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”But, What Do You Want Me to Teach?”: Best Practices for Teaching in Educational Makerspaces (RTP)

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"But, what do you want me to teach?" Best Practices for Teaching in educational Makerspaces (RTP)

Introduction

Makerspaces, a conception of constructionist learning principles that many believe evolved from the likes of shop class, technology education, and Stager's constructivist learning laboratories, have now become a part of learning environments in schools, libraries, and museums in the United States. Even though dating earlier conceptually, the establishment of Maker Ed in 2012 can be considered a watershed moment in the history of educational Makerspaces. Maker Ed was founded with the aim of transforming education through Making activities. Makerspaces manifest constructionist principles of learning by doing by emphasizing the connection between the Maker and that what is made or the artifact, accommodate individualized learning, support students to feel personally connected to the activities they engage with and have the potential to be lucrative sites for open-ended problem-based learning activities. Other reasons of interest in these spaces by the educational community include the community-oriented nature of Making and learning activities, the skills that students can develop using tools and technologies that are being considered essential for the present and future of design and prototyping, and the more elusive goal of raising a STEM-literate citizenry.

This paper is situated in the ongoing conversation about the Maker movement and its educational potential. Using a conceptual framework as a lens to understand Making as an educationally meaningful activity, we analyze relevant narratives and educational theories, to present best practices for educational Makerspaces.

Rationale

It has been half a decade since the launch of Maker Ed, and Makers and proponents of educational Making have conducted research and published opinion pieces on the potential of Makerspaces and the need to establish them in formal educational settings such as schools. Several new Makerspaces have been set up in schools and other formal and informal educational settings. Now we are faced with the challenge of reaping their claimed educational benefits in schools, and our first line of defense is our ever so brave teachers. In a reflective paper that we published in 2014, we predicted the opportunities and challenges that educational Makerspaces are harbingers of. Since that work, we have instructed more than 1000 students from diverse racial, ethnic, and socioeconomic backgrounds at several workshops in Makerspace settings across the World. This study presents qualitative participatory work on critical points of reflection experienced by the authors of this paper and our co-instructors from the past four years. The data that comprises the study include written reflections of the four authors responding to the prompts: How do you cater to the different needs and interests of your students? Is there specific equipment that you need in a Makerspace to teach well? What kinds of activities have you conducted that work well for your students, and those that did not? Further, we draw from established theories of learning and development that apply to Making and recommend best practices for teacher development. It is important to note that the recommendations, best practices, and motivations behind the narratives are in alignment with our conception of educationally meaningful Making, which may or may not bear resemblance to others' conceptions.

Conceptual Framework

We use a framework which conceptualizes educational Making as three aspects, namely, the people involved, the technological means used, and the activities performed in the setting, as the conceptual framework for this paper. This framework is based on the assumptions of interconnectedness between the three aspects and of the contextual nature of each of the aspects. In a particular Makerspace, the people can comprise all of the teachers, parents, community members, and students, or some or none of them. Similarly, the means can be all, none, or some of the tools, materials, technologies, and skills. The activities can be defined by the curriculum or the pedagogy, and reflective practice can be one such activity. Figure 1 is a representation of the framework.

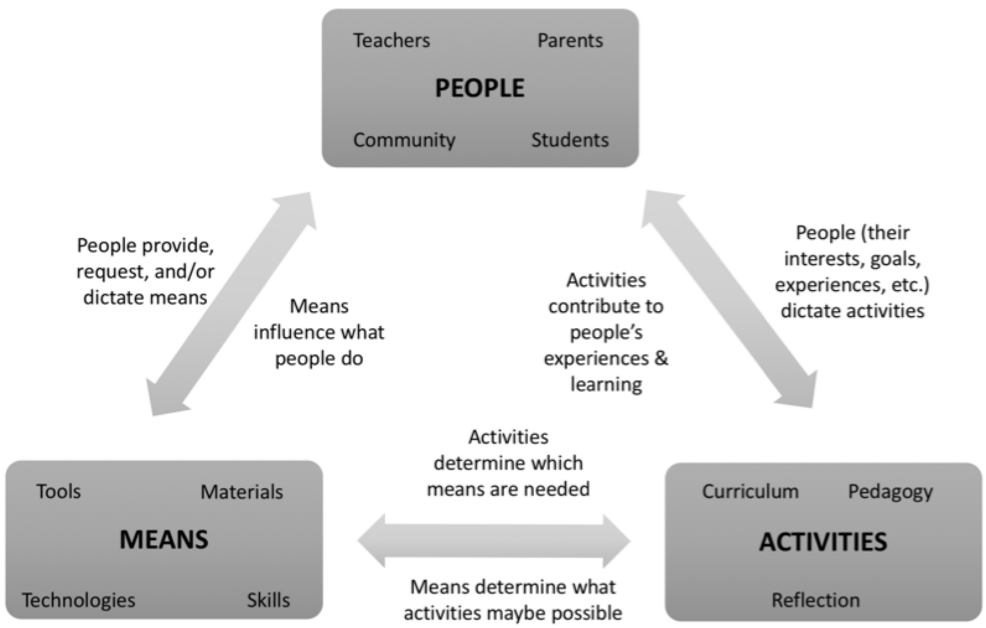

Fig. 1 Representation of the people, means, and activities framework for educational Makerspaces (Authors, 2018)

Critical Reflections

Guided by the conceptual framework, in this section we discuss critical reflections from our experiences to suggest practices for teaching in educational Makerspaces. However, before sharing our narratives the following is an explanation of the different contexts in which we have practiced educational Making activities. These contexts should help situate our learning and recommendations.

Contexts

Morgan:

I use the idea of Makerspaces in contexts for teaching engineering design to pre-college students. I have been introducing pre-college students (primarily late elementary and middle school students) to engineering for a number of years now and find that engineering design works well as the content and context for these students. I have attempted all sorts of design projects ranging from well-structured, LEGO-based design challenges to open-ended, ill-structured design challenges using craft or found materials. As the idea of Makerspaces became more popular, I liked the idea that students could generate ideas for solutions and then work with myriad materials and tools to have their ideas come to life. For the past few years, I have been delivering engineering design workshops in a Makerspace environment that includes 3D printers, a laser cutter, a vinyl cutter, electronic tools and materials, cardboard, craft supplies, wood, and other such materials. My goal in creating the Makerspace environment is on having a wide variety of tools and materials that allows students to think creatively about prototyping solutions that are meaningful to them and gives them an opportunity to create them with some fidelity. The activities I engage students in focus on problems the students choose based on something personally interesting to them. The associated research investigates how an interest-based, human-centered approach to engineering design in Makerspace learning environments can appeal to a broader group of students.

Chanel:

My work and research takes place in informal settings with high school aged students to elderly persons. Typically, people I am working with are underrepresented in the field of engineering or completely disconnected from engineering s a profession or identity. My research primary asks participants to reflect on their experiences and think systematically about changes they would like to see and problems they observe. In general, I attempt to make spaces where I build genuine relationships with my participants and foster honest dialogue about our surrounding communities.

Kayla:

My involvement in Maker education began at home predominantly situated around art and design. I often began with my electronic sketch pad to design jewelry, blankets, or clothing from found materials for family and friends as a form of relaxation after work. It wasn’t until my son became old enough to start playing with LEGOs that I realized that my personal Making activities and the engineering design process I used to develop new medical devices as a biomedical engineer overlapped. This is when I began exploring how to introduce students underrepresented in engineering to the discipline through the lens of Making to allow students to shape their projects around topics that are personally meaningful. Since this realization, I have been on a variety of teams that partner with informal learning organizations to introduce engineering using a Maker curricula. I have led a variety of Maker activities for pre-college students that shift the power dynamics of teaching from teacher-led to student-led so that students become empowered to make meaning of the world around them and create change. I believe Maker education can allow students to discover their passions in a way that develop leaders of change.

Avneet:

> I've been involved with Maker educational activities in a few different ways. It started by me being a Maker myself predominantly in the engineering context. I made remote controlled aeromodels with friends and other mechatronic contraptions to participate in technical competitions in my undergraduate years. Upon realizing how my Making experiences had contributed significantly to my knowledge and skills in engineering, and having access to relevant opportunities, I decided to pursue research and outreach activities related to Making in graduate school. I have been on teams where we have designed and implemented curricula for Maker activities in schools and out-of-school informal environments. I have also lead the development and implementation of a course related to Maker practices across different cultures, and student-led initiatives. For me, the biggest draw towards the Maker educational activities is the potential for agentive behavior and social emancipation via Making. However, I believe that this potential can only be achieved by intentionally developing and implementing Maker activities, as like most phenomena it has the possibility to be limited and monopolized by a select few.

People

The first set of narratives we present are geared towards the people aspect of the conceptual framework. All four researchers respond to the question:
How do you cater to the different needs and interests of your students?

Morgan:

> In developing a Maker/engineering design activity I try to organize the activity around a broad theme that allows flexibility in what students can choose to do. I think this along with having a wide array of materials and tools to make allow students to pursue their interests. For example, we gave students the design task of creating a module for a community center that would focus on one issue the student thought was important. They each received a rectangular wooden box as a template for their module and had access to craft materials, 3D printers, and a laser cutter. This allowed students to pursue a number of different interest pathways. For example, they could pursue more technical interests in learning to use the 3D printers and design something using CAD software. They could have pursued more artistic interests in the design and creation of the pieces they put in their modules. Or they could have really focused on the social, human dimensions of the problem to think about how people would interact in their module. In choosing this broad theme, we were intentional in making sure there were clear groups of people that would serve as clients, that there was opportunity for technical innovation, and that there were many sub-problems within the theme students could choose to pursue.

Chanel:

> I let the experiences and expertise of my student guide research questions and efforts. I make the research process as transparent as possible and ask for feedback and input at as many points as feasible. Student needs are usually emergent and therefore hard to anticipate fully ahead of time. Thus. I try to manage research projects with enough flexibility to be changed and altered midway through. This effects research questions, locations, publication and even continuation.

Kayla:

When developing activities for my students, I like to create structures that allow students be active participants in choosing the direction of the project. I like for the projects to encompass and support the variety of interests, experiences, and expertise within the learning environment. To help, I often focus projects around community centered themes to ensure the projects are relatable and authentic learning experiences, that provide enough flexibility for students to shape the project along the way. During the project the students and I are able to negotiate and change the project structure to better align with their needs and interests while meeting learning objectives.

Avneet:

I think that catering to the different needs and interests of students is primarily the reason that draws me to use Makerspaces for engineering education in K-12 and undergraduate engineering settings. It starts off by creating a democratic classroom/Makerspace, where the learners can voice their inclinations for or reservations against the topical areas chosen to Make. A big part of it is encouraging student voice, as it is closely linked to what I consider is possibly one of the most important aspects of Makerspaces and the Maker movement, agency. If the students are not agentive in their approach and practice, they are not really Making. So one way for students to explore and live their agency is to be agentive about the needs or interests they are Making for. This can be done in different ways, grouping students with similar interests together, or grouping students with varying interests together and prompting them to Make something that caters to everyone's or the group's interests. Which way to go can also be asked of the students, further facilitating agentive behavior.

Based on the above narratives, practices that cater to the people aspect of the framework include:

- Providing students with a broad range of topics to work on
- Being flexible with activities and expectations
- Introducing people and community-centered authentic activities
- Making scope for technical innovation
- Encouraging students to be active participants
- Being cognizant of the evolving and emergent nature of student engagement

Means

The second set of narratives pertain to the means aspect of the framework. The researchers respond to the prompt:

Is there specific equipment that you need in a Makerspace to teach well?

Morgan:

I do not believe there are any specific tools or materials that are necessary. I think having variety allows students to choose the making methods that they are most comfortable with or interested in. That being said some of the equipment that has become synonymous with Makerspaces such as 3D printers, lasercutters, vinyl cutters, electronics, and mini CNC cutting tools can draw in certain students interested in learning about and using these technologies. I have found that young students find the 3D printers fascinating and are extremely satisfied in receiving the 3D item they designed on the computer just hours earlier. The laser cutter also provides professional looking results for creating simple structures for their designs. Laser cutting cardboard can produce high-quality pieces as compared to hand-cutting cardboard. Ultimately, with any tools or materials I think it is important to think about how students will be able to customize their creation with colors, shapes, textures, etc. to really personalize it to their interests and ideas. Random materials also allow students to express their creativity and think of different ways to achieve complex results with simple materials. This promotes the sort of critical and creative thinking we want to develop in our students.

Chanel:

Aside from computers with decent processing speeds, appropriate programming and internet access, the "equipment" I find myself needing the most is the expertise and perspective of stakeholders and change agents. Because my research is situated in social context, success of projects is often directly constrained by the absence of certain perspectives. Namely, the voices of marginalized end users and relevant change agents could make my spaces more effective.

Kayla:

In my opinion, the greatest aspect of makerspaces is that the complexity of available materials and tools can be modified to fit any budget. However, having a variety of basic building materials as well some higher tech options can provide opportunities for students to explore their interests or begin to learn new skills. At a minimum, I often find having access to tools, like computers, that have reliable access to the internet helps support students self-directed learning when answers to their questions may not be available at that time within their maker community.

Avneet:

No, not really. I've run Maker activities with everything from fancy 3D printers and laser cutters, to cardboard and craft supplies. Making is really about taking something in one form whether it is pieces of paper or a plastic spool of a 3D printer, and turning it into something that has meaning for the Maker. I do also want to address the virtual Making which happens in places that are often called Hackerspaces. Any artifact which has meaning for the Maker and is an outcome of the Maker engaging with tools, materials, technologies, or even data, I believe is a Maker artifact. Thus, the equipment required for this Making really is all that I need. Often the equipment is dictated by the kinds of Making the students want to do and are competent to do, as in I won't take machine tools to a Maker workshop of 12-year-olds, or at least do it for them. Also, the equipment gets dictated by the affordances of finances and space.

The above narratives suggest the following practices:

- Not needing prescribed tools and technologies across different Makerspaces
- Providing a variety of materials
- Providing tools that enable personalization of artifacts
- Capitalizing on the novelty of certain technologies like 3D printing
- Facilitating access to the involved human agents such as stakeholders and change makers
- Providing tools informed by the context and affordances
- Providing access to Internet-ready devices

- Promoting use of tools and materials that enable students to make meaning of their artifacts

Activities
The third and the final aspect that the researchers reflect on is that of activities. They respond to: What kinds of activities have you conducted that work well for your students, and those that did not?

Morgan:

> The activities that work well allow students to choose problems that are personally meaningful and relevant in their lives. When students are able to relate real problems to an activity it reinforces that their lives are important and solving such problems is an actual career pathway. Real problems also allow students to bring their rich prior knowledge to the activity where they can feel like they already have some expertise. Matching this sort of informal expertise with the knowledge and skills they have been developing in school can help them see the value in what they've learned while also having them feel confident in their ability to solve the problem and create something meaningful. I find that the activities that tend not to work as well miss on one or more of these elements. For example, if we push everyone to design something in CAD to print on a 3D printer, it might not work for some students. They may not be interested in learning the tools, they might not see a need to use the tool given their problem, or it might extend beyond their skills or abilities having them feel inadequate in the moment. It is important to think about the students as a whole and not just as a learner for a specific skill or topic. If students feel they are being respected for their ideas and can bring their own expertise to the problem solving setting, they have a better chance of flourishing in the environment.

Chanel:

> The activities that have been the most successful have been the ones where I prepared students to take on a professional identity that allows them to investigate their own interests. The role of designer seems to have enough wiggle room to allow students to embody their concerns and priorities in relation to a stakeholder or client. Informing them of design behaviors/perspective (ie question asking, taking notes, modeling, etc) provides students with a tool box of options for engagement with their work. These options, I believe, allow students to feel like they are in control of their work and what comes of it.
>
> The least successful activities have been ones where I failed to scaffold the expected behavior for the students. Asking students to give feedback to other students, for example, has been a strong area of contention because I have not prepared students with the skills needed to provide constructive and deep feedback. While it could be argued that experience giving feedback may be the only adequate scaffolding for such skill development, I know I could spend more time developing that portion of the experiences I design for students. Fortunately, the ability to give constructive feedback has been a tangential goal of my interaction with students, so their inability has not been very confounding.

Kayla:

The projects I find to be the most successful with students of all ages are projects that focus on helping others by encouraging students to create change in the world around them. These projects allow students a lot of flexibility around the topic and can be scaled if needed due to time restrictions to themes. Even when scoping to a theme based model, the themes are complex enough that students are able to seek pathways that align with their interests. I find in these projects students feel empowered to be agents of change in their communities of influence.

The projects I find to be least successful are projects with structure ways of creating a specific item. The more structured projects that only require the team to "follow these steps" often fail to include social context situating the need. Therefore, students often have difficulty making connections with the activity beyond a single situationally "fun" moment in time.

Avneet:

I've learnt that for the activity to work well, there are two critical elements to it. The first, of course, is the activity in itself, i.e. what the students are doing, but then also who the students are and how they interact with each other is also very important. So first, if the students see a reason behind what they are Making and are able to align it with their hopes, dreams, and interests, the activity works. I distinctly remember a student who wanted to be on the team that was working on "sports" and somehow ended up on the "books" team. He was just not engaged with what he was doing, and in fact, made it hard for others to work too. On the other hand, a team had come together because they all cared about the body-image issues in teenagers initiated by perfect looking runway models. This team worked on a technically hard project, but never gave up. Another essential element I believe is how students working on different projects interact with and support each other, and the environment created by the facilitator and the relationship between the facilitator and the students.

Thus, practices catering to the activities aspect include:

- Designing activities that are personally meaningful and relevant to the students
- Enabling students to recollect prior knowledge and experiences
- Directing students to take on professional identities as they solve problems
- Scaffolding different elements of the activity
- Conducting activities in which students are helping others and/or changing the world
- Striving for students to experience more than a situationally "fun" moment while Making
- Promoting interactions between students
- Developing a positive relationship between the facilitator and the students

Recommendations for Teacher Education

The educational potential of Makerspaces is grounded in several well-established theories of learning and development. In this section, we explore the nature of learning and development in Makerspaces to make recommendations for teacher development.

People

For the people aspect of the framework, we recommend the following practices for teacher development:

- Case Studies
- Authentic Tasks
- Pedagogical Content Knowledge

Case studies can present the breadth of contexts that a teacher facilitating in a Makerspace might have to face, and also present scenarios diverse enough to be relevant for teachers at different levels of experience. Levin (1995) reported that the social interaction which is often a part of the case study discussions is the most fruitful for teachers. For the more experienced teachers the discussion catalyzes reflection and metacognition, and for the lesser experienced teachers it clarifies issues. Especially in a classroom setting that involves technology that requires the teachers to understand the theory, tools, and implementation, involving teachers in authentic tasks that make them aware of the available resources and information in the classroom provides a useful scaffold (Nicaise & Barnes, 1996). Teachers' pedagogical content knowledge is of primary importance to involve students in a Makerspace while upholding constructivist principles. Case studies and authentic tasks in addition to other opportunities to teach, observe, reflect, and conceptually integrate the curriculum in their practice can help develop teachers' pedagogical content knowledge (Cochran, Deruiter, & King, 1993).

Means

The following practices for teacher education can prove to be beneficial to cater to the means aspect of a Makerspace:

- Motivation to use technology
- Knowledge of technology and appropriate scaffolding
- Technological Pedagogical Content Knowledge

Wishart (1997) reported a weak but significant correlation "between being internally controlled and being more prepared to use a computer. This correlation appear[ed] more strongly in those who have had little previous involvement with information technology such as the women in this study" (p. 271). In a study on preservice elementary students, it was observed that using technology (particular multimedia) for a constructivist-based instruction, developed positive attitudes towards the use of technologies for teaching among teachers (Kim, Sharp, & Thompson, 1998). Knowing how to use technology and how to integrate it into their teaching practices appropriately is also important. This includes being in control of a computer, knowing how to integrate it into the regular curriculum, having curricular guidelines, and standards for time-allocation for these activities (Yaghi, 1996). Mishra & Koehler (2006) argue the role of a new model they call technological pedagogical knowledge in integrating the use of technology in teacher education. They believe “that this model has much to offer to discussions of technology integration at multiple levels: theoretical, pedagogical, and methodological” (p. 1017). Also, Bitner & Bitner (2002) propose an eight-point model for teacher technology education: "1. FEAR of change 2. TRAINING in basics 3. PERSONAL use 4. TEACHING models 5. LEARNING based 6. CLIMATE 7. MOTIVATION
8. SUPPORT” (p. 98).

Activities
For the activities aspect, we recommend the following for teacher development:

- Reflective practice
- Zone of Proximal Development
- Focus on community

The benefits of reflection for teacher education include the development of teachers' own identities (Agbenyega & Deku, 2011), practicing transformative learning (Zeichner, 1981), and being able to teach following constructivist principle. However, to achieve the real potential of reflective practice for teacher education necessary scaffolds via explicit curriculum are important (Clarke & Chambers, 1999). Nyikos & Hashimoto (1997) report on how teachers, when educated in groups, benefit from the Zone of Proximal Development (Chaiklin, 2003) at play. “The teachers working groups exemplified division of labor, role taking and switching, desire for challenge, power relationships, the languages used to express these concerns, and the need for social interaction to actualize constructivist claims." (Nyikos & Hashimoto, 1997, p. 506). Teacher education programs are often carried out in groups, and the teachers in such a program have been observed to form a community of practice. If this community is online, it benefits from a vibrant socio-technical ecosystem developed to aid the back and forth between curriculum design and implementation (Schlager & Fusco, 2004). Even though teacher education at initiation usually focuses on a particular community of teachers, lessons learned from one community have often helped others (Au, 2002). Also, where teacher development is understood as mundane and procedural for teachers, Au (2002) proposes that teacher education should be looked at as the broader community's ongoing effort for providing care for the teachers.

Conclusion

This work is situated in the growing interest in the educational potential of Makerspaces. Identifying teachers as the first resource to implement educational interventions, in this paper, we present best practices informed by narratives of educators with experiences in educationally meaningful Making activities, and theoretically grounded best practices for teacher development. The people, means, and activities of Makerspaces are defined by the contexts they present themselves in, as proposed by the conceptual framework of this work. This contextual nature which is informed by the affordances and constraints of the setting of the Makerspace, beget the human agents, the teachers, to be well prepared to facilitate learning. The contributions of this paper are a timely interrogation to understand what it truly means to teach in a Makerspace, best practices for teachers, and a direction for future teacher development in the area of educational Makerspaces.

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