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Becoming a Maker Teacher: Designing Making Curricula That Promotes Pedagogical Change

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In this article, we focus on the case of a Canadian teacher and her students who engaged with a researcher in a year-long design-based research study exploring the implementation of curriculum within a makerspace context. Together, the grade six teacher and researcher co-designed, co-enacted, and co-reflected on three curricular making cycles, one related to sky science, another to mathematical transformations, and a third focused on core concepts of democratic systems. The two-fold purpose of this DBR was to promote pedagogical change through designs for making and to articulate design principles that could be utilized when engaging with curriculum for making. Findings show that the makerspace as learning environment and design-based research as methodology provided a double helix scaffold that compelled the teacher to reconsider her frame when enacting curriculum. For this teacher, collaboration on design-based research and designs for learning in the makerspace promoted a shift in pedagogy and led the teacher and her students to rethink notions of curriculum while questioning what is important to know. An expansion of the intervention to engage multiple teachers in multiple sites to determine scalability is recommended. Study findings point to the makerspace as a promising design frame for rethinking curriculum and pedagogical practice.

Keywords: makerspace, making, maker, design-based research, curriculum, professional learning, pedagogy

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INTRODUCTION

To promote positive change in education for Canada's youngest citizens, classroom-based teaching practices need to shift from standardized delivery of content to supporting students' interest driven knowledge building in the highly complex and technology mediated worlds in which we now live. Bereiter (2014) argues educational research must go beyond attempts to document "best practice" and move toward promoting "invention" (7) and creating sustainable transformations and innovative practices through creative approaches to designing for learning using design-based research (DBR), conducted collaboratively with real teachers in real classrooms (Brown, 1992). Makerspace learning environments serve as a unique platform to enact innovation in schools, elevate teacher and student learning, and sponsor interdisciplinary inquiry in humanities, design, and STEM disciplines (science, technology, engineering, math).

Makerspaces are collaborative learning spaces in which makers engage in design thinking, tinkering, and playing with ideas using a variety of technologies and materials. Participants prototype ideas with materials ranging from found and recycled items to contemporary digital technologies (such as 3-D printers and laser cutters). Current research suggests that the makerspace environment lends itself to formal educational settings in that learners can prototype, construct, and build conceptual ideas through making (Bevan, 2017; Becker, 2019; Becker and Jacobsen, 2019). Participating in making can support the exploration of topics of study in the school curriculum (Harron and Huges, 2018) and perhaps more importantly, provide authentic opportunities for students to risk take, problem solve, and learn from failure (Oxman Ryan et al., 2016; Paganelli et al., 2016; Becker, 2019; Becker and Jacobsen, 2019). However, though there is research that supports the overall benefits of making for learning, there is a gap in teacher education and classroom-based research on how curriculum might be enacted in makerspaces (Kjällander et al., 2018).

To address this gap, we focus on the case of a Canadian teacher, Riley, and her students who engaged with a researcher, Sandra, in a year-long DBR study exploring the implementation of innovative curriculum within a makerspace context. Together, Riley and Sandra, co-designed, co-enacted, and co-reflected on three curricular making cycles, one related to sky science, another to mathematical transformations, and a third focused on core concepts of democratic systems. Sandra and Michele engaged in on-going DBR conversations and reflections on the cycles of collaborative learning, teaching, and research engagements in Riley's classroom. Consideration and analysis of research data and information collected in each cycle informed the next iteration, and also informed the development of design principles that emerged from the research.

The two-fold purpose of this design-based research was to promote pedagogical change and innovation through designing for making (practical solutions) and to articulate design principles (theoretical insights) that could be useful to others when approaching curriculum through making. Two research questions guided the study. *How can teachers be supported in the development of teacher knowledge, pedagogy, and practice within an elementary school makerspace environment? How can teachers support the development of students' conceptual understanding of disciplinary topics in an elementary school makerspace?*

We posit that designing for making provides a unique frame with which to ponder curriculum and may promote ways to consider innovative pedagogy despite the external influences and complexity in education that can impact teachers' work. It is a challenge to design and implement innovative pedagogies and projects while working within the constraints of a standardized curriculum and provincial achievement testing (Alberta Education, 2017), which can pressure teachers to default to teacher directed instruction models (Davis et al., 2015) and to focus on summative assessment (Volante and Ben Jaafar, 2008; Volante, 2010). External influences on practice, coupled with a lack of contextualized teacher professional learning opportunities (Fullan et al., 2006; Bruce et al., 2010), can often prevent teachers from innovating their practice. The dispositions espoused in a makerspace as valuable for students, that is a desire for innovation, collaboration, creative problem-solving, and risktaking, can also serve to inspire and enfranchise teachers.

Three elements were considered as key aspects of this study in an elementary makerspace: curriculum, learning environment, and design. In the rest of this article, we focus on sharing how our design-based research approach to expanding upon the curriculum through designs for learning within a makerspace environment led to practical solutions and theoretical insights for both the teacher and the researchers. First, we explore notions of curriculum as conceptualized by van den Akker (2013) and others within a DBR context. Next, we present how these curricular conceptualizations were designed, enacted, and reflected upon in this study, and how this process of living out the curriculum in the makerspace and classroom contributed to our understanding of makerspace as a collaborative professional learning environment for the teacher and the researchers. Finally, we consider design principles that emerged from this enactment of curriculum through making that can be taken forward in future research and practice.

In the case of our study, we started with the official curriculum as articulated in the programs of study set out by the education ministry, the governing educational body in the Canadian province in which the research took place. Our goal was to examine how a teacher might be supported in approaching curriculum as praxis, engaging in design thinking for discipline focused learning in the makerspace, and enacting three designs for learning through making by utilizing the mandated curriculum. When designing the study, a focus on praxis, the interaction of action and reflection on curriculum, informed the focus on enactment, where "teachers and learners together create their own curriculum realities" (van den Akker, 2013, p. 62) which "forms the cornerstone of our vision on design research in the curriculum domain" (McKenney et al., 2006, p. 72). Analysing curriculum enactment provided an opportunity to frame our design-based research with a curricular lens and to consider revisions to our designs using that lens (McKenney et al., 2006).

CONSIDERING CURRICULUM

van den Akker's Conceptualization

van den Akker (2013) has developed a model of curriculum components, a typology of curriculum representations, and a description of curriculum at various levels; he suggests that in order to create innovation we must "build bridges between levels, factors, and actors" (p. 54). An advocate for design-based research, van den Akker acknowledges the historically feeble connection between curriculum and research and advocates for the exploration of "a better cross-fertilization between educational research and curriculum development" to strengthen "the information base of curriculum policies and classroom practices" (van den Akker, 2013, p. 54).

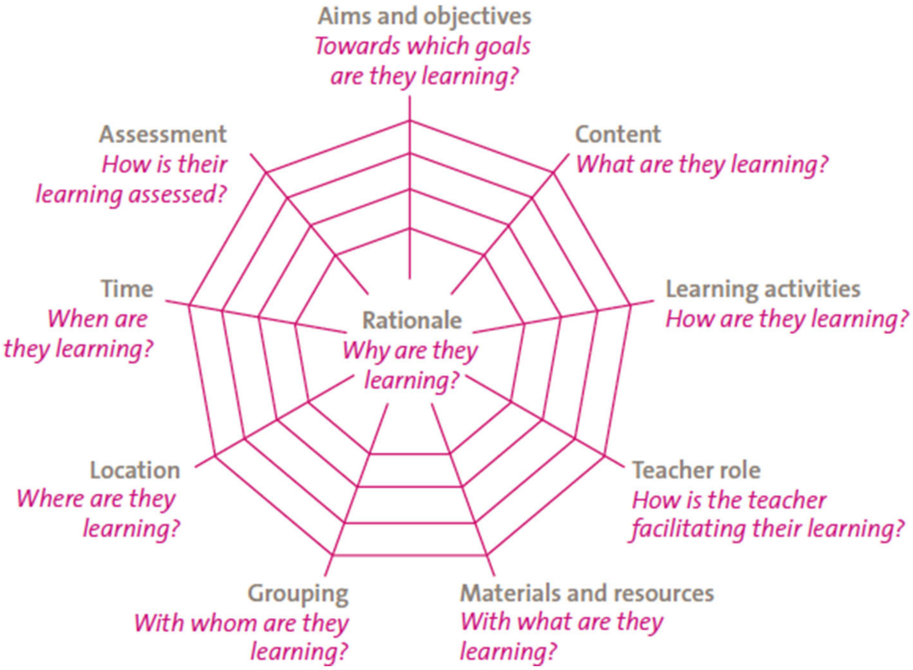

FIGURE 1 | van den Akker's (2013) curriculum spider web. Source: van den Akker, "Curricular development research as a specimen of education design research" in Educational Design Research, 2013. Image used with permission from the author and the publisher, SLO.

The provincial curriculum provided a springboard for our analysis and revisioning, but also assisted us in considering how we might use making to bridge the curriculum as-it-is with innovative practices while conceptualizing different ways of engaging students and ourselves in living the curriculum topics as-they-might-be. van den Akker's conceptualizations of curriculum were employed within this research to guide our dialogue and thinking when reflecting on curriculum as a scaffold in the makerspace as compared to the classroom environment. van den Akker's curriculum components also provided a structure for considering implementation stability within the three different cycles of making.

van den Akker's (2013) model of curriculum components (**Figure 1**) provides a conceptualization of curriculum as a spider web, where each ingredient, when linked to the others is part of a strong network. However, it is important that all the components of curriculum remain in balance (van den Akker, 2013). A heavy focus on one component over the others can pull the entire system out of alignment and cause it to fracture. The complexity of curriculum work is suggested in the spider web with the delicate balancing required to consider and to enact all components. van den Akker's model is meant to show that all elements are important, and that if even one is out of alignment, the entire system can be upended (van den Akker, 2013). This inclusive emphasis on balance and alignment was helpful to understand in the context of this study, because we were interested in determining how curriculum components stayed connected, and how they might detach with the transition from curriculum as content to curriculum as praxis.

TABLE 1 | Typology of curriculum representations (van den Akker, 2013).

Intended	Ideal	Vision (rationale or basic philosophy underlying a curriculum)
	Formal/Written	Intentions as specified in curriculum documents and/or materials
Implemented	Perceived	Curriculum as interpreted by its users (especially teachers)
	Operational	Actual process of teaching and learning (also: curriculum in action)
Attained	Experiential	Learning experiences as perceived by learners
	Learned	Resulting learning outcomes of learners

Source: van den Akker (2013), used with permission.

van den Akker (2013) proposes that each of the curriculum representations (**Table 1**) relates to different stakeholders within the system. "Traditionally, the intended domain refers predominantly to the influence of curriculum policy-makers and curriculum developers (in various roles), the implemented curriculum relates to the world of schools and teachers, and the attained curriculum has to do with students" (p. 56). Within this study, we intentionally used van den Akker's typology as a discussion point and analysis tool with Riley.

Finally, van den Akker (2013), also considers the various levels about which curriculum discussions are held. The levels, as adapted and utilized in the study, are found in **Table 2**.

TABLE 2 | van den Akker (2013) curriculum levels, adapted for use.

Level	Description
Supra	National/International
Macro	Provincial/District
Meso	School
Micro	Classroom
Nano	Student

Source: van den Akker (2013).

Interestingly, Riley initiated discussions on several occasions about makerspace implementation at the meso (school) and macro (district) level, which is discussed in more detail in a subsequent section.

We utilized van den Akker's (2013) components, representations, and levels in the context of cultivating and studying teacher enactment of designs for learning in the makerspace. It was our intention to determine how Riley might reconsider her focus on curriculum-as-content, and how through action and reflection, the active process of design thinking and designing for and evaluating making, might prompt her to imagine curriculum differently. We were interested in knowing what aspects of curriculum-as-content constrained her attempts to connect the curriculum to making, and what aspects freed her to imagine curriculum as praxis and explore other possibilities for learning that were reciprocally related and integrated into the makerspace.

Other Conceptions of Curriculum

The need for increased, prescriptive and reliable understandings of curriculum in the design of learning experiences in makerspaces in elementary classrooms was a key catalyst for this study (Becker, 2019). Curriculum holds a multiplicity of meanings in educational research, e.g., curriculum as content priorizes the content and objectives students need to and should learn (Klep et al., 2004), and the content and methods teachers implement (Kauffman et al., 2002). Friesen and Jardine (2011) synthesize four dominant orientations to curriculum: (1) Curriculum as a syllabus or outline of content to be transmitted, a body of knowledge-content and/or subjects, and effective methods of delivery; (2) Curriculum as product, education as technique with set objectives and measures of outcomes; (3) Curriculum as an active process, the interaction of teachers, students and knowledge, classroom actions and decisions, preparation and evaluation; and (4) Curriculum as praxis, developed through dynamic interaction of action and reflection, constituted through an active process of planning, acting, and evaluating that is reciprocally related and integrated into the process. Leveraging the potential of design thinking in working with curriculum and pedagogy has also been advanced by several educational scholars (Friesen, 2009; Trebell, 2009; Laurillard, 2012; Tsai et al., 2013; Friesen and Jacobsen, 2015), and also informs the connection between design thinking and curriculum as praxis in this study.

TABLE 3 | Approximate time used to design, enact and reflect in three making cycles.

	Cycle 1 sky science (Nov.-Feb.)	Cycle 2 math transformations (Mar.-Apr.)	Cycle 3 social studies (May)
Design	3 h	1 1/2 h	1/2 h
Enact	6 weeks	2 weeks	4 days
Reflect	Ongoing	Ongoing	Ongoing

STUDY CONTEXT AND METHODOLOGY

The research was conducted in a K-7 rural school in Alberta, Canada with an elementary teacher, Riley, and her class of 27 grade six students. Approximately one third of the students were English language learners, and many had parents who had come from overseas to work as temporary foreign workers. Given the levels of remuneration provided by the main industry of the town, approximately one fifth of the parent/workers had to take on second or even third jobs to make ends meet. Access to learning technologies in the school was limited. The class had part-time, shared access to a mobile cart of Chromebooks and iPads that were approximately 4 years old. However, the school did have a designated makerspace, located adjacent to the library, that housed found materials that had been gathered from various classrooms in the school.

The design, enact, reflect timelines for the three making cycles (presented in **Table 3**) serve to demonstrate how Riley became more adept at designing curriculum for maker activities as the school year progressed. However, our research also documents how time pressures in the school year and provincial achievement testing played a role in how and when each cycle was implemented.

Each of the three cycles of making in this study consisted of some pre-making work with students in the classroom, enacting and iterating design ideas in the makerspace, followed by post-making reflection in the classroom. Pre-making work included ideation, research, drafting design ideas, and determining the materials to be used for making. This was followed by students making iterations of designs in the makerspace. Students constructed artifacts, either physical or digital, based on the design plans previously developed in pre-making in the classroom. Finally, each cycle concluded with student and teacher sharing and reflecting on making processes and objects of learning constructed in the makerspace. Though the disciplinary emphasis was different in each cycle, the three-part making cycles remained similar.

The curriculum focus in cycle one was on the topic of sky science (see **Table 4**). The maker work in this cycle involved individual scientific modeling projects based on topics of interest determined by the students. The projects varied from static models of the solar system and satellites, to moving models of black holes and colliding stars.

As indicated in **Table 4**, incidents of direct teaching and homework assignments also took place to address outcomes. For

TABLE 4 | Provincial learner outcomes and their enactment by the classroom teacher.

Sky science: specific learner content expectations as stated in provincial curriculum	Enactment of specific learner expectations
1. Recognize that the Sun and stars emit the light by which they are seen and that most other bodies in space, including Earth's Moon, planets and their moons, comets, and asteroids, are seen by reflected light.	Addressed by teacher with direct teaching.
2. Describe the location and movement of individual stars and groups of stars (constellations) as they move through the night sky.	Outcome addressed in pre-making, to introduce students to early modeling through the use of star charts.
3. Recognize that the apparent movement of objects in the night sky is regular and predictable, and explain how this apparent movement is related to Earth' s rotation.	Connected to outcome 2, 7, and 8 which involved night sky viewing and documentation as homework. Note: Riley reported greater student engagement in this activity as compared to experiences with students in past years.
4. Understand that the Sun should never be viewed directly, nor by use of simple telescopes or filters, and that safe viewing requires appropriate methods and safety precautions.	Addressed by teacher with direct teaching.
5. Construct and use a device for plotting the apparent movement of the Sun over the course of a day; e.g., construct and use a sundial or shadow stick.	Addressed by teacher with direct teaching.
6. Describe seasonal changes in the length of the day and night and in the angle of the Sun above the horizon.	Addressed by teacher with direct teaching.
7. Recognize that the Moon' s phases are regular and predictable, and describe the cycle of its phases.	Connected to outcome 3 and 8 and addressed as evening homework.
8. Illustrate the phases of the Moon in drawings and by using improvised models. An improvised model might involve such things as a table lamp and a sponge ball.	Connected to outcome 3 and 7 and addressed as evening homework.
9. Recognize that the other eight known planets, which revolve around the Sun, have characteristics and surface conditions that are different from Earth; and identify examples of those differences.	Explored by some students in the makerspace and in pre-making research and shared with others.
10. Recognize that not only Earth, but other planets, have moons; and identify examples of similarities and differences in the characteristics of those moons.	Explored by some students in the pre-making phase and shared with others.
10. Identify technologies and procedures by which knowledge, about planets and other objects in the night sky, has been gathered.	Explored by some students in the pre-making phase and making phase and shared with others
11. Understand that Earth, the Sun and the Moon are part of a solar system that occupies only a tiny part of the known universe.	An overarching theme that emerged during pre-making research, making and post-making reflection.

each cycle, the outcomes set forth in the program of study framed the design, but the decisions made always involved reflection and considerations around pre-making, making, and post-making. In cycle two, students made stop animation stories that illustrated mathematical transformations. Students created storyboards and researched animation ideas in the pre-making phase. Post-making, each student showcased their animation and were offered final comments and feedback. In cycle three, students designed and made physical manifestations of metaphors that exemplified their understanding of one element of democracy, for example, freedom, equality, and equity. In this cycle, students were offered the choice to digitally design and then 3-D print or CNC (computer numerical control) mill their idea. Some students chose to build their model using physical materials such as beads and rocks.

Given the alignment with maker curriculum and pedagogies, DBR was selected as the methodological framework to guide inquiry. Defining characteristics of DBR that are universal across this approach to studying innovations in learning include: it is theoretically oriented, collaborative, iterative, interventionist, and responsively grounded (Barab, 2014; Jacobsen, 2014; McKenney and Reeves, 2019). Therefore, the choice of DBR was important for several reasons: (a) it mirrored the iterative, generative, and collaborative nature of making; (b) the participatory nature allowed the teacher to envision the designs brought to life in a real-world makerspace learning environment (Barab, 2014); (c) the research design could be responsive and flexible as required (Barab, 2014; Jacobsen, 2014; McKenney and Reeves, 2019); (d) teacher knowledge and experience informed and brought value to the research (Brydon-Miller et al., 2011); (e) the research would provide usable, but theoretically grounded knowledge about curriculum as praxis that could be used to advance understanding on learning in makerspaces (McKenney and Reeves, 2019). The design process involved considering how the curricular outcomes might be enacted prior to making, during making, and proceeding making. While there was continual collaborative dialogue throughout each cycle, a systematic and reflexive process of inquiry, evaluation and reflection by Riley and Sandra accompanied each "making" activity to determine revisions within that design, subsequent iterations of the design, and to inform design principles. On-going research conversations by the research team about curriculum, teaching, design, and research engagements in the school, iterative and cyclical collection and analysis of data, reflections on the collaborative researcher-teacher learning, informed the development of design principles and theoretical insights from this design-based research. Data sources included: (a) researcher field notes; (b) audio-taped, semi-structured

TABLE 5 | Key design decisions and actions enacted during research cycles.

Cycle	Curriculum topic and making activity	Stage	Key design decisions
1	Science -build a model to answer a question of interest about the night sky	Pre	-Offer choice in question, topic, materials -Introduce scientist characteristics -Research early astronomers
		During	-Film students presenting and discussing their model
		Post	-Take scientist characteristics to next cycle
2	Mathematics-tell a story through animation that includes transformations	Pre	-Offer choice in storyline, materials -Focus on giving/receiving feedback -Research on animation possibilities
		During	-View films in production to offer feedback and ideas
		Post	-Take scientist characteristics and feedback mechanism to next cycle
3	Social Studies-Design and make a metaphor that embodies one element of democracy	Pre	-Offer student choice in element, materials -Convey to students limited teacher knowledge of digital tools -Focus on giving/receiving feedback
		During	-Create a digital museum to showcase metaphors
		Post	-Take scientist characteristics, feedback mechanisms, and risktaking to next year

reflective interviews between the teacher and the researcher; (c) video recordings of makerspace sessions; and; (d) student and teacher designs and artifacts created both inside and outside the makerspace.

FINDINGS

In this section, we synthesize what we determined to be the key design decisions that were connected to Riley's change in practice when envisaging curriculum as praxis through making. Then, we carry out an examination of the enactment of making using van den Akker's curriculum components, typology, and levels in light of the cyclical curricular work implemented during this year-long design-based research.

Design Decisions Lead to Learning for Students, Teacher, and Researchers

In each cycle of the design research, Riley and Sandra made design decisions prior to, during, and after making, as presented in **Table 5**. During reflective interviews conducted after each cycle, the teacher and researcher discussed the learning that arose for the students and themselves based on those decisions. Our analysis focuses on data that emerged from teacher/researcher post-cycle reflective interviews, specifically the teacher growth and change that resulted, and the tradeoffs that sometimes had to be made in light of the external constraints we faced when designing.

The collaborative decision to change the framing of curriculum in the makerspace from a content focus and a series of learner expectations to be checked off to creating the conditions that engaged students in personal and interest-driven inquiry presented benefits and challenges. We identify four design decisions that emerged in the cycles, were carried forward, and that we determined had the greatest impact on the teacher in terms of her pedagogical growth: (a) student choice of topic and materials; (b) students engaging in research to support making; (c) students and teacher implementing structured feedback, and; (d) students and teacher modeling risktaking.

Promoting Student Choice in Topic and Materials for Making

Riley articulated that when students explored topics of personal interest in the makerspace, this approach led to deeper and more meaningful learning for students. After cycle one, she commented, "It was having those students go more into one concept they were interested in.... the students are able to actually remember and talk about their topic," which she indicated they had not been able to do in the past. In contrast to the content-driven approach to monitoring learning expectations in the classroom, the possibilities and relevance of learning expanded within the makerspace. In an interview, Riley commented that "There was a lot of incidental learning, too. A lot of kids learning different things because they came across something else."

Riley also noticed that giving students the opportunity to make choices about the materials they used for model making led to growth in students' flexible thinking. She found students entered the makerspace with materials in mind for making, but often, those materials didn't serve their needs. "They were dead set in using certain things. But it didn't work." Riley suggested that having to consider different materials over multiple iterations when the original idea wasn't working "pushed these kids out of their comfort zone." Because students had choice over topic and materials, they were also tasked with coming up with their own ideas for solving problems when making. Riley and Sandra provided feedback and suggestions on the students' projects, but the students were the ultimate decision makers. For example, in cycle one, a student whose first language was not English, chose to build a model of the satellite Juno, sent by NASA to Jupiter to collect data. Building the model helped the student to understand the different parts of the satellite and their functions, and it also provided him insights into how data is collected in space and sent

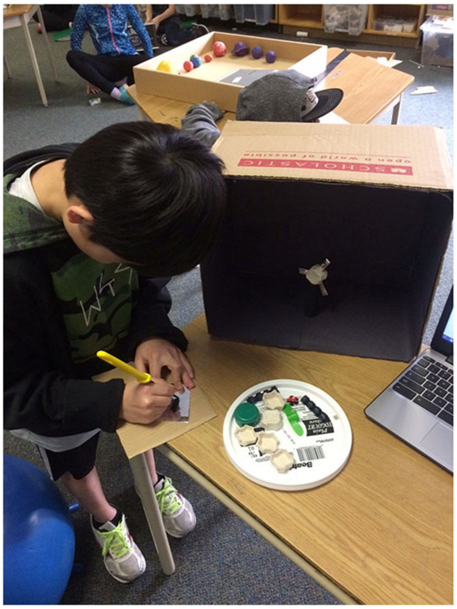

FIGURE 2 | Student making a model of the Juno satellite, with materials for consideration at hand (Becker, 2018).

back to earth. He and Sandra spent some time discussing possibilities for found materials that he could use in building the model satellite. He gathered a selection of materials and then began to iteratively "play" with ideas and different parts to build the satellite (**Figure 2**). In considering the student's work Riley commented, "That's probably the best project he has ever done, the most research he has ever done, and also just the vocabulary he learned." She attributed part of this student's increased engagement in his learning to ownership and choice: "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."

A trade-off for Riley in the decision to provide students with the opportunity to explore their own topics of interest in cycle one was the challenge of tracking all of her students' different learning's, as she indicated in the cycle one post-interview. "One area that I was very scared about at the beginning... I don't know enough about this topic to have the kids just go off in 27 different ways." In particular, Riley wondered about student misconceptions and her ability to "correct" those misconceptions, when she herself was not knowledgeable about all of the topics the students chose to study. Riley's apprehension over her own lack of scientific knowledge while she released her students to explore topics that she did not have deep expertise in was never completely addressed. A teacher's anxiety about holding adequate disciplinary knowledge of the curriculum to lead student learning does speak to one of the challenges we faced in adapting the curriculum for the makerspace context. Riley initially felt a loss of control, particularly when attempting to assess students' knowledge as related to content outcomes, and in addressing individual student misconceptions. In contrast, Riley indicated after cycle two that student focus on the same curriculum outcomes while providing flexibility in the animation story and material choice was less stressful. She stated, "Because we only chose to cover a fewer amount (sic) of targets it helped to develop that focus and for me it actually helped because everyone was working on the same concept." Note, targets here refer to content learning outcomes in the program of studies. In part, the external pressure of preparing students for the provincial exams, and Riley's continued belief in the importance of "covering content" that may be referenced in exam questions, weighed heavily on her. The challenges inherent in transitioning from curriculum as content, which is amplified by curriculum outcomes and external assessments, and integrating maker activities holistically within the design based on the curriculum, was evidenced by Riley and may challenge on-going implementation of curriculum as praxis using a maker focus given how curriculum outcomes appear more as content to be covered vs. opportunities and processes of action, reflection and learning to be explored.

Riley did acknowledge that after cycle one her perspective changed ontologically. That is, she realized that her students were thinking like and becoming scientists (Becker and Jacobsen, 2019). "I've actually kind of switched my thinking and it's not about the product at the end, even though that's what I've been saying. It's about their process and what they've actually learned. For me, the biggest thinking is that they *are* scientists." Engaging with curriculum as praxis, through an interactive and reflexive process of designing, enacting, and evaluating integrated into the making, led Riley to question, in deep and important ways, what teachers need to know in order to teach well. Through this interactive process of design, enaction, and reflection, Riley reconsidered her own implementation of the grade six sky science curriculum in past years: "That's always a huge stress, is making sure that we cover the outcomes. A lot of the times, it's the outcomes and it's the bare minimum. This [sky science model project] is something bigger, but I see more value in projects like this. Instead of, everyday we're doing just a different outcome. And it's teacher directed." In making the transition from seeing curriculum as a way for content to be delivered and checked off, to a design approach to enacting curriculum as praxis in a makerspace, Riley underwent a transformation in her ontological understanding of how to create the conditions for scientific inquiry with her students.

Engaging in Pre-making Research to Expand Thinking

In the three design cycles, Riley and Sandra chose to *add* to the mandated curriculum by inviting students to engage in pre-making research. The last two cycles involved researching possible technologies they might use for making, while cycle one included research on early astronomers. In cycle one, they decided it was important for the students to know about astronomers from the past, including the topics that interested them, the theories they developed, and the social and cultural difficulties that emerged for them as a result of their thinking about the night sky (Becker and Jacobsen, 2019). Riley and Sandra also continuously referenced during this cycle what it means to be a scientist with the students (Becker and Jacobsen, 2019) and invited students to reflect on their own thinking and practices as scientists. In the post-cycle interview Riley stated, "We really focused on the tools they used... They're building models, they're observing the world, they're asking questions, they're disputing each other and agreeing, so I think it's actually the same thing [history of astronomers and how scientists work]. It [research on early astronomers] was a great way to introduce it, it was a great way to get the kids to think." Though the idea of adding to an already "full" curriculum felt risky at first, Riley regarded the transition to scientific thinking in the makerspace as beneficial. We purport that engaging in pre-making research was important not just for the students but also for Riley, because she became a learner alongside her students and it afforded her a new way of seeing science and learning (Becker and Jacobsen, 2019).

Exploring different possibilities for stop animations in cycle two demonstrated how students were engaging in research outside the school. One student, as noted by Riley, discovered through her own research at home, a new way to animate using simple materials. Her method was validated by others in the classroom when several students adopted it in their own animation work. We found in the course of the study that students often engaged in research outside school that related to the content or materials. This indicated to us that the students also deemed the research process as an important part of making and for their own learning.

Implementing Assessment and Feedback Throughout the Making Process

One of Riley's goals prior to engaging in the study had been to help her students improve in the giving and receiving of feedback. Though we had noticed that giving and receiving feedback happened quite naturally in the makerspace, Riley identified this as an area for improvement in the preplanning for cycle two. Riley created structures in the pre-making phase that addressed this need, which included students and the teacher offering written feedback on maker planning designs, as well as justifications for why they did or did not accept the feedback.

For Riley, learning to give and receive feedback was an important learning outcome no matter what the topic of study. Within the context of making, students were able to practice giving and receiving feedback with each other. In addition, Riley and Sandra were able to comment on how students were implementing feedback from their peers. During the making phase, Riley also selected individual animations in process for review, so the class could provide feedback as a group. Group review and feedback provided an opportunity for Riley to comment on the usefulness of the feedback that was being given and offer suggestions in the way students might offer feedback. After the three cycles, Riley indicated an overall improvement in her students' ability to give and receive feedback. She linked this and other changes to their growth in flexible thinking.

R: So just being flexible, I just found kids were way more flexible this time than they were in the last one.

S: In terms of materials?

R: In terms of materials, in terms of feedback. Also in terms of okay, our project isn't working out. Not that we're gonna... I know [student] did it, but not a lot of them scrapped the whole thing, but they made adjustments which I thought that was a huge growth from our first one.

Making the explicit choice to design and test a feedback structure led to changes in how the students approached their learning and what Riley came to value in curriculum as praxis.

Embracing and Modeling Risk-Taking

In reflective interviews after the third cycle, Riley stated, "I thought this was the best round, not in terms of the products, although I was quite impressed with those too, but more in terms of the attitude of the students. I'd say the majority of them chose something out of their comfort zone." Sandra pressed Riley, to articulate in more detail what made this cycle "the best:"

R: I felt from all three projects that we did, you and I really stepped back, and they were helping each other, they were doing research on their own so I felt like I actually didn't have a role which I think is a good thing because they're moving away from that neediness of us.

S: What do you attribute that to?

R: I think being comfortable for one, with the projects that we've done.

S: This being the third one? So they're getting used to making? Maker mind-set, kind of?

R: Yes, for sure. And also just working in that community. There were a lot of kids that helped each other out. And we did facilitate by asking, who knows how to rotate this and five kids would put their hand up. We did help in that sense, but it wasn't us and I think part of that was you and I didn't actually know how to use the program.

S: So that actually was a plus. The not knowing.

R: Yes, and even that we *shared* that with them. That we don't really know, so if you're choosing to do this, you're going to need to be figuring things out on your own. So they knew that going into it, and I still liked how some of the kids still chose to do it instead of not. Which our first round, a lot of them probably wouldn't.

In our analysis of the cycle three post interview, the researchers noticed how Riley's initial comments focused not on curriculum content, *per se*, but more on the dispositions and behaviors that students exhibited in the third cycle. In particular, Riley identified how the risk she and Sandra took in articulating their limited technology expertise led to her students' opportunity to engage in risktaking.

The teacher's shift from a sharp focus on curriculum content and coverage of learner outcomes, to an emphasis on how, what, and why the students were learning through making, appeared to be an interesting shift toward curriculum as praxis. After the third cycle, Riley herself highlighted the importance of students' dispositions as learners first. Though some of the dispositions are articulated in the front matter of the provincial curriculum documents as targets (e.g., in science, inventiveness, open-mindedness, perseverance, flexibility; in mathematics, take risks, exhibit curiosity, persevere; in social studies, engage in active inquiry, engage in problem solving) (Alberta Education, 2020), earlier in the study Riley had tended to focus on the learner outcomes related to knowledge the students were to

TABLE 6 | Curriculum components as enacted by the teacher and students (Becker, 2019).

van den Akker (2013) curriculum components	Enactment in the study
Rationale: Why are they learning?	While the original focus was on curriculum outcomes, the teacher came to understand that by embedding making in the work the students were learning how to be learners.
Aims and objectives: Toward which goals are they learning?	Students' goals focused on making models, stop animation videos, and physical embodiments of democratic concepts. The teacher focus was on student learning about curricular concepts.
Content: What are they learning?	Students learned content based on their interests, needs, and as determined by specific curriculum outcomes. Teacher focus was on content outcomes identified in the curriculum.
Learning activities: How are they learning?	Students learned through an iterative design process which included research and prototyping of ideas through physical or digital construction.
Teacher role: How is the teacher facilitating the learning?	The majority of the teacher facilitation happened in the design phase prior to entering the makerspace. Once most of the students began making, feedback happened in a just-in-time and responsive manner.
Materials and resources: With what are they learning?	Students choose their own materials, and often shared resources they located themselves with their peers.
Grouping: With whom are they learning?	Students chose with whom they would work, but often provided feedback to a variety of students in the class in a just-in-time and responsive manner.
Location: Where are they learning?	Students' learning took place in multiple locations, including but not limited to the makerspace, the classroom, and at home.
Time: When are they learning?	Many of the students' learning experiences moved across contexts, as they explored ideas, tools, and resources at school and at home.
Assessment: How is their learning assessed?	Assessment methods (both formative and summative) included the use of tests, rubrics, conversations and written reflections. Feedback loops (written and oral) took place prior to and while in the makerspace to move learning forward.

van den Akker's articulation, used with permission (Table from Becker, 2019).

acquire vs. dispositions they were to develop. In our analysis of data across cycles, we identified that by cycle three, Riley was engaging with curricular designs for making, the enactment of designs in the makerspace, and reflections on the learning that occurred using an interactive process in which her planning, acting and evaluating were reciprocally related and integrated; in short, Riley was approaching curriculum as praxis vs. curriculum as content.

van den Akker's Curriculum Elements as Tools for Analysis

As part of on-going reflection and analysis of the making cycles, Sandra and Michele used van den Akker's (2013) curriculum components, representations, and levels to analyse how experimenting with the implementation of curriculum through making appeared to have changed Riley's pedagogical thinking about designs for learning, the challenges she encountered in designing for making, and the nature of supports she needed to be able to work in these ways to combine design, making, and curriculum, moving from curriculum as content to an understanding of curriculum as praxis.

Curriculum Components

The components (**Table 6**) are discussed in relation to our observations during enactment.

As elaborated upon in **Table 6**, a great deal of Riley's curriculum design work for making took place in envisioning the rationale and goals for learning. In collaboration with Sandra, Riley's focus rested on the pre and post activities, including assessment. Students took some or all responsibility for content, learning activities, materials and resources, grouping, location, and time in the makerspace. The greater student engagement in directing their learning not only gave the students agency, it also changed how Riley expressed herself as the teacher in the makerspace. Instead of serving as the primary source and provider of content, Riley was able to spend more time engaged in observing, supporting and responding to her students' learning.

Prior to this study, Riley had developed and used many one-off maker activities for her students and other teachers in the school; however, prototyping curriculum with a maker focus was not something she had considered prior to this collaboration. Participating in the collaborative design work as part of the design-based research assisted Riley in seeing and working with the curriculum differently; she began to see curriculum as planning, enacting, and evaluating possibilities for making and inquiry that went beyond curriculum as content to be covered. Riley became better able to imagine learning differently, and also how to think about design differently in support of her students' learning. Making and the makerspace, nested within the design-based research, served as a frame for Riley to consider inquiry-based approaches to learning, while still fulfilling her need and obligation to address curricular outcomes. This shift meant that both she and her students developed agentially as learners and become a community in which students felt inspired to contribute.

As part of the design-based research, Riley indicated on numerous occasions, that she required and benefitted from Sandra's support in envisioning and enacting curriculum with a maker focus. Choosing DBR as a methodological framework was an intentional and necessary component of the study in that the collaborative, participatory, interventionist, iterative, and risk-taking nature of this research allowed Sandra and Riley to walk together in transition and transformation, and for Riley to challenge her notions of curriculum as content in a supportive learning space.

In terms of curriculum balance, we noticed that external assessment requirements linked with the curriculum spider web were forcing things off balance. In grades three, six and nine, all students in Alberta schools complete provincially mandated exams at the end of the school year. The provincial exams and reporting requirements are external summative assessments that had an impact on pedagogical design and timelines with regard to making. This was evidenced in part by the length of time spent on design and enactment (**Table 3**). Cycle one enactment began in mid-January and continued to the end of February. This was in contrast to cycle two which took place for 2 weeks in April, where Sandra noted "Riley has not been as available to meet." The deep exploration of curriculum happened less and less as Riley's attention was taken up by other obligations. In May, when starting cycle three enactment, Sandra wrote, "Riley seems very overwhelmed these days with upcoming provincial achievement tests, and the fact that she has not covered curriculum topics." A further observation acknowledged, "There are many interruptions to deal with—I get the feeling Riley would rather not be doing this—it is one more thing on her plate."

However, as Sandra and Riley cycled through the three making activities with students, they were able to ideate and prototype formative assessments, including developing structured feedback loops that assisted students in deepening and refining their learning ideas. At the conclusion of the third cycle, Riley commented in the follow-up interview, "I think we did really well on assessment, with that checklist that we had. The only thing I would do differently is having that from day one instead of just at the end, because we kind of created [it] toward the end of the project, where if we had it toward the beginning I could take notes specifically on the outcomes that we created. But, I really, I'm planning on using that piece of assessment next year." Riley's growing confidence in creating meaningful formative assessments in the context of making helped her to manage the omnipotent constraints she experienced with the external provincial achievement test obligations. The imbalance created by impending external assessments was real and not easily addressed because while the assessments were required, it also meant that outside stakeholders at the meso (parents and school administration), and macro (district and provincial government administration) levels would be scrutinizing the work.

Curriculum Representations

In **Table 7**, the researchers' analysis and synthesis of data show the key connections we made in how Riley conceptualized and enacted the curriculum as praxis through making.

Developing an intended maker integrated curriculum for the three cycles in this study was an iterative process in which what was documented and learned in a cycle informed and was built upon in the subsequent cycle. Given there were no formal/written curriculum documents on which to base this maker work in elementary school, we drew on theoretical research published on making to enlighten our decisions (Halverson and Sheridan, 2014; Vossoughi and Bevan, 2014; Oxman Ryan et al., 2016; Wardrip and Brahms, 2016). We argue that this lack of documentation on maker and making in K-12 actually led to the creation of a rich learning environment for the teacher to consider and question big ideas around curriculum implementation, such as what is important for students to know? What knowledge is most worthwhile? Should all students learn the same things? How is knowledge acquired or created? And, having considered these questions, how might we design for student learning? This questioning, reflection and design process had implications for curriculum as praxis because Riley experienced the value in using the collaborative design process as part of design-based research to reflexively determine what might be left out and what might be added to learning activities, processes, and materials to best support her students' learning in the moment.

Regarding curriculum as praxis, the shift we observed in how Riley modeled, and articulated learning for and with her students, was key in understanding her transformation. In reflecting upon

TABLE 7 | Researchers' reflections on the teacher and students' notions of representation of curriculum (Becker, 2019).

Van den akker's curriculum representations (2013)		Researcher reflections from the study
Type*	**Description***	**In the study**
Intended		
Ideal	Vision, underpinned by philosophy	The teacher needed support in envisioning what the curriculum might look like through making.
Formal/Written	Intentions specified in government/ curricular documents	The teacher was unsure how to enact formal written curriculum in a maker context.
Implemented		
Perceived	Curriculum interpreted by the teacher	The teacher came to understand curriculum differently by *adding* curriculum content and processes to support disciplinary learning.
Operational	Actual teaching and learning process	The teacher came to value different aspects of teaching and learning (e.g., habits of mind).
Attained		
Experiential	Learning perceived by learners	The teacher made explicit for the students a different view of learning as lived through making.
Learned	Resulting learner outcomes	The students and the teacher came to see learning differently.

**van den Akker's articulation, used with permission (Table from Becker, 2019).*

and talking about moments when she truly did not know, when she miscalculated, or was not sure, Riley demonstrated and represented for her students what it means to be a learner. Through Riley's actions, and through on-going conversations about learning, making, and knowledge, the students came to value this exploratory, problem posing and ideating approach in their own learning. For the students and for Riley, learning became less about remembering and spewing known facts as proof of understanding and became more about exploring and playing with materials to make sense of the ideas and questions the students were grappling with in the makerspace.

Designing for making also helped Riley experience and question curriculum differently. That is, curriculum went from being a static document imposed from an external body, to being an organic chronicle of planning, acting, and reflecting that could be added to, revised, reconsidered, and reconceived. Riley was able to observe the ontological changes in her students through this revision of her notions of curriculum, which also made her think differently about what learning to value in a learning process, product, and environment. The teacher's changes in perspective on curriculum appear to be sustained; Riley continues to reflect and rethink what learning might look like across the curriculum, how she can design for interdisciplinary learning in the makerspace, and how she enacts projects with students.

Curriculum Levels

There are various levels at which the curriculum is utilized (van den Akker, 2013). Nano refers to student utilization, micro is classroom; meso, school; macro, district and provincial; and supra, national and international. Through the research process, Riley initiated many conversations about how we might scale what we were learning with students (nano) in the classroom (micro) to benefit other teachers and students in the school (meso). She was eager to take a leadership role in sharing what was learned in the makerspace with her colleagues at the school level (meso), at the division level (macro), and beyond. Riley's commitment to knowledge sharing resulted in a collaborative presentation at the annual teachers' conference with educators and school leaders from across school jurisdictions. She was also invited to be part of a district and community innovation group that was started by a local parent who established a noon hour maker club in another school. He lauded Riley's work, particularly her creativity and willingness to risktake. Riley has also offered to support teachers in her own school, on her own time in exploring curriculum through making. Many of Riley's earlier attempts to share her learning within the school were met not with resistance, but with indifference. Riley has expressed frustration and discouragement in relation to her desire to assist colleagues in change and wondered at their reluctance to do so. In this study, a powerful change took place in Riley's pedagogical designs and practices and continues to take place at the nano and micro levels. It is at and for the meso, macro, and supra levels that this design-based research needs to continue. The local impact and study outcomes with Riley and her students demonstrates the possibilities and impacts of collaborative design-based research on learning through making and makerspaces. There are also major challenges in this work, and a challenge in the methodological approach of the study, which is addressed more fully in the discussion.

DISCUSSION

Willms et al. (2009) advocate for more intentionality in curriculum implementation and indicate that "teachers must go beyond developing techniques" (p. 33). We contend that by designing, enacting and evaluating curriculum through making, Riley engaged in curriculum as praxis and innovative practices that were beyond technique. In collaboration with Sandra, Riley went beyond "best practice" as Bereiter (2014) suggests and moved to "invention" (p. 7) in cultivating her understanding of curriculum as praxis. What we find inspiring is that the students and Riley together came in their own way and time to explore ideas about themselves as learners and learning as a process in general.

"Promising Stances"

van den Akker (2013) identifies three promising stances that may assist in stabilizing curriculum components, representations, and levels. These are: (a) Rather than considering curriculum learning as separate disciplines, encourage an interdisciplinary approach that provides for wide-ranging, more holistic learning; (b) Design for learning that takes place not only at school, but also at home, and in the broader community, and; (c) Design learning opportunities that are personal, thereby nudging students to learn more deeply.

We propose that designing, enacting and evaluating curriculum through making can foster all three of van den Akker's promising stances on curriculum. While we designed, enacted and evaluated making tasks in alignment with identified curriculum outcomes, we discovered that pre, during, and post making activities often necessitated interdisciplinary study, including disciplinary and technical research, storytelling, digital creation, and plans for printing objects. Our data indicates that making provided opportunities for students to develop fundamental dispositions such as the ability to ideate, risktake, communicate, collaborate, problem solve, and give and receive feedback. We found that because students engaged in topics and maker projects that interested them, they often carried on with their maker work outside of school, as they researched topics of interest and made decisions about effective materials for making, as well as prototyping ideas that they had conceived of in the makerspace.

In this way, the makerspace served as a pivotal element in the curriculum design in that it facilitated through the making processes we developed, to "mediate participants' interactions, and thus learning" (Sandoval, 2014, p. 23). Sandoval (2014) advocated for the development of structured methods when conducting design research, and proposed conjecture mapping as one such approach. Drawing on Sandoval's, 2014 conjecture mapping structure (See **Figure 3**), we started the design research with a "*high-level conjecture*" (Sandoval, 2014, p. 21)—that the makerspace as learning environment could serve as a scaffold for teachers and students to explore and shift their notions of curriculum in new and different ways. This conjecture was made

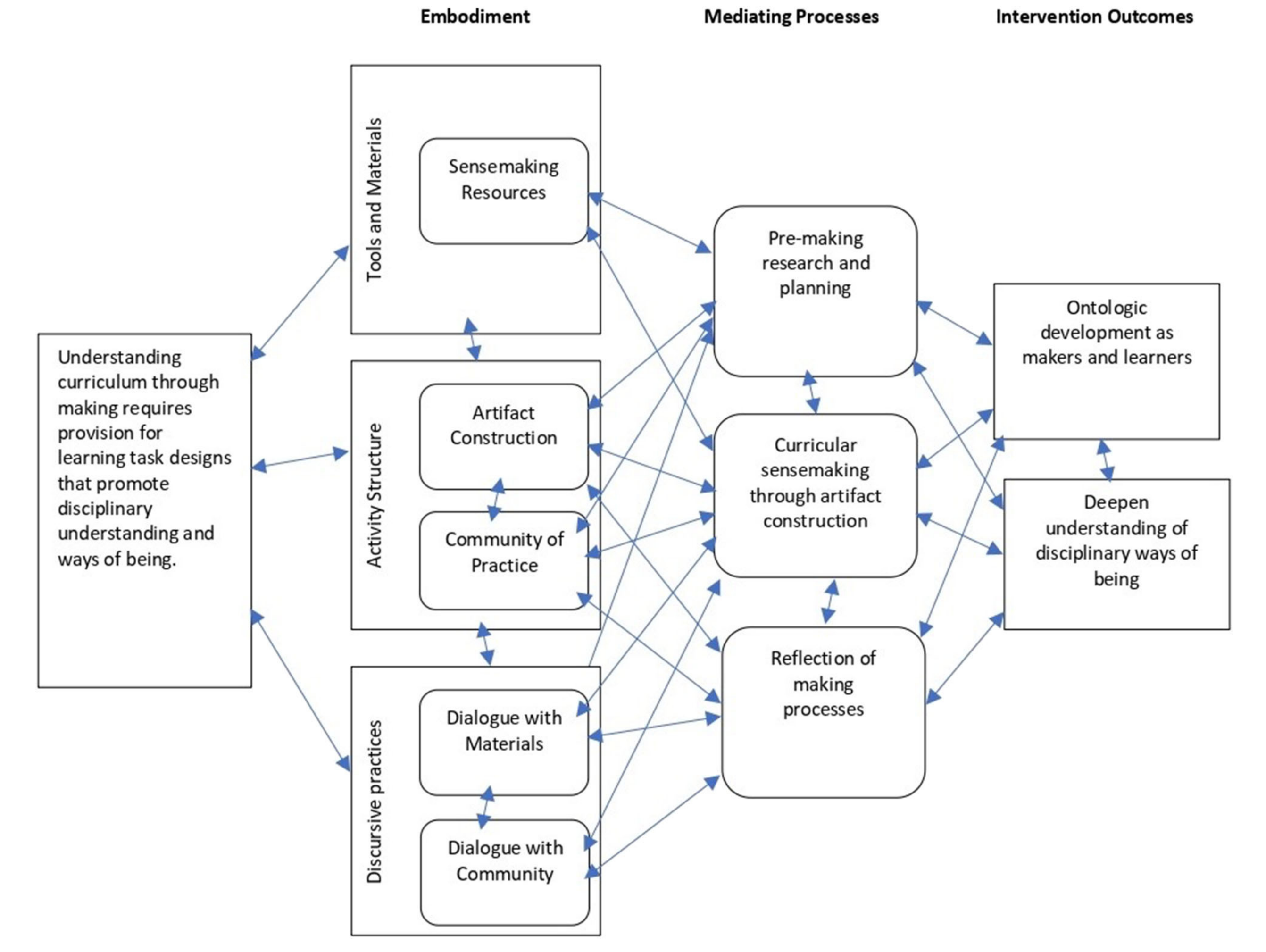

FIGURE 3 | Conjecture map detailing embodiment, meditational processes, and outcomes.

real through the "*embodiment*" (Sandoval, 2014, p. 21) of the design-based research, that is in our analysis, enactment and evaluation of specific curriculum designs using a maker focus. In order to embody these designs, we developed "*mediating processes*" (Sandoval, 2014, p. 21), consisting of pre, during, and post making activities, which led to intervention outcomes (Sandoval, 2014).

Through the course of this design-based research we were able to understand the mediating processes by observing and reflecting on Riley and Sandra's interactions with the students and with each other, and by analysing the artifacts we created for curriculum implementation, and the ideas, designs, and objects the students created in the makerspace. Though there has been significant research conducted on inquiry-based learning (Friesen, 2015) as a signature pedagogy for learning, we found that the makerspace as learning environment served to scaffold the mediating processes needed for developing inquiry as pedagogy. Key to this scaffolding was the reciprocity built into the processes and embodying structures we created when designing, making, and reflecting. In the interconnected, relational forms implicit in making processes we witnessed how reciprocal actions and discursive practices took place between a myriad of participants. Riley and Sandra's dialogue about how we as humans might learn about the night sky became an overarching thread between the students, Riley, and the researchers. Engaging in discursive practices with sensemaking resources and materials led the students to think about big scientific ideas rather than individual outcomes and led Riley to think about how her students *could* learn. Making stop animations led all of us to consider and problematize the complexity inherent in dialoguing and communicating with materials. In making metaphors about democratic concepts they cared about, the students were able to participate as a community while exploring meaning making that was deeply personal. It was the discursive and reciprocal nature of this work that led to all of us developing ontologically as a learning community. Riley indicated in the follow-up interview after cycle three that she observed changes in her students:

TABLE 8 | Study viability as related to implementability (McKenney et al., 2006).

Viability	Rationale
Is it practical?	-Can take place with few materials
	-Can take place in incremental steps, one activity at a time
	-Can improve skills and knowledge over time
Is it relevant?	-Can make curriculum more relevant to students and teachers
	-Can promote more agency in both students and teachers
	-Can lead to innovation in curriculum implementation
Is it sustainable?	-With support is a vehicle for prototyping and risktaking
	-Can lead to transformational change in practice

Source: McKenney et al. (2006).

> Something that I did see as really the most valuable, seeing those specific kids change throughout the first one [cycle one], through the last one [cycle three]. I've seen a lot of growth. More than I have in the last 2 years and I don't know if it's this. I don't know if it's me, it's now my third year, I don't know if it's the group. There's a lot of other factors but this is the first year I can actually say I've seen positive growth in you know, a lot of the kids. To see the effort and taking the feedback. It just makes my heart so happy when the kids come back and they have figured something out and when I asked how did they do that, "Oh I watched videos on it last night." They are loving it. They love to learn, right? Even though it's not a requirement.

Two important considerations are worth commenting on here. Riley noted that students have taken their discursive practices that originated in the classroom and makerspace to a broader community at large. Her joyful expression of student engagement is juxtaposed with the notion of learning as "requirement." This indicates an ontological shift in the students and the teacher in how they view and approach "required" learning and how they have shifted agentially in implementing discursive practices outside school for personal learning.

Research Viability

McKenney et al. (2006) address the need for research viability when conducting DBR from a curriculum perspective: "Viability relates predominantly to the implementability of a design" (p. 79). The authors articulate three ingredients in viable DBR designs. They are "practicality, relevance, and sustainability" (p. 79). We explored curriculum with a maker focus to determine if these conditions had been met (**Table 8**).

It was through the double helix of concurrent engagement in design thinking, enactment of making and evaluation of learning via three discipline-oriented cycles of making, and in the theoretically oriented, interventionist, collaborative, iterative and responsively grounded design-based research process for making, that Riley began to rethink her notions of curriculum as content. Therefore, in reflecting upon whether Riley's transition from curriculum as content to understanding and engaging with curriculum as praxis was sustainable, we accepted several signs that in Riley's case it was truly transformational. Riley and Sandra continue to keep in touch and engage in conversations and reflections on curriculum and practice, and through this ongoing relationship, it is evident that she is sustaining her stance as a maker teacher and her approach to curriculum as praxis. Further research is needed to determine if Riley's transformation is a unique case, or if this may be a way to consider supporting innovative approaches to curriculum implementation.

Design Principle(s)

Though the realized intent of this study to develop "local theory" (McKenney and Reeves, 2019, p. 40) by closely examining a specific learning experience within an elementary context, three design principles emerged and are presented in a form that may promote further dialogue around questions of implementation and scalability. One, teacher development can be supported in collaborative design based research with a focus on implementing innovations in maker practice, in which teachers are continually advised to critically appraise the design "frame" used to guide their learning plan, and they continually question whether their learning designs provide opportunities for both "sensemaking" *and* evidentiary displays of knowledge. Two, it is recommended that teachers scaffold their students' learning by designing opportunities to conduct work in the way that experts in the field do (Friesen, 2009). This design principle means students are supported in pursuing questions of interest, ideating and conducting research prior to making, and interacting collaboratively to solve problems that arise throughout the process. Three, teachers must live and share with their students their own experiences of failure, being unsure, and not knowing; in so doing, the teacher models what it means to be a maker and a learner (Becker, 2019). Riley, by living out these three design principles in practice, that is, designing learning experiences that placed equal weight on making as knowledge building and making as sharing, attending to knowledge building as discipline experts do, and remaining open to risktaking and failure, her teaching practice was transformed. Her approach to curriculum transitioned from content to praxis and she came to question ontologically what it means to be a learner and a teacher. The collaborative aspect of engaging in DBR with Sandra as key to Riley's personal learning and growth were an important component of her transformation. Another significant feature of DBR is that it narrows the gap between theory and practice. Given that there is a weak link between curriculum and research, methodologically it makes sense to connect classroom embedded research focused on curriculum to teaching practice. Therefore, we suggest this design-based research on curriculum enactment through making adds to the research literature by providing an example of local impact and the development of three design principles, while envisioning and testing a frame for implementation of curriculum as praxis. In these ways, the learning that took place and was documented and analyzed locally, coupled with the developed design principles, serves as usable knowledge (McKenney and Reeves, 2019) that can inform the work of others.

Implementing DBR as methodology is challenging given the investment required to build and maintain authentic, collaborative research relationships. Anderson and Shattuck (2012) summarize the temporal and resource demands of DBR.

In this study, both Riley and Sandra were deeply dedicated to the research process, which led to ontological growth on the part of both. This is not to say there were not challenges. DBR can be messy and complex work that needs to take place over extended periods of time. In addition, external pressures and the day-to-day demands imposed on Riley had an effect on our ability to carry out the study. Issues of time, particularly related to curriculum coverage and standardized testing, and also in response to other events in the school, involved on-going negotiation and sometimes a rethinking of the enactment timetable between the researcher and practitioner. In addition, given that DBR is carried out in authentic contexts, such as elementary school makerspaces, these studies often require multiple methods of data collection over several cycles of iterative design, enactment and evaluation. This study took place over the course of a year and involved the collection of large amounts of data that then had to be organized, analyzed, and synthesized.

Operating on the edge of innovation can cause anxiety and frustration for both the practitioner and the researchers. This was especially the case in relation to designing making tasks in three different disciplines in which the teacher and researchers had varying levels of pedagogical content expertise and experience. However, DBR is meant to take place within the ecological validity of schools and in this instance creating a makerspace and designing for cross-disciplinary learning through making demonstrated an authentic research premise in the day-to-day life of elementary teachers who are expected to consider curriculum implementation in multiple disciplines on an ongoing basis.

As an approach to studying innovation, design-based research involves the iterative development of solutions to these and other practical and complex educational problems and also provides contexts for empirical investigation and evaluation of innovation that yields theoretical insights, usable knowledge, to inform the work of others (McKenney and Reeves, 2019). There are limits to generalizability, however, we suggest the outcomes of this study inform continued dialogue in three important research areas: (1) makerspaces as learning environments, (2) curriculum implementation using a maker frame, and (3) DBR as methodology for linking curriculum and empirical research.

CONCLUSION

Two key recommendations emerged from this study. One, it is recommended that further research regarding the scalability of the learning and design principles articulated here be considered in a variety of school contexts. At present, we plan to enact the research design presented here in multiple school locations with multiple teachers. We are focused on the creation of a Community of Practice (CoP) in which multiple teachers form a community of shared interest in consort with our research team in order to create and develop experiences of curriculum exploration through making. A key aspect of this work is Lave and Wenger's (1991) notion of legitimate peripheral participation (LPP), whereby teacher participants take up valid positions on the periphery to provide multiple entry points into learning. In that way, the study can reflect the spirit and essence of the makerspace, an environment that values creativity and innovative solutions for implementing interdisciplinary curriculum.

Secondly, our further empirical curriculum research in elementary school contexts, undertaken using a DBR framework, may elevate the state of curriculum and curriculum implementation as it now stands. Using innovative practices to imagine new manifestations of learning may help us to promote creative approaches to implementation but also to envisioning curriculum as documented and lived in subsequent research.

The findings and principles shared from the study do suggest that possibilities exist for teachers to explore innovations to curriculum using a maker lens, and that ontological growth and shifts in understanding and approaching curriculum can occur for teachers, students and researchers. Though studies like this one require not only pedagogical but emotional support for teachers, the transformations to pedagogical practices can be beneficial, both from a personal standpoint, but also potentially on a larger scale as we grow knowledge about making in elementary schools and how to best support continuous professional learning of teachers in the discipline of learning sciences.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Conjoint Faculties Research Ethics Board, University of Calgary, Calgary AB, Canada. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

Both authors made substantial contributions to the conception and design of the work, the analysis and interpretation of the work, and the drafting and critical revision aspects of the work SB and MJ. One author was responsible for the acquisition of data by working in a participatory capacity with the research participants SB.

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