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“How Can I Build a Model if I Don’t Know the Answer to the Question?”: Developing Student and Teacher Sky Scientist Ontologies Through Making

Sandra Becker[1] · **Michele Jacobsen**[1]

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Abstract

Makerspaces provide a viable option for constructing and sharing knowledge in schools. Inherent in the designing, tinkering, and playing that learners engage in through making are competencies, such as the ability to create, problem solve, and innovate, decreed as critical by education policymakers. This paper summarizes results from a study in a Canadian elementary school in which a researcher and a sixth grade teacher worked collaboratively to co-design, enact, and reflect on a makerspace project focused on sky science. Results with students showed higher engagement, deeper learning, and a way of being that extended beyond the study of one science topic. Results with the teacher demonstrated changes in pedagogical thinking about learning designs to enhance students’ abilities to develop their own questions, to build models in attempts to answer those questions, and to embody the ontology of a scientist.

Keywords Makerspaces · Making · Science inquiry · Nature of science

In the past decade, there has been significant advocacy in education for the implementation of makerspaces as design-based learning environments in K-12 school settings (Freeman, Adams Becker, Cummins, Davis, & Hall Giesinger, 2017; Martin, 2015). Research suggests that making provides opportunities for learners to practice twenty-first century skills such as collaboration, problem solving, innovating, and learning from failure (Bevan, Gutwill, Petrich, & Wilkinson, 2015; Ryan, Clapp, Ross, & Tishman, 2016). Drawing on the work of Seymour Papert and his theory of

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✉ Sandra Becker
sandra.becker@ucalgary.ca

Michele Jacobsen
dmjacobs@ucalgary.ca

[1] Werklund School of Education, University of Calgary, 2500 University Drive NW, Calgary, AB T2N1N4, Canada

constructionism (Papert & Harel, 1991), research on makerspaces purports that students are able to build knowledge and ideas through the construction of the physical and digital artifacts that they create in the makerspace. Proponents submit that work conducted in makerspaces not only develops discipline knowledge, but also the habits of mind necessary for creative competence in a knowledge economy (Vossoughi & Bevan, 2014). This paper argues that making promotes knowledge building (Holbert, 2016) and a maker mindset (Chu, Quek, Bhangaonkar, Ging, & Sridharamurthy, 2015), and that makerspaces also can provide an opportunity for students to explore ontologically what it means to be a scientist.

This design-based research study involved a sixth grade teacher and her students' exploration of interdisciplinary making within a sky science context. Two over-arching research questions for the study were (1) how can teachers be supported in the development of teacher knowledge, pedagogy, and practice within an elementary school makerspace environment? And, (2) how can teachers support the development of students' conceptual understanding of disciplinary topics in an elementary school makerspace? As part of the participatory design process enacted in the makerspace, the researcher and teacher invited students to make scientific models based on a question they had about the night sky.

The first section of this paper reviews literature on topics of making and makerspaces, science inquiry, and the nature of science in education. The review is followed by an explanation of the purpose of the selected research methodology, as well as a detailed description of the research setting, participants, and data collection methods. Next, study findings are presented as these emerged via pre-, during, and post-making sessions. Following that, an analysis and explanation of the results is presented. Finally, the limitations of the research are discussed, and recommendations for future studies are outlined.

Learning Through Making

Though makerspaces have roots in grassroots community organizations (Martin, 2015; Vossoughi & Bevan, 2014), there have been efforts to envison and study making in K-12 education (Halverson & Sheridan, 2014; Martin, 2015). Described as "physical environments that foster opportunities for hands-on learning and creation, often enabled by emerging technologies" (Freeman et al., 2017, p. 40), makerspaces are seen as learning environments in which students can learn to innovate, problem solve, and test ideas. In makerspaces, students use materials, both high and low tech, to innovate solutions to problems of personal interest. The literature on making argues that learning is deeply embedded in making (Martin, 2015; Sheridan, Halverson, Litts, Jacobs-Priebe, & Owens, 2014) and that making is linked to the development of STEM (science, technology, engineering, and math) skills (Bevan, 2017; Freeman et al., 2017), improved self-efficacy, and identity as a learner (Chu, Schlegel, Quek, Christy, & Chen, 2017; Martin, 2015), while promoting a growth mindset (Martin, 2015). Given these learning outcomes, there exists potential for making to offer a natural approach to scientific inquiry.

Teacher Knowledge of the Nature of Science and Science Inquiry

Research suggests that the majority of science lessons conducted in classrooms do not relate to the legitimate work of scientists. Chinn and Malhotra (2002) state that scientific classroom activity “is antithetical to the epistemology of authentic science” (p. 175). This gap is exemplified by traditional science teaching approaches whereby all students complete the same standardized tasks and defer to the teacher’s knowledge and authority as dispenser of information (Anderson, 2002). This approach is due in part to a lack of understanding by teachers, even those with science backgrounds, about the nature of science (NOS) and science inquiry (SI). Studies have found that even students with advanced degrees have had little opportunity to experience authentic scientific inquiry and therefore have limited understanding of the work scientists do (Abd-El-Khalick & Lederman, 2000; Schwartz, Lederman, & Crawford, 2004).

Researchers assert that simply having students and their teachers conduct science inquiry (SI) will not promote understanding of SI or the nature of science (NOS) for either students or teachers (Lederman, Lederman, & Antink, 2013; Schwartz et al., 2004; Williams, Ma, Prejean, Ford, & Lai, 2007). Rather, explicit teaching is required for students to learn about the NOS and SI (Peters, 2012; Peters & Kitsantas, 2010; Stone, 2014). There is some evidence to suggest that participation in authentic science endeavors assists students in science achievement. Students who are engaged in units of inquiry that more closely resemble authentic tasks benefit on test scores (Geier et al., 2008).

The methods of inquiry conducted by working scientists can include building models, conducting experiments, and using observation and comparison to develop theories (Nehring, Nowak, zu Belzen, & Tiemann, 2015). In contrast, the inquiry methods used in classrooms are oversimplified as compared to authentic SI (Chinn & Malhotra, 2002). There is a need for students and their teachers to participate in authentic, rich SI, coupled with explicit teaching on the NOS to build on their extant knowledge. However, designing for authentic science experiences is often compounded in elementary classrooms with teachers’ lack of preparation and insecurity with science content.

Elementary Teachers’ Scientific Knowledge

Elementary school teachers tend to lack confidence in the subject area of science, which is linked to limited understanding of science content knowledge (Appleton, 2006). In fact, “several studies have demonstrated that primary teachers may often lack a personal scientific background on which to draw and that, indeed, many may themselves hold misconceptions of current scientific ideas” (Parker & Heywood, 2000, p. 90). This often leads to a preference for teaching of non-science subjects (Appleton, 2006). Harlen (1997) identifies coping strategies teachers use to address confidence issues when teaching science. These include avoidance of certain topics, most notably in the physical sciences, while relying on prescriptive, teacher-directed pedagogical approaches to instruction. There remains a significant challenge for elementary teachers in building their pedagogy, conceptual knowledge, and confidence when it comes to the teaching of science.

Developing Effective Teaching Practices Through Inquiry

The school district in which this study took place had for the previous 5 years enlisted in a partnership with the Galileo Network, an educational organization that promotes innovative professional learning practices (www.galileo.org). The network was recognized in 2017 by the Organization for Economic Co-operation and Development (OECD) Centre for Educational Research and Innovation (CERI) because of its use of innovative pedagogies in powerful learning networks. The collaborative work initiated by the Galileo Network, on the practice of authentic inquiry, continues today in the school district with a focus on developing instructional excellence through the use of the Teaching Effectiveness Framework (Friesen, 2009). The Framework outlines five core principles that are foundational for teaching and learning to address the complex skillset required for living in a knowledge society, with the first principle being "teachers are designers of learning" (Friesen, p. 4). Friesen (2009), in the accompanying Effective Teaching Practices Rubric, explains that as part of this core principle, the "teacher designs learning experiences that engage the students in doing work that requires distinct ways of thinking about and acting in the world that particular disciplines embody" (p. 7). Prior to this study, though the teacher participant had engaged in collaborative experiences with colleagues to develop and refine her practice, she had not yet made the connections or found ways to design learning activities so that students could enact and embody different disciplines of study.

Methodology

Design-based research (DBR) was selected as methodology for this study given the alignment between this research approach and the processes found in making. While collaborative in nature, both DBR and making juxtapose structure with creative iteration, and risk-taking with systematic support while developing solutions to an identified need. In order to develop usable knowledge (McKenney & Reeves, 2012) and give credibility to research findings, it was important that the study take place in the emergent complexity of a classroom. Acknowledging criticism that DBR studies may not be replicable, and therefore may not be scalable, the aim here is to present findings in such a way that readers can take a local story of impact pedagogy and learning, and generalize principles to their own situation, while attending to the theoretical constructs underpinning the narrative (Barab, 2014).

Research Participants and Setting

The makerspace was enacted in a typical grade six classroom with a diverse set of students. Sandra worked collaboratively with a grade six teacher, Riley,[1] and her students in a rural school division in Alberta, Canada. Of the entire K-7 population of 423 students at this school, 36% were designated English language learners (ELL). This diverse school demographic was represented in the selected classroom in which approximately one third of the 27 students were ELL and three had identified

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[1] A pseudonym

exceptional learning needs. One student who was non-verbal with severe learning needs had full-time support with a teaching assistant, and two students presented with mild to moderate learning needs.

Grade six students in the province of Alberta undergo provincial achievement testing (PATs) in June of each year. Standardized testing in science, mathematics, social studies, and language arts (with separate portions on reading and writing) takes place over several days. Though the stated goal for the testing is to improve student learning (Alberta Education, 2018), research indicates that the high stakes assessment can have a negative impact on teaching and learning (Burger & Krueger, 2003; Cheng & Couture, 2000; Klinger & Rogers, 2011). In this study, the impending PATs were often mentioned by Riley when considering decisions around curriculum implementation and the required content coverage. For example, in one design session, she remarked, “As long as I get everything in. And unfortunately toward the end of the year it becomes just drilling the content which is not the best solution.” The pressure of high stakes assessment was often forefront in the mind of the teacher.

The school’s access to high tech tools was limited. The staff had recently replaced an older collection of Chromebooks with 130 new ones. The school also had two sets of iPads (10 per set) housed in different locations. As well, each teacher had an iPad and a Chromebook for their own use.

When Riley was approached by the school principal, she readily volunteered to engage in the study. Riley graduated with a BA in psychology and had completed an after degree in education. Neither Riley nor Sandra has a background in STEM (science, technology, engineering, and math) which presented an interesting dynamic with regard to conceptual knowledge, understanding of SI and NOS, and instructor confidence. The implications for this will be addressed later in the article.

With 3 years of teaching experience, Riley had already emerged as a leader among staff in terms of her willingness to explore and test out innovative ideas. Prior to the study, Riley participated in a district professional learning community that was exploring making and makerspaces as innovative learning environments in schools. As part of that community, she visited a makerspace in a charter school in a large urban center within an hour’s drive of where she teaches. Above and beyond regular classroom teaching duties, Riley had spent considerable time organizing materials, designing activities, and promoting the potential of makerspaces to teaching staff.

According to the school principal, the initiation of a makerspace in the school was a grassroots movement promoted by several educators on staff. There were three primary ways in which the makerspace had been used prior to this study: (1) Interested teachers offered noon hour makerspace clubs separately for grades 1–3 and 4–6; (2) some teachers took their students to the makerspace to participate in one-off STEM activities; and (3) Riley developed and organized a Christmas maker challenge for grades 1–3 and 4–6, which included the creation and development of a step-by-step lesson plan and the provision of materials. Other than Riley’s teaching partner and herself, no other classes engaged in the challenge.

Over the course of the year, Sandra and Riley designed and enacted three making cycles based on specific curriculum topics in science, mathematics, and the humanities. The results presented in this article focus on making in science, though the teacher learning from this work carried through to the other two design cycles. Each cycle followed a similar pattern: (1) Explore and analyze making practices; (2) design and implement makerspace activities; and (3) evaluate and reflect on making as learning, with the second and third aspects taking up most of the collaborative work time.

Data Sources

Qualitative data was collected in the form of pre- and post-interviews with the participating teacher, artifacts that included student models, short videos of students articulating their thinking around the model design, and researcher field notes based on daily work conducted in the makerspace, as well as follow-up discussions with the teacher hinging upon individual observations.

Data Analysis

The analysis of data took place concurrently in order to inform iterative changes to the design and implementation. For example, in the initial planning between teacher and researcher, the data indicated a convergence on technology over pedagogy. Noting this focus led the researcher to take a more intentional stance on pedagogy over technology. All sources of data were also triangulated to analyze and distill overarching themes about learning. Key moments of learning for students and the teacher were identified as themes in first cycle coding. For example, a pivotal theme of students becoming sky scientists arose prominently in the data. Second cycle coding followed in order to determine causes related to cycle one themes. In this case, second cycle coding indicated that students selecting questions that they did not have answers to presented a key insight into how they experienced SI and the NOS.

Findings

Pre-Making: Designing for Making as an Iterative Learning Process

Riley and Sandra met over three sessions to design the first round of making. Initially, pedagogical discussion focused on finding a technological tool that would be compatible with Chromebooks and that the students could use to digitally model something in space. Ideas ranged from modeling the solar system, creating a solar system, or modeling a recently discovered solar system that had been featured in news reports (Brennan, 2017, February 23). The teacher and the researcher believed that it was important to use technology that had mass application and transferability. In retrospect, we regarded this first design as not true to the maker philosophy in that it was teacher directed with little student choice in the use of tool.

As part of this initial planning, there was considerable discussion about learning outcomes, particularly as these relate to the solar system. The teacher shared that in the two previous years, her students made a model of the solar system, with smaller groups of students learning about one planet and presenting what they learned. About this process, Riley remarked, “The kids had fun building with papier mache and making the Powerpoints, but can they really remember? If you asked them to tell you any fact about their planet, they couldn’t do it. The work was superficial.” During the design phase, some of the teacher and researcher’s discussions focused on how to create designs that required students to delve more deeply into understanding. For example, not just "recognizing that the moon's phases are regular and predictable," (Alberta Education, 1996) but promoting student understanding of how we know that and why it is important.

As Riley and the researcher explored ideas about the night sky, such as how scientists use orbits and mathematical modeling to predict the existence of planets, and how early astronomers used tools to try to answer questions, we began to shift our own design to thinking more about how we might allow students to make sense of the questions they had about sky science. This shift was heightened by our inability to find a digital modeling technology that suited our needs, due in part to the lack of robust technological hardware at the school, and our own limited knowledge in using the software tools.

The design that emerged consisted of an introduction and four main parts. We began by introducing the notion that scientists cultivate certain characteristics in the way they approach their work. Together, the teacher and researcher wrote and discussed what we thought were the important characteristics of a scientist:

1. Scientists are curious and they are always observing the natural world.
2. Scientists develop scientific ideas by building on previous theories and understandings.
3. Scientists often build models to help them understand complex ideas that they are not completely sure about.
4. Scientists work in communities that are constantly asking questions, seeking answers, and disputing ideas.

We posted the scientist characteristics in the classroom in language suitable for the students and referred to them regularly when discussing maker projects with individual students and the class as a whole. The use of these scientist characteristics within the design of the project became a crucial element in the outcome of the work for both the students and the teacher.

Our plan was to build background knowledge in part 1, provide examples of 2D, 3D, and digital models in part 2, present current sky science questions that are being addressed by scientists in part 3, and then have students make their own model in part 4. It should be mentioned that because of the teacher's concern regarding preparation for PATs, she also addressed each of the stated outcomes from the Program of Study (Alberta Education, 1996) before, during, and after making. Some of these involved completing assigned homework for class discussion (e.g. observing the moon phases), and explicit teaching lessons focused on required content (e.g. recognizing which heavenly bodies emit or reflect light).

The teacher expressed two concerns about the design for sky science: (1) whether students would be able to come up with their own substantive questions, and (2) whether students would be able to envision and build models on their own. When the researcher suggested that the teacher needed to tell the students that they would not have "all the answers," Riley replied, "I think for them that is really difficult because that's not what they're used to school being like." Riley reiterated her worries about the students' abilities further into the planning: "So they're going to come up with their question, and I think the biggest challenge for them is what can they do because I don't think they've been given the opportunity.. ." The researcher later confirmed these emotions by stating, "This could be a tough one, could be tough for us, and it could be tough for the kids too, because like you said, it's really stretching all of us. You know, we're doing things in ways we're not comfortable." Later in the discussion, the teacher's own anxieties about SI and NOS were surfaced with regard to model making: "Some of the kids were even asking deep thinking questions, and I was thinking, oh my, I don't even know how you would go about doing anything with that." This apprehension about how scientists carry out their work, specifically determining questions and ways to model understanding, was clearly felt on the part of the researcher and the teacher before starting.

The challenge of coming up with their own questions and developing models to answer those questions was also felt by the students. Once students had chosen their question, the teacher introduced a maker planning sheet she had designed to scaffold preliminary ideas about how students would make their model. During a class discussion, one of the students asked in earnestness, "But how can you build a model if you don't know the answer to the question?" This led to a weighty discussion about scientific inquiry, how scientists conduct their work, how they do not have the answers to questions, and how they sometimes make models to help them build on existing or observable knowledge. The learning moment was a perfect segue for the teacher to refer back to the four scientist characteristics posted in the classroom.

The teacher and researcher developed ways to scaffold the question finding process. Earlier in the year, Riley had conducted some work with the students on the notion of surface level questions and deep thinking questions. We built on this background to help students develop questions that were more complex, such as moving from "How many planets are there in the solar system?" to "How could we find out and prove there is another planet in the solar system?". As students brainstormed possible questions to pursue, we provided feedback as to whether the question was deep thinking or surface level, and assisted students in framing their questions so that they became deep thinking.

Additionally, when introducing the topic of sky science, Riley asked each student to bring in an article that was of interest to them. The class watched videos about sky science phenomena, and we shared web links with individual students related to questions they were raising in class. Themes began to emerge as students talked about what they were seeing and reading. In particular, the entire class appeared very interested in the nature and behavior of black holes, the possibility of new solar systems and planets, and the controversy over whether Pluto is or is not a planet. Though some students required support in creating their questions, by providing these scaffolds and piggybacking on the energy in the class, all students went into the makerspace with a question. Once the making began, some of the students refined and tightened their questions to be more deep thinking.

An important aspect of the design was an assessment tool, the scientist's log book, which was developed by the teacher. At the end of each making session, and based on the four scientist characteristics, students were asked to record how they exemplified the role of a scientist that day. Comments in their logbook might reference new questions they were asking, peers they collaborated with, and theories they were considering. The scientist log book was introduced prior to going into the makerspace, but once there, the students needed support for this task. When we saw a student embodying one of the characteristics, we often brought it to the awareness of the class so that they could see in themselves and others how we were becoming a scientific community.

During Making: Deepening Understanding of What It Means to Be a Scientist

Teacher concerns during the design phase regarding the students' ability to question and design thinking models were put to rest once the student work began in the makerspace. In particular, we noted levels of student engagement, and emergent opportunities for differentiated learning. Part of this related to the design work the students completed prior to making. For example, one student was very interested in finding out more about the gravitational pull on earth. Originally on his planning sheet, he thought of adopting a basketball as a model for earth. When asked about how to model gravitational pull, he seemed perplexed as to what material might serve the purpose. As ideas surfaced in discussion, such as the use of magnets for modeling gravity, the student realized that a basketball would not be a practical object for the idea he was trying to interpret. He then brainstormed other possibilities, including a baseball or a tiny, rubber bouncy ball.

The pre-planning work on the part of students led to a smooth transition to the makerspace. Students entered with a focused question, a design plan, and material ideas for making.

> I think the biggest surprise was how engaged everyone was from the start. And you know after building those questions, and scaffolding the project at the beginning, when we actually got into the maker lab, it was pretty seamless. We didn't have to instruct for the most part what the students should be doing. I was able to take a step back a couple of days and listen and you could just hear the conversations, actually hear the building process so that was really, that was more than I expected it was gonna be.

In retrospect, investing time with the students to scaffold the question development and design plan was a key aspect of making.

We were able to see how the design and structure of the sky science maker project granted students access to learning in ways that suited them and allowed them opportunities to explore the specific aspects of sky science that interested them. The teacher noted the accomplishments of an ELL student. "You know the project with the satellite. That for him, that's probably the best project he's ever done, the most research he's ever done, and also just the vocabulary he learned in that process." Sandra's interaction with this student began with a conversation about possible materials for making the satellite model. Throughout the process, the researcher and student continued to dialog. As the student went deeper into the making, more questions emerged. He was interested in knowing all the parts of the satellite, how they worked, and what their purpose was. Learning about the cameras on the satellite led him to question, "How do they send the photos back to earth?" His question resulted in a discussion about digitization of data and how technological innovations have made it possible for scientists to gather specific information they have only been able to access recently.

The teacher reflected on the accomplishments of another ELL student who has been in Canada less than a year. Her question related to why it was so cold in Canada and so hot in the country of her birth.

> So language is really really difficult, and she was able to, you know, you need to be able to pull a little bit to get her ideas, but she kind of started off with this really big, abstract idea and you chatted with her a couple of times and so did I, and once we narrowed it down a little bit and was able to make the connection bringing in her home country, she was able to understand a little bit about earth's rotation.

Not only did the model-making assist in helping the student develop a pertinent question related to a key scientific idea, it also provided the opportunity for her to develop the vocabulary needed to articulate those ideas.

Making presented challenges for some of the more capable students; in Riley's words, "pushing them out of their comfort zone." The teacher expressed disappointment that some students she thought would gravitate to making in order to explore their topics, did not. "A couple of kids who I actually thought would have those deeper, great, amazing questions didn't." She problematized why this might be the case.

> In my opinion, I don't know why, I'm just assuming . . . and this has been through conversations, their school careers haven't been . . ." She imagined a conversation with a student about right answers. ""Okay, pick a question. There doesn't have to be an answer. You don't really have to find out. The end product doesn't have to be the right answer." . . . I don't think a lot of them are used to that. I think a lot them, there has to be that answer. You need to truly *know* to get a good mark on that project. So I think they struggled there.

This excerpt shows how the teacher was coming to see that what constitutes knowing for the students and for her would be challenged in the makerspace.

As observers, we marveled at the ingenuity of the students in creating and attempting to model ideas in ways that would help them make sense of their questions and come to know about their topic. One student was interested in what happens when something gets sucked into a black hole. To imagine this, he constructed a marble run with multiple tracks in order to explain different possibilities. Another student developed her question based on an article she had read that predicted a collision of two stars in 2022. Noting that there would be forces in space that may lead to this, she played with the ways she might enact this within a model. She suspended two spheres within a box using fishing line. By spinning the spheres around each other, she was able to model how the rotating motion drew the two orbs toward each other.

Another ELL student took what seemed at first to be a simplistic approach to modeling. Using a Google slide, he created a 2D model of the solar system. Sandra learned that this student's mathematical knowledge was quite extensive and thought that drawing on this strength would allow him to gain a deeper understanding of the size and scale of the planets and the relative distance between them. She guided him to research the size of the planets and scale them based on their sizes. The student also learned the distances between the planets, but given the limitations of the software, was unable to correctly model this. When presenting his model in video form, he indicated an important learning: Though scientific modeling assists in understanding, there are also limitations to modeling as a way to represent phenomenon. While the model was simplistic, the student's learning showed deeper understanding.

One student attempted to model the forces that hold heavenly bodies in orbit. Using a piece of plastic tubing, and a small rubber ball, he displayed perseverance in attaching the tube to a cardboard frame in order to set the ball in motion in an orbital path. Challenges with materials (cardboard, tubing, duct tape, glue) made us question what this student was trying to accomplish. However, it was when we filmed him discussing the theories behind his model that we developed the insight that, though struggling with materials, he was actively making sense of important scientific concepts such as the forces of gravity and what a theory is.

The teacher also reflected on the students' ability to learn from each other. "I think there was a lot of incidental learning too. A lot of kids learning different things because they came across something else. The amount of times I've heard that, right?" She reiterated the words of one of the students. "I didn't know there was another solar system." Within the maker environment, we observed the students to be engaged in a scientific culture of curiosity and inquiry, which was cultivated through the students' questions and modeling, and scaffolded through the teacher's enactment of a design approach to pedagogy.

Post-making: Seeing Students and Teachers as Emerging Scientists

Throughout the cycle, the teacher and researcher gained specific insights into the way the students-as-scientists conducted their work, which led them to observe a shift in the students' ontologies as learners. Specifically, students developed an ontological awareness in their making practices related to several characteristics of the NOS as identified by Lederman et al. (2013), including the creative, inventive aspects of science, the subjective theory-laden aspects of science, the changing nature of scientific knowledge, and the distinction between scientific laws and theories. By experiencing the innovative, yet developmental nature of scientific study, students altered their notions not only of what science is, but also what knowing is. Students also engaged in the science practices of investigating (by asking questions), sensemaking (by constructing models and explanations related to the models) and critiquing (by researching, communicating, and participating in dialog around theories in sky science) (McNeill, Katsh-Singer, & Pelletier, 2015).

Emerging Scientists as Theorists. While early on in the makerspace, students were asking "What is a theory?", by the time they created their final sharing videos, several of the students were able to articulate possible theories regarding their topics. The teacher related a classroom discussion around planets, restating her students' comments. "We're having conversations about, well, "it's hypothetical, it's a theory still. Why do we think it's a theory?" Those [conversations] we did not have before." Though students did not present evidence of theory construction, they deepened their understanding around what a theory is and how scientists come to develop and question theories. For example, some students learned through their own research that astronomers, by observing anomalies in the orbits of certain objects, have been able to theorize about the existence of a new planet (NASA, 2018). An important aspect for student learning around scientific theories was coming to understand that scientists look for evidence upon which to build theories, "through theoretical mechanisms that are not directly observable" (Chinn & Malhotra, 2002, p. 182).

Emerging Scientists as Knowledge Experts. The teacher observed her students probing deeply into topics that interested them. "They're pursuing their own interests with the same topic using the tools and the real world. Again, it's the criteria of a scientist." The four characteristics of a scientist became a central reference point not only for the students but also the teacher when considering how the learning unfolded. "They all had their own thing. It wasn't one topic that we were working toward. So the students felt like they were the expert instead of them feeling like I was the expert." Because students were exploring multiple topics at once, it meant that the teacher was unable to keep her traditional role as sole expert and knowledge keeper. The shift from teacher as keeper of knowledge to the emerging student scientists becoming experts in specialized fields contributed to a community of learners. Students shared with each other ideas that they were learning about sky science phenomenon and did not look to the teacher as the only expert in the class. "I think the other thing that was beneficial too was explaining that *we* were learning." This articulation of teacher-as-learner created an interesting dynamic in that students, in order to build their model, had to seek out knowledge about their topic and could not look to the teacher as dispenser of information. This changed role did prove challenging for the teacher in that it became difficult for her to vet all of the information on multiple topics. She expressed concern about a lack of control. "That's one area that I was very scared at the beginning. Like I don't know enough about this topic to be able to have the kids just go off in 27 different ways." The teacher's fear that students' scientific understanding may have been flawed was a recurring theme in discussions with the researcher.

However, the teacher did begin to see herself as a different type of knowledge expert, in that she brought understanding of teaching and learning to the work. When asked to articulate powerful aspects of the project she stated, "Again, interesting, challenging topics. No teacher control. Knowledge of domain. How we learn." The researcher responded to the teacher by suggesting that her control existed in a different way. "So in a way, that was the control you had. Your knowledge of the domain of how scientists work." The teacher agreed, and then stated, "But not of a specific topic." Making introduced Riley and her students to key aspects of SI. Through the process, they learned that in SI, scientists begin with a question and that there is no single method with which to answer the question, but rather their procedures are disciplined and guided by the questions they ask (Lederman, Lederman, Bartos, Bartels, Meyer, & Schwartz, 2014). Additionally, they needed to defend decisions made during the making from available evidence (Lederman et al., 2014).

Emerging Scientists Guiding Their Own Learning Process. Once students began the making process, the teacher recognized how they directed their own learning. "I wasn't facilitating the learning. I don't feel I was." When asked to explain more fully how she felt even when her role as facilitator was curtailed, she disclosed that at the beginning, she did provide support. "At the beginning. But that faded. It faded once everybody picked their questions, and then I felt that I was there a little bit to help guide them in one direction or another, if needed, or kind of challenge them a bit more, but at the end, there were many days where I felt unneeded." The researcher pressed her by asking, "Do you think that was a good thing or a bad thing?" In her explanation of how students' experiences as emerging scientists had carried over into other aspects of classroom life, the teacher reflected:

> I think it was a good thing. I'm noticing it more in other areas now where the last couple of weeks, the kids have kind of been completely independent. We're doing an experiment in math. The kids are creating their own experiment and yesterday everybody got ready and I turned around and looked and everybody's doing exactly what they should be, and that's new. That's not something that was happening a couple of months ago.

When asked if she had any insights into what led to this active engagement, Riley asserted:

> I think a bit of it is giving them that freedom to develop their own question of what they're interested in. Yes, we scaffolded certain steps. And they knew there were clear steps and expectations that had to get done before they were allowed building, but once the building started, you know, some kids would ask for advice on materials, others would just do things like Gavin.[2] It wasn't working the way he wanted and I didn't understand what he was trying to do. So I think that's probably a huge reason. Cause they all had their own thing.

Gavin's struggle to make his model work the way he envisioned demonstrated for the teacher that sometimes she had to let her students flounder with their ideas and come to the learning in their own way.

From Ontology of a Scientist to Ontology of a Learner

In reflecting on the maker work, the teacher was asked what was more powerful learning, the notion of her students taking on the role of scientists or making the models. She replied, "I think taking on the role of scientist. For me, as well as the students." This reference to her own learning was crucial. Riley came to realize that for her as well as for her students, it was important to understand ontologically what it means to *be* a scientist. Riley referenced specific aspects of the design that attended to the ontology of a scientist. "You know, having them look at understanding the tools that were used for space. ... myths. . . observations. .. , I think that was a really big one. We wanted them to know there are all these scientists and all these theories are constantly changing. I don't think I really realized that, early on when we were planning." In acknowledging her own deepening appreciation of the work of scientists, she channeled this understanding of SI with her students. Riley's statements indicate her own growing understanding of NOS in that scientific knowledge, while empirical, is creative in nature and changeable over time (Lederman et al., 2013). By studying with her students, astronomers theories such as Copernicus' heliocentrism (Westman, 2018),

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[2] Pseudonym

or recent controversies over whether Pluto is a planet (Powell, 2018), she and her class came to see science as culturally connected and thereby subjective (Lederman et al., 2013). This allowed them to see that scientists live in a perpetual state of inquiry, and gave all of them, including the teacher, permission to enter that state.

As the class moved into planning and designing their models, the teacher observed them not only taking on the scientist role but also saw them *becoming* scientists. Referring students regularly to the four characteristics of a scientist provided a scaffold. “And just for me it helped with that language. When I’m observing kids doing something, in all subjects, I tell them, “That’s what a scientist does.””

The teacher recognized that this experience was different than in the past stating, “But it’s more.” Riley explained that previously, she would bring experts in for different aspects of a project, “and having kids. .. *pretend* to be these experts but it’s only for the main part. Right, like okay, these kids are thinking like architects because they’re building a bridge right now. But they’re not thinking what they did beforehand. You know?. .. So we actually started that whole process on day one.. .. I think that has been probably the most powerful thing.” Embodying the role of a scientist from the beginning meant that students not only made models, but also they developed their own questions, engaged in research to find out what was already known, envisioned and created a model that could help them make sense of their questions, and worked in a scientific community to share and test their ideas and also to further their own understanding.

The learning for the teacher moved beyond this particular maker experience, when it became a way for her to see teaching as a whole. The maker experience had a measured effect not only in how she saw her students as emerging scientists, but how she saw them as learners. The learning she gained from this experience transformed the way she approaches designs for learning and responsive teaching in that she now promotes the ontology of scientist, as the ontology of a learner. “I use that in all subject areas now where we go back and look and it’s not only scientists, it’s learners. You know, “We as *learners* do this.””

Discussion

The findings of this study demonstrate that making has the potential to promote learning not only for students but also for teachers in elementary schools. We posit that creating conditions for the teacher and her students to be makers led them to understanding what it means to be a scientist and a learner. Several key components we feel provided an explanation for this outcome:

1. The explicit teaching of the nature of SI in the form of the four scientist characteristics was a crucial aspect of this work (Peters, 2012; Peters & Kitsantas, 2010; Stone, 2014). Consistently and explicitly referencing student use of the characteristics throughout the project affirmed not only the intellectual and emotional aspects of SI that are critical for scientific work, but also for makers. This meant that participants, in being makers, could *become* scientists rather than *pretend* to be scientists.

2. Making provided a complexity to SI that is often not found in classroom settings (Chinn & Malhotra, 2002). By challenging students to select their own deep thinking question, followed by envisioning and prototyping their own model to attempt to answer that question, students were pushed to engage in SI in more authentic ways.
3. Participating in the making of scientific models proved transformative for participants in terms of how they saw themselves not only as scientists, but as learners. The teacher and students not only became creators, but also problem solvers, meaning makers, and innovators.
4. It was not only necessary for students to become scientists, but for the teacher to become a scientist as well. Though the teacher in this study had been exposed to the *idea* of embodying the disciplines of science as an effective teaching practice (Friesen, 2009), it was the lived experience with her students that for her, made it a real component of her pedagogy. In reviewing the Effective Teaching Practices Rubric (Friesen, 2009), as a result of this work, the researcher observed the teacher moving from an emphasis on subject matter acquisition (stage one), and occasionally bringing in discipline experts (stage two) to designing experiences that required disciplinary ways of thinking and acting (stage four).
5. Neither the teacher nor the researcher had a background in STEM which added to their anxiety during implementation. Approaching this work as designers of learning (Friesen, 2009) required them “to enter an iterative cycle of defining, creating, assessing, and redesigning” (Friesen, p. 5) which nudged them into living the ontology of a scientist. Through this experience, the teacher and researcher not only advanced their understanding of SI and NOS but also further developed their own conceptual understanding of the big ideas related to sky science.
6. The selection of DBR as methodology of choice was a crucial element of the study in that it permitted us to address the research question: How can teachers be supported in the development of knowledge, pedagogy, and practice within an elementary makerspace environment? The continual, reciprocal, collaborative processes of design, implementation, and evaluation created an atmosphere of risk-taking and trust, enabling the testing of an innovative intervention within a complex real-world setting (Jacobsen, 2014). Working extensively with one teacher and her students led the researcher to consider the second research question: How can teachers support the development of students’ conceptual understanding of disciplinary topics in an elementary school makerspace? Iteratively designing and co-enacting allowed the researcher to identify the ways in which the teacher created conditions for her students to come to understand the discipline of sky science in new ways.

Conclusion

Though the DBR study that took place was in many ways transformative for the teacher, there are components of the study that need further consideration and would benefit from further research. Firstly, while the content outcomes listed in the program of study (Alberta Education, 1996) focus more on observable phenomena (e.g. the moon, the stars, the planets), the students demonstrated a desire, through their choice of questions, to explore more deeply the unobservable forces at work (e.g. gravity). In the future, it would be worthwhile to investigate learning designs that focus on the unobservable phenomena in the night sky to determine whether and how these designs can assist students in developing conceptual understanding. Taking this approach would require teacher support, in that elementary teachers may not have the conceptual background or confidence to pursue this direction.

Secondly, the teacher made it clear that having an additional support person in the form of a researcher was pivotal to conducting the work. Riley expressed how she would not have been able to explore making in this way without someone working side-by-side with her through the research-based process. Envisioning creative ways for teachers to be supported in collaborative learning around making will be critical to success in the future.

Thirdly, due to concerns related to upcoming PATs, the teacher did go back and explicitly address curricular outcomes that she felt were less well understood by students after the work in the makerspace was completed. However, she is also rethinking her learning design for future years as she would like to more thoughtfully intersperse explicit lessons based on specific outcomes throughout the making, based on the needs of the students at the time.

Fourthly, it was important to examine the program of study as an interpretive document with the teacher acting and seeing herself as a designer of learning (Friesen, 2009). This allowed for a more creative approach to an exploration of sky science. Further research on how teachers might grow into this role of teacher as designer in other topic areas and disciplines will be helpful.

Finally, designing for learning can he a highly esthetic experience, while fraught with tension related to teacher confidence and student knowledge and achievement. Having teachers recognize and acknowledge the emotional aspects of designing for making may bring an articulation to the process that alleviates some of the stress.

The results from this study reveal that making has the potential to offer elementary students and their teachers genuine opportunities to explore and question big ideas in science, while experiencing some of the joy and the pitfalls of what it means to *be* a scientist. In part, this means that teachers and students must live with the risk of uncertainty. That in itself will take them partway to advancing their ontological understanding of the nature of science.

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References

Abd-El-Khalick, F., & Lederman, N. G. (2000). The influence of history of science courses on students' views of nature of science. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 37*(10), 1057–1095.

Alberta Education. (1996). *Science*. Retrieved from https://education.alberta.ca/media/159711/elemsci.pdf.

Alberta Education. (2018). *General information bulletin: Provincial achievement testing program grades six and nine*. Retrieved from https://education.alberta.ca/media/3795656/ach-gib-2018-19-entire.pdf.. Accessed 7 Jan 2018

Anderson, R. D. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education, 13*(1), 1–12.

Appleton, K. (2006). Science pedagogical content knowledge and elementary school teachers. In K. Appleton (Ed.), *Elementary science teacher education: International perspectives on contemporary issues and practice* (pp. 31–54). New York, NY: Routledge.

Barab, S. (2014). Design-based research: A methodological toolkit for engineering change. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (2nd ed.). New York, NY: Cambridge University Press.

Bevan, B. (2017). The promise and the promises of making in science education. *Studies in Science Education, 53*(1), 75–103. https://doi.org/10.1080/03057267.2016.1275380.

Bevan, B., Gutwill, J., Petrich, M., & Wilkinson, K. (2015). Learning through STEM-rich tinkering: Findings from a jointly negotiated research project taken up in practice. *Science Education, 99*, 98–120.

Brennan, P. (2017, February 23). *Earth-size planets: The newest weirdest generation*. Retrieved from https://www.nasa.gov/feature/jpl/earth-size-planets-the-newest-weirdest-generation

Burger, J. M., & Krueger, M. (2003). A balanced approach to high-stakes achievement testing: An analysis of the literature with policy implications. *IEJLL: International Electronic Journal for Leadership in Learning, 7*(4), 7.

Cheng, L., & Couture, J. C. (2000). Teachers’ work in the global culture of performance. *Alberta Journal of Educational Research, 46*(1), 65–74.

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education, 86*(2), 175–218.

Chu, S. L., Quek, F., Bhangaonkar, S., Ging, A. B., & Sridharamurthy, K. (2015). Making the maker: A means-to-an-ends approach to nurturing the maker mindset in elementary-aged children. *International Journal of Child-Computer Interaction, 5*, 11–19.

Chu, S. L., Schlegel, R., Quek, F., Christy, A., & Chen, K. (2017). ‘I make, therefore i am’: The effects of curriculum-aligned making on children’s self-identity. In G. Mark, S. Fussell, C. Lampe, M. C. Schraefel, J. P. Hourcade, C. Appert, & D. Wigdor (Eds.), *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (pp. 109–120). New York, NY: ACM.

Freeman, A., Adams Becker, S., Cummins, M., Davis, A., and Hall Giesinger, C. (2017). *NMC/CoSN Horizon Report: 2017 K–12 Edition*. Austin, Texas: The New Media Consortium. Retrieved from https://cdn.nmc.org/media/2017-nmc-cosn-horizon-report-k12-EN.pdf.. Accessed 27 Jul 2018

Friesen, S. (2009). *What did you do in school today? Teaching effectiveness: A framework and rubric*. Toronto, Canada: Canadian Education Association.

Geier, R., Blumenfeld, P. C., Marx, R. W., Krajcik, J. S., Fishman, B., Soloway, E., & Clay-Chambers, J. (2008). Standardized test outcomes for students engaged in inquiry-based science curricula in the context of urban reform. *Journal of Research in Science Teaching, 45*(8), 922–939.

Halverson, E., & Sheridan, K. (2014). The maker movement in education. *Harvard Educational Review, 84*(4), 495–504.

Harlen, W. (1997). Primary teachers’ understanding in science and its impact in the classroom. *Research in Science Education, 27*(3), 323–337.

Holbert, N. (2016). The powerful ideas of making: Building beyond the curriculum. *Journal of Innovation and Entrepreneurship, 5*(1), 30. https://doi.org/10.1186/s13731-016-0058-4.

Jacobsen, M. (2014). *Design-based research. Sponsoring innovation in education*. Retrieved from http://www.cea-ace.ca/education-canada/article/design-based-research. Accessed 31 Jul 2018

Klinger, D. A., & Rogers, W. T. (2011). Teachers’ perceptions of large-scale assessment programs within low-stakes accountability frameworks. *International Journal of Testing, 11*(2), 122–143.

Lederman, N. G., Lederman, J. S., & Antink, A. (2013). Nature of science and scientific inquiry as contexts for the learning of science and achievement of scientific literacy. *International Journal of Education in Mathematics, Science and Technology, 1*(3), 138–147.

Lederman, J. S., Lederman, N. G., Bartos, S. A., Bartels, S. L., Meyer, A. A., & Schwartz, R. S. (2014). Meaningful assessment of learners’ understandings about scientific inquiry—The views about scientific inquiry (VASI) questionnaire. *Journal of Research in Science Teaching, 51*(1), 65–83.

McKenney, S., & Reeves, T. (2012). *Conducting educational design research*. London, England: Routledge.

McNeill, K. L., Katsh-Singer, R., & Pelletier, P. (2015). Assessing science practices: Moving your class along a continuum. *Science Scope, 39*(4), 21–28.

Martin, L. (2015). The promise of the maker movement for education. *Journal of Pre-College Engineering Education Research, 5*(1), 30–39.

NASA (2018). *Hypothetical Planet X.* Retrieved from https://solarsystem.nasa.gov /planets/hypothetical-planet-x/in-depth/.

Nehring, A., Nowak, K. H., zu Belzen, A. U., & Tiemann, R. (2015). Predicting students' skills in the context of scientific inquiry with cognitive, motivational, and sociodemographic variables. *International Journal of Science Education, 37*(9), 1343–1363.

Papert, S., & Harel, I. (1991). Situating constructionism. In I. Harel & S. Papert (Eds.), *Constructionism* (pp. 1–11). Westport, CT: Ablex Publishing.

Parker, J., & Heywood, D. (2000). Exploring the relationship between subject knowledge and pedagogic content knowledge in primary teachers' learning about forces. *International Journal of Science Education, 22*(1), 89–111.

Peters, E. E. (2012). Developing content knowledge in students through explicit teaching of the nature of science: Influences of goal setting and self-monitoring. *Science & Education, 21*(6), 881–898.

Peters, E. E., & Kitsantas, A. (2010). Self-regulation of student epistemic thinking in science: The role of metacognitive prompts. *Educational Psychology, 30*(1), 27–52.

Powell, C. S. (2018). Here's the answer that will finally settle the "Is Pluto a Planet?" debate for good. (yeah, right). [Web log comment]. Retrieved from http://blogs.discovermagazine .com/outthere/2018/06/05/the-is-pluto-a-planet-debate/#.W3QttS0jmCc.

Ryan, J. O., Clapp, E. P., Ross, H., & Tishman, S. (2016). Making, thinking, and understanding: A characteristical approach to maker-centered learning. In K. Peppler, E. R. Halverson, & Y. B. Kafai (Eds.), *Makeology: Makerspaces as learning environments* (Vol. 2, pp. 29–44). New York, NY: Routledge.

Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education, 88*(4), 610–645.

Sheridan, K., Halverson, E., Litts, B. K., Jacobs-Priebe, L., & Owens, T. (2014). Learning in the making: A comparative case study of three makerspaces. *Harvard Educational Review, 84*(4), 505–531.

Stone, E. M. (2014). Guiding students to develop an understanding of scientific inquiry: A science skills approach to instruction and assessment. *CBE-Life Sciences Education, 13*(1), 90–101.

Vossoughi, S., & Bevan, B. (2014). Making and tinkering: A review of the literature. *National Research Council Committee on Out of School Time STEM*, 1–55. Retrieved from http://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_089888.pdf.. Accessed 15 Aug 2018

Westman, R. S. (2018). *Nicholas Copernicus: Polish Astronomer.* Retrieved from https://www.britannica.com/biography/Nicolaus-Copernicus.. Accessed 4 Jan 2018

Williams, D. C., Ma, Y., Prejean, L., Ford, M. J., & Lai, G. (2007). Acquisition of physics content knowledge and scientific inquiry skills in a robotics summer camp. *Journal of Research on Technology in Education, 40*(2), 201–216.