Authors' Response

Professional Development and Policymaking in Maker Education: Old Dilemmas and Familiar Risks

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> Abstract • Maker education is a new instantiation of the decades-old project of project-based, constructionist, inquiry-driven learning. However, unlike other past implementations, it offers many unique characteristics, makes possible novel educational outcomes, and challenges policy makers and teachers with new infrastructural needs. In this response, using examples from school and district-wide implementation, we address three categories of questions raised in the commentaries around maker education: the uniqueness of makerspaces and the artifacts produced within them (and how they differ from projects and artifacts produced in other educational environments), teacher professional development for this novel type of school environment, and new approaches to assessment. Our conclusions point to recommendations that could be useful for policy makers, teachers and educators working on the implementation of maker programs.

« 1 » The fast dissemination of makerspaces in pre-college education is one of the most noteworthy events in the history of educational technologies – comparable to teaching machines, educational television, and the Logo language. It brings familiar issues and dilemmas that have concerned educators and designers for decades: How much open-endedness should we allow in schools? How to integrate these new spaces within the current school infrastructure? How to do assessment? How to prepare teachers to use those technologies? What learning goals can be uniquely achieved within these novel environments?

« 2 » These recurring dilemmas come back for a reason: despite the vast advances in educational theory and research in the last 50 years, one fundamental issue still divides the world of education like no other: the infamous dilemma of instruction versus construction. While traditionalists have insisted on direct instruction for decades (Engelmann & Carnine 2016; Mager 1988; Kirschner, Sweller & Clark 2006), every progressive educational reform promises to bring openness, authenticity, inquiry, and personally meaningful curricula to classrooms (Dewey 1916; Montessori 1965; Papert 1980; Freire 2008). This dilemma percolates through the entire educational ecosystem and its components, such as national standards, curricular design, and teacher preparation.

« 3 » In our target article we have primarily discussed one crucial aspect of this divide: when classrooms move towards more progressive approaches and project-based learning, how do we reframe what students are learning? Is the mere execution of a project evidence, or a proxy, for learning? We have argued that "doing" or "making," while certainly powerful as tools to promote engagement, do not necessarily lead to learning. Such a statement could be taken as trivial, but a brief analysis of the current discourse around maker education (Blikstein & Worsley 2016) will reveal that such a view – that merely making something equates to learning about the scientific and engineering concepts within the artefact – is quite prevalent. We have, thus, proposed to bring back the classic constructivist lens into maker activities, with students' action a key point in the design and implementation of learning activities.

« 4 » The three commentaries identify a host of cascading questions deriving from this discussion. These questions can be approximately grouped into three main categories: the uniqueness of makerspaces as learning environments, professional development, and assessment and the nature of students' artifacts.

The uniqueness of makerspaces as learning environments

« 5 » Arthur Hjorth asks whether there is something specific about maker education that allows for the "inversion" of traditional pedagogical transactions, placing "action" even before conceptual exposition. He is concerned with what is unique about makerspaces (Q1) and the artifacts that students develop in them (Q2). One of the distinctive characteristics of makerspaces or digital fabrication laboratories ("FabLabs") is their variety of tools and possible activities, which is a consequence of the history of the movement (Blikstein 2018). Even though the original FabLabs were relatively uniform in terms of equipment, most contemporary makerspaces and digital fabrication spaces can be very different in terms of infrastructure. This generates challenges, but it also creates numerous "entry points" for children. Whereas in a "classic" robotics club or a Logo computer lab there were few types of activities and objects produced, an artifact created in a makerspace could range from a programmable robot to an "analog" art piece. This diversity enables students to engage in the "action" phase (Figure 5 in our target article) in different ways: building an art installation, an e-textile project, a sensor-based science experiment, or an invention to solve an everyday problem. This diversity of tools also makes it easier to design activities that engage with more content areas and take advantage of "teachable moments" – even in the humanities. Finally, it affects designing activities and the orchestration of the classroom: students can easily transition between group and individual work, alternate between low- and high-tech, and combine projects inside and outside of the school walls. These possibilities are not unique to makerspaces, but they are much richer and flexible in those spaces.

« 6 » These characteristics are also reflected in the artifacts created in makerspaces, as opposed to more traditional ones such as essays or math problems, as Hjorth highlights in Q2. Many of the technologies present in makerspaces are not new (robotics, 3D printers, laser cutters, craft tools, art materials, etc.), but their availability in one single physical space makes the artifacts produced there potentially much richer, offering multiple entry points into their construction. A student who enjoys art can start a robotics project with the props and decorations to the robot, then move on to the mechanical construction and coding – and teachers can design such customized paths based on students' previous interests (Blikstein 2008). The interdisciplinarity of the projects also offers teachers and students possibilities to mix and match techniques and learning goals, adapting the activities to different contexts. The "OmniAnimal" activity, for example, which was developed in the context of Blikstein's lab, offers multiple levels of engagement. The goal of the activity is to create exotic, imaginary animals from laser-cut pieces. For short, one-hour workshops, students receive a basic set of pieces and have to design a few new ones, which are cut by a facilitator for time efficiency. For longer workshops, students get to learn how to use the laser cutter and cut their own pieces. When even more time is available, we have added several options: using a vinyl cutter to design decorations for the animals, creating algorithmic designs and engraving them onto the animals, adding LEDs and simple circuits or incorporating full-fledged robotics with motors and sensors. These possibilities use very different types of tools and engage students in diverse ways, which would be challenging outside of a makerspace. These new "maker" artifacts thus offer possibilities that were not present in previous types of environments, such as computer labs or robotics clubs.

Professional development

« 7 » The second category of questions from the commentaries is about the types of professional development needed for maker education, raised by **Hjorth** (Q3) and **Mareen Przybylla** (Q1). Given this flexibility and diversity of tools and activities, how can teachers possibly thrive in the space when they were prepared to inhabit very different environments? To answer this question, it would be useful to bring some additional data from the schools described in the original article. The implementation of the project in these schools was somewhat unusual, but it points to a route that has been successful in many school systems, in the US and abroad. The "unusual" approach was to convince school systems that each makerspace needed its own dedicated teacher. This was, at first, a surprise to the school district, but an argument was made based precisely on the technical and pedagogical complexity of running a makerspace. Even though this idea is often met with resistance from policymakers, no one would question the need for the hiring of other types of specialized teachers. If a school wants to start a sports program, the need for a coach or physical education teacher is obvious. To have an art program, a school needs art teachers.

« 8 » In several implementations around the world, we have observed that the tasks involved in running a maker program are just not compatible with the amount of time available to regular teachers. A makerspace needs constant cleaning and organization, well-organized management of consumables, careful design of lesson plans, special after-school support for students, and technical maintenance. Makerspaces offer many benefits, and diverse and flexible tools – but those come at a price. The need to hire specialized teachers brings up the familiar argument about the lack of funding in public schools. However, we have found that it is quite important to educate policymakers about the cost of their choices – if they want a functional makerspace, they have to invest in the teachers that will run it, as opposed to simply purchasing equipment and leaving teachers to their own resources.

« 9 » There are countless examples of educational technology implementations that fail because they focus on buying equipment, with the hiring of specialized teachers an afterthought. Thus, in places where there is a specialized maker teacher in place, such as the school described in the target article, the work is done in pairs: a science, math, or art teacher co-designs and co-teaches an activity with the maker teacher. The teacher preparation is done differently for the two audiences. Disciplinary teachers will get training mostly geared towards understanding the pedagogical possibilities of the machines and technologies, with less focus on their operation. We focus on techniques for lesson plan redesign, pedagogy, different forms of classroom orchestration, and assessment in project-based environments. The maker teachers would get more in-depth training on the technologies, often spanning several weeks and tens of hours. Both groups would be prepared to work together as a team, both for activity design and delivery.

« 10 » We found that this combination had a number of advantages compared to the traditional approach of only designing professional development for the disciplinary teachers. First, it was an enormous relief for regular teachers to know that they would not be burdened by extensive technical training, given that not only are they busy with their regular work, but they might not enjoy such training or feel prepared for it. A particularly striking case was of a teacher who resisted implementing any maker-related activities in his science class for months. There were many justifications for his refusal, from lack of time to claiming that it would not benefit students. However, this teacher had never quite understood that he would not be alone when implementing activities. When he finally understood that there would be another teacher helping him deliver the redesigned unit, and in charge of all the technical aspects, he not only agreed to try the new lesson plan, but became an enthusiast of the project.

« 11 » Second, by focusing the training of the regular teachers on pedagogy and lesson plan redesign, we give them tools to not only use the new technologies but to create sophisticated new educational designs, achieving new and ambitious types of learning goals. At the same time, we are able to provide in-depth technical training to the maker teachers in a much more cost-efficient way, since there is just one of those per school.

« 12 » Third, the lab teacher automatically becomes a trainer and evangelist in her own school, promoting lab visits, workshops, training, outreach activities, etc. Over time, new teachers are brought to the fold and become part of this community of practice.

« 13 » Indeed, as **Hjorth** (§10) and **Przybylla** (§4) state, the types of tasks and practices needed in makerspaces are quite different from the ones in traditional classrooms. We often believe that teachers will, overnight, spring into a completely new paradigm of work, facilitating project-based learning, assessing complex artifacts, and establishing dialogical relationships with children, automatically abandoning their "old ways." We know that such transitions require extensive amounts of time in practice, and that localized, short training sessions without regular follow-up will simply not generate the expected changes. We have found that placing a maker teacher in the school can accomplish many of those goals since the school becomes less dependent on the implementation team, and local training can be increasingly taken over by the maker teacher. If this teacher is appropriately trained, she can be a constant force for change, following up with teachers, organizing regular professional development sessions, writing up lesson plans, creating new types of assessments, and accumulating exemplars of students' artifacts.

« 14 » At the same time, the maker teachers often might be more radical than what the school system allows for, or simply have a very simplistic and naïve view of schooling. In that case, the regular teachers would help them understand the system, its dynamics, leverage points, and limitations, and together find productive entry points and pathways for the implementation of new practices. Also, the regular teacher can establish the dialog between the concepts used in the product or project development and the curriculum. The maker teacher may not know how curriculum activities are discussed and approached in the classroom.

« 15 » The need to hire an additional teacher in every school to manage and teach in the makerspace could sound unfeasible for public schools. Nevertheless, many schools and secretaries of education spend vast amounts of funding on equipment and facilities, while with better resource allocation it would be possible to have functional, lower-cost makerspaces and at the same time hire specialized maker teachers. This combination of a well-trained lab teacher and a regular disciplinary teacher has proved to be the key to the success of many maker education programs around the world (Martinez & Stager 2013; Halverson & Kimberly 2014; Kurti, Kurti & Flemming 2014; Riley 2015; Clapp et al. 2017). Arguably, being upfront about the overall costs of a maker program (including extra teaching staff) could be helpful for policymakers to communicate to city councils and elected officials the exact resources needed for successful implementations of the programs. Often, the resources exist, but policymakers need a good justification to make use of them.

Assessment and the nature of students' artifacts

« 16 » The third cluster of questions revolve around assessment, and the nature of artifacts developed by students. For example in Q3, **Przybylla** is concerned with the assessment of creative works and artifacts and whether the examination of these artifacts in isolation is appropriate, i.e., whether students should be graded based on the performance, functionality, and look of these interactive objects. **Liudmyla Kryvoruchka** (§7) interrogates us about the difference between "'success' in performing desired activities" and understanding, and makes parallels between makerspaces and work in post-secondary education. She suggests that research laboratories might generate artifacts that are, in nature, quite similar to those generated in makerspaces, since both are places for interdisciplinary experimentation and innovative investigation. In previous work, we have discussed the compromise between product- and process-based assessments (Blikstein & Worsley 2016). In product-based assessments, teachers look at the final artifacts produced by students and employ some rubric to assess it. In process-based assessments, teachers and peers attentively track the development of a project and apply rubrics not only to a final result but to intermediary milestones. Even though product-based assessment could work in some limited cases, it often generates undesirable unintended consequences. In search of a better final result, students often split the labor based on their current abilities, which ends up reinforcing inequalities in the classroom. The students with more experience in engineering end up doing the technical tasks, and the less experienced wind up doing less complex manual tasks. In other cases, a good final product might obfuscate a poorly designed process or very little learning. Process-based assessments, conversely, allow for teachers to establish several project milestones, and different criteria for success. If an important learning goal is collaboration or a particular curricular topic, the process rubric can include it. If the teacher is particularly concerned with equal group contribution, that can also be part of how groups will be assessed. Frequently, a final product that looks unfinished or even not functional, can be the result of a very rich learning experience – especially for novices with ambitious goals.

« 17 » This issue connects with **Przybylla**'s Q3 on assessment, and Q2 on whether maker programs can be a "window into the learner's mind." First, she asks if we can we take students' artifacts in isolation and assess their functionality. It seems that, in maker education, the appearances of flashy artifacts can be deceiving. Having access to the extensive repositories of resources and premade objects on the Internet, as well as the machines in a makerspace, it is arguably easy to produce objects that are relatively sophisticated without any deep understanding of how they work. Our article discusses how making and understanding are not automatically linked, but the issue is even more problematic in an environment where there is an ever-growing disconnect between the quality of the products and the effort put into making them. There are new maker machines being launched on the market every other month, each more capable than the other. In a few years it will likely be possible to 3D-print objects embedded with electronics and mechanical parts – at that point, how would we distinguish students who designed their own circuits and robots, and the ones who simply downloaded the entire project from the web and printed it with the click of a button?

« 18 » If we set the standard in makerspaces to be about the production of objects, it will be on increasingly shaky assessment ground in years to come, as students devise new ways to produce objects with less effort. If the production of objects and the learning goals are not tightly connected in our curricular and assessment designs, we risk trivializing maker education to the point where makerspaces would no longer be a place for invention but a mere production facility of cool and curious contraptions. Investing in robust process-based and formative assessments is our insurance policy against the rapid development of maker technologies. Let us take as an example the constructions of simple circuits and analog electronics. To make an LED blink in the 1980s, a student would need a degree in electronic engineering and tens of hours of work, between printed circuit board design and soldering. In the 2000s, the same could be accomplished in a couple of hours using a microcontroller board. Today, using some of the more modern physical computing kits, a student could accomplish the same in a few minutes. Przybylla's Q2 on maker programs being a possible "window into the learner's mind" is also relevant. There is great potential to "open" such a window and gain a deeper understanding of students' cognition while creating objects, in the same way that the Logo language was used to gain unprecedented insight into mathematical and computer-science reasoning. However, makerspaces comprise many more tools and types of activities, so visibility into students' cognitive moves is challenging. For example, there are ways to compensate for lack of knowledge about hardware construction in software (and vice versa), with the exact same functional result. The lens into students' cognition, thus, has to be embedded in carefully designed activities, process-based assessments, and project milestones.

« 19 » We should focus considerable attention on these process-based assessments, and not look at products in isolation, but consider how hard it is to generate those products relative to the types of toolkits available for children. This relates to the main argument of our article – the relationship between learning and making. The establishment of learning goals should always precede the definition of technologies or activities to be done with students. If a teacher is interested in Newtonian physics, as in the example in the target article (§§43ff), the quality of the catapults produced should not be the main assessment item – it should be only one of the elements. The catapults should be part of a larger lesson-plan design on Newton's Laws that includes scientific inquiry, statistical calculations, and experiments with different materials.

« 20 » That is not to say that traditional approaches to curricular design have to be the main driving forces in makerspaces, "schoolifying" and trivializing maker education. Granted, as we place the production of maker artifacts within larger disciplinary contexts, there is a risk of switching back to old approaches and models and forgetting that there is enormous richness in the process of construction of interactive objects and artifacts. Not all of maker education should be in the service of learning traditional disciplinary knowledge. At times, perhaps there could be a maker activity only concerned with the design of the most spectacular catapult, with no concern for the scientific experiments that can be performed with it. Teachers should be aware of that compromise and make informed choices about their specific goals.

Conclusion

« 21 » The dissemination of makerspaces in pre-college education is indeed one of the most noteworthy events in the recent history of educational technologies – but it is not automatic that it will also be a learning revolution. Over the last decades we have seen technologies come and go without delivering the promised learning outcomes. By now, we have understood that technologies by themselves do not deliver learning: it is the intentional insertion of technologies within a productive context that delivers results. It is all too easy to design technocentric solutions, which focus on equipment and technology training, just to later blame technology for the failure to deliver the expected learning outcomes. Maker education is just one more chapter in our quest to expose children to the most powerful ideas humanity has created. As we develop more sophisticated knowledge and techniques, more complex forms of schooling, classroom orchestration, curriculum design, and assessment are necessary. It is impossible to teach all the new content topics that the 21st century is producing if we are not generating new formulations for learning environments, new approaches to professional development and new modes of participation in schooling. Those have a cost, but they also have incommensurable benefits.

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