pieces to make all of your personalized pieces fit together as a team.

Start by working together to create a scaled drawing on graph paper of how your pieces will fit together. Each team member needs to create a drawing with the basic outline of everyone's piece with measurements in mm indicated.

Once you have a layout start to personalize your puzzle piece with your name and some other design that helps identify you (tree, tent, ski, basketball, game controller, jewelry, etc…). Once you have created your puzzle piece you must print it on a 3D printer to complete the project.

Puzzle Piece Rubric	1	2	3	4
Plan	No planning shown	Creates drawing of own piece.	Creates detailed drawing of how pieces fit together	Creates drawing with outline of each shape including measurements in millimeters.
Communication/ Collaboration	Does not work with team	Communicates and shares ideas with some team members.	Shares ideas and communicates with all team members, but there is not a willingness to help others.	Team is in regular communication with each other. Evidence of teamwork and supporting one another is clear during class time.
Craftsmanship- Final Product	Pieces either not made, or do not at all fit with team.	Pieces kind of fit. Sizing of pieces do not meet requirements. Missing tabs or indents.	Size is close to meeting criteria. Most pieces fit together well. Can see name and personalized item. All but one of the tabs fit together perfectly.	Pieces fit together with less than two MM gap. Stays within 50 mm x 50 mm x 5 mm Name is easily identified on piece, and there is some part personalizing it. There is one tab or indent per side.

Appendix C

Student Name ____

Makerspace Project Rubric

	1	2	3	4
Abided by project criteria and constraints (x2)				
Evidence of pre-research and creativity with sketches				
Prototype /Project Build Quality				
Utilized EDP: ASK IMAGINE PLAN CREATE IMPROVE (x2)				
Safety Organization Equipment Use				
Thoughtful reflection on the process and skills learned during project. (x2)				

*EDP = Engineering Design Process
*(x2) = Double point value

Appendix D

Engineering Project Checklist

ASK:

_____ Identified specific criteria
_____ Identified at least 2 constraints

IMAGINE:

_____ Recorded brainstorm ideas
_____ Created a materials list
_____ Made some rough sketches

PLAN:

_____ Sketch is finished
_____ Sketch includes labels and dimensions
_____ Sketch is clear and easy for someone to follow
_____ Created budget if needed

CREATE:

_____ Prototype is built to the plan
_____ Included an image/video of the design
_____ Tested my design multiple times and recorded data

IMPROVE:

_____ Identified what worked well
_____ Identified what needs to be improved
_____ Repeated the plan, create, improve cycle

Appendix E

Balloon Powered Car Final Reflection

Name and Hour: ____

Reminder: you should be using complete sentences and taking your time when answering each question!

1. CRITERIA AND CONSTRAINTS

    a. Which criteria were hardest to meet? Why?

    b. Which constraints did you find most challenging?

2. INITIAL DESIGN

    a. How did your first design perform? Include at least 2 sentences. Remember to include data in your sentences.

    b. Reflect on at least one thing that went well and at least one thing that did not go as well (or could be improved).

3. IMPROVEMENTS

    a. Discuss your second design for the balloon powered car, including any changes you made.

    b. Include your reasoning for changing certain parts of your design.

    c. If you had more time, what improvements would you make next.

4. SCIENCE AND MATH CONNECTIONS

    a. What forces or factors did you have to account for in your design?

    b. Which of Newton's laws best describe how a balloon car works? Why?

    c. How did the mass of your car affect its performance?

5. Rate yourself on a scale of 1-5 (1 being low and 5 being high) in the following areas for the project.

Individual effort during the project:
1 2 3 4 5

Group participation:
1 2 3 4 5

Use of class time:
1 2 3 4 5

Responsibility with materials:
1 2 3 4 5

Appendix F

Weekly Innovation Reflection

You may choose to make a copy of this and fill out to turn in, or submit a screencast video answering all of the questions below.

Daily Goal: (reference module and step number, 4Cs, or engineering cycle in your goal)

	Monday	Tuesday	Wednesday	Thursday	Friday
Goal: (be specific)					
Goal Met: (Y or N)					

You can answer these questions at any point during the week. Do not wait until the very last day to answer them all! Pay attention to your own thoughts throughout the week to make sure that you are noticing the great things you are capable of learning and creating. You must use complete sentences.

What challenged you this week?
How did you get past this challenge? *(include a screenshot or screencast if it makes sense to do so)*

What did you learn this week that you hope to remember?
Why is it important? *(include a screenshot or screencast if it makes sense to do so)*

What did you learn this week all own your own? (without help from your teacher or from another student)

Share something that you're proud of by pasting a screenshot, picture, or screencast below.
Why are you proud of this work? (you may include this answer in your screencast)

How did you show creativity this week? *(include a screenshot or screencast if it makes sense to do so)*
How did you collaborate this week? *(include a screenshot or screencast if it makes sense to do so)*
How did you think critically and problem solve this week? *(include a screenshot or screencast if it makes sense to do so)*

Appendix G

Collaboration Badge

About this Badge: This badge demonstrates the ability to effectively work as a team towards a common goal. The owner of this badge is someone you would want to have on your team.

Requirements:

- Consistently engaged with team both mentally and physically
- Willing to be both a leader and a follower
- Openly share ideas and looks for ways to assist
- Positively encourage and support team
- Get high marks from team on peer feedback form

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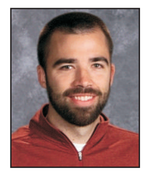

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