

## Learning to Teach in the Digital Age: Enacted Encounters with Materiality

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### Abstract

*This study looked at teacher responses to the maker movement in a K-12 school. Guiding questions asked how teaching practices engaged with digital making and learning tools and materials; and whether teaching was changing as a result. This was as a qualitative, single-case study with multiple units of analysis. The study site was an independent K-12 girls school in a major metropolitan area of the Northeastern United States. Twenty-two teachers and administrators participated, selected for maximum variation across academic domain, age and length of service. Interviews and observations followed a sociomaterial disposition that was interwoven with new materialism and posthumanism. Methods were inspired by narrative inquiry and actor-network theory. Findings suggested that digital making and learning pedagogies were stabilizing at the school, but not in a linear way; and that the teaching practices that most robustly engaged the ethos of 21<sup>st</sup> century learning enacted a kind of knowing sometimes discussed by artists, poets, musicians and other innovators. This observation leads to the proposition that a different kind of language might be needed to adequately describe the effects of digital making and learning on teaching practice.*

### Keywords

Maker movement, new materialism, 21<sup>st</sup> century learning, posthumanism, teacher education

## Introduction

This study began from the proposition that tools and materials are basic ingredients of educational settings. As such, *digital* tools and materials—for example, computers and peripherals such as screens and scanners, 3D printers, and electronic circuits—were held as a subset of a vastly broader suite of technologies that contribute to learning. In the words of a third grade teacher who participated in the study, “That pair of scissors is a technology ... and your pencil sharpener is a type of technology, [too].” At root, I am interested in how changing tools and materials affect learning and teaching across the curriculum, from art to science to history. Inquiry questions asked how K-12 teachers were learning to use digital making and learning tools in FabLabs and makerspaces, and whether doing so was changing their teaching. Findings suggested that the adoption of a digital making and learning ethos was uneven; some teachers embraced make-to-learn as a way of knowing, but others resisted it. Intriguingly, some of the teachers who were the most enthusiastic appeared to follow a learning trajectory that has been reported by musicians, poets, novelists, and advanced theoretical scientists, where—after everything else is in place: skills, material resources, affective capacity, grit, curiosity—knowing arrives suddenly and as if by accident, seemingly from the materials themselves. I came to understand this way of learning as an *enacted encounter with materiality*, and to wonder how teachers might learn to amplify it in their classrooms.

A focus on teacher learning is at the core of this study. While researchers in the field of art education have discussed how digital tools affect learning (Knochel, 2013; Sweeny, 2010), and have explored specific digital materialities in classrooms, including games (Patton, 2013), video (McClure, 2010), computer code (Knochel & Patton, 2015) and data visualization (Sweeny, 2013), very little work has been done on how teachers learn to use digital technologies in their practice. This study responds to repeated calls for such work from art educators (Castro, 2012; Knochel & Patton, 2015) and from other disciplines (Ajayi, 2011; Twining et al., 2013). My hope is that looking at specific digital making and learning practices from the teacher’s point of view might suggest a line of inquiry into teacher education and curriculum reform.

## Study Parameters

This qualitative field study used a single-case design (i.e., a K-12 school) with multiple units of analysis (i.e., teachers and administrators) (Yin, 2009). The study site was a K-12 girls school in the Northeastern United States that espoused an inquiry-based approach to technology; the school had constructed two digital fabrication labs (FabLabs) and several afterschool makerspaces, and teachers were encouraged to explore digital and non-digital technologies in

their teaching. The research approach, following Ito (2010), was ethnographic and exploratory, where the aim was to observe and describe relationships in a particular learning ecology, with the goal of “grasping the contours of a new set of cultural categories and practices” (p. 5).

**Participants.** Twenty-two teachers and administrators participated in multiple interviews, observations, and casual conversations, and by sharing lesson plans, assessment rubrics, notes, and emails. Participants were selected for maximal variation across academic domains, age and length of service, and included faculty from across the curriculum—from art to science to Humanities; from elementary through high school; and from 2 to 15 years of service.

Additional participants included faculty who did not consent to interviews or direct observation, but who nevertheless welcomed me into the community; their ad hoc conversations helped me understand the dense fabric of the school. As well, the school itself—the entry halls, cafeterias, stairwells, gymnasiums; the media events and art shows; as well as the myriad custodians and staff—should be considered a participant. That is, my presence during the 2013-2014 school year resulted in so many spontaneous interactions that the study site became a rich web of relations, and acquired its own, distinctive voice.

**Timeframe.** In-depth interviews, observations and conversations occurred from August 2013 through June 2014. Additional conversations and email contact took place until August 2015. Interpretation and writing occurred throughout the study period.

**Disposition and Method.** The collection and interpretation of interviews and observations followed from a sociomaterial disposition (Fenwick et al., 2011), and was inspired by *actor-network theory* (Fenwick & Edwards, 2011, 2012; Latour, 2005; Law, 2004) and *narrative inquiry* (Britzman, 1995; Chase, 2011; Richardson, 2000). My research was guided by Latour’s instructions to treat actors symmetrically, both human and non-human, and to follow them wherever they led; Law’s analysis of juxtaposition and overlap as a kind of logic; and Richardson’s framing of writing as a way of doing research. It’s worth reiterating that as an ethnographic and exploratory study, I held these research traditions as dispositional rather than strictly analytical; that is, my goal was to bring to presence relationships of practice and to postpone, or hold at bay, the desire for all encompassing explanations of the structural or spatial contingencies of those practices.

In the field, my day-to-day approach also interwove with challenges from *new materialism* (Barrett & Bolt, 2013; Bolt 2007, 2013; Coole & Frost, 2010) and *posthumanism* (Braidotti, 2013; Hayles, 1999). Scholars from these traditions push back on notions of agency and

causality that hold human subjectivity at the center of making and learning. For example, Bolt (2013), an artist and art historian, argues that a *material turn* in the humanities questions “the anthropocentric narrative that has underpinned our view of humans-in-the-world since the Enlightenment, a view that posits humans as makers of the world and the world as a resource for human endeavors” (p. 2). And Hayles (1999), a scholar of literature, urges us to reimagine our commitment to the “vision of the human in which conscious agency is the essence of human identity,” arguing that “mastery through the exercise of autonomous will is merely the story consciousness tells itself to explain results that actually come about through chaotic dynamics and emergent structures” (p. 288). These skepticisms informed my work at a granular level, in part because they conformed to my own tacit knowledge of arts learning, and in part because I am persuaded by theories of learning and knowing that posit intermingled co-emergence, or, as Jagodzinski and Walling (2013, p. 32) put it, a “hominid ecology that shapes and is shaped by the materiality of ‘things’ as they inter-communicate between each other by means that is beyond our comprehension.”

**The method assemblage.** Law (2004) critiques the way research enacts a version of the truth without holding the enactment itself up for analysis. In his view, equating an asymmetric coherence of method and result with ‘good’ research, like a self-fulfilling prophecy, challenges the scientific process, casting doubt on what can be studied or known. As a corrective, Law (p. 41) adopts “the term ‘assemblage’ ... from the English translation of Deleuze and Guattari’s *Mille Plateaux*” to coin “a (partial) neologism”: *method assemblage*. With this word Law foregrounds the proposition that all research must begin by “crafting ... realities [as] ... interactive, remade, indefinite and multiple” (p. 122). That is to say, Deleuze and Guattari’s (1987) *assemblage*, with its connotations of a decentered and indefinite, continually unfolding, processes-oriented reformulation and rebuilding of knowledge, enables Law to propose a counter logic to coherence—one of overlap and juxtaposition, like a pinboard or collage, where relationships remain open, nonlinear and up for grabs. This move frames method as an amplification rather than a diminishment of uncertainty, and empowers research to better represent the flux of life. Following Law’s understanding of the method assemblage as “a combination of reality detector and reality amplifier” (p. 14), “that is at most only very partially under any form of deliberate control” (p. 42), my approach to the collection and interpretation of material at the study site can be thought of as a searching for relational contrasts between teaching practices. As such, rather than try to erase the contradictions I encountered, I wanted to hold dissonances unresolved so that new metaphors for teaching and learning might appear.

**Writing as interpretation.** Law (2004) maintains, “There are no right answers” (p. 117). Rather, research relies on metaphors: “craft, bundle, hinterland, condensate, mediation, pattern, repetition, similarity and difference, object, gathering, allegory and representation” (p. 117). My interpretative work began as participants’ stories turned from interviews and observations into transcripts, then into thematic clarifications, and then into reports. Richardson (2000) argues, “Although we usually think about writing as a mode of ‘telling’ about the social world, writing is not just a mopping-up activity at the end of a research project. Writing is also a way of ‘knowing’—a method of discovery and analysis” (p. 924). Indeed, the writing of memos, on-the-fly expositions, and long emails to participants were important to my understanding of what I was learning. Throughout this report, whether explicit or not, my work has been informed by Richardson’s notion of “creative analytic practice ethnography ... [that] displays the *writing process* and the *writing product* as deeply intertwined” (p. 930, original emphasis).

## Findings

As I began working at the study site I struggled to understand the learning and knowing teachers were bringing to presence. Was I simply seeing old wine in new bottles? Were teachers doing the same old thing but with fancy new tools? Or, were the FabLabs and makerspaces contributing to an evolution of practice?

**Framework.** To gauge what I was hearing at the school I gathered digital making and learning pedagogies into a matrix (Table 1) that compared characteristics of traditional classrooms with those of makerspaces and FabLabs. I considered this framework to be like a weather vane that would help me figure out which way the wind blew.

TABLE 1 FRAMEWORK OF DIGITAL MAKING AND LEARNING

Traditional Classrooms	Maker Ecologies	Digital Making and Learning Ecologies
Teacher centered	Learner centered	Teachers and students as co-learners
Instructionism	Constructionism	Recursively enacted and multiply sourced learning
Cognitive (Learning is in the head)	Affect (Learning is feeling)	Cognitive-Affect: The feeling of knowing
Goal-bound progression (toward pre-established objectives)	Interest-driven goals (Toward student-set objectives)	Fractionally coherent, emergent curricular objects (Toward iterative definitions)
Time controlled by teacher/institution	Time controlled by learning needs	Time as intersection of iterative needs
Locked to standards	Individualized pathways	Entanglement of world and materials
Focus on reproduction	Focus on constructing the new	Focus on presence & recursive spirals of old and new
Achievement	Empowerment	Emancipation; a new ethos and new culture of leaning
Teach to control & deliver content	Teach to liberate & amplify imagination	Teaching as hearing the voices of materials in order to enact encounters with materiality

*Representative Sources:* Agency by Design, 2015; Barrett & Bolt, 2013; Blikstein, 2013; Bolt 2007, 2013; Brown & Adler, 2008; Brown & Duguid, 2002; Burton, 2000, 2009; Coole & Frost, 2010; Gee, 2004, 2007, 2010, 2013; Gee & Hayes, 2011; Halverson & Sheridan, 2014; Hetland et al., 2013; Ito, 2010; Ito et al., 2009, 2013; Jenkins et al., 2009; Kafai, Peppler & Chapman, 2009; Lankshear & Knobel, 2011, 2013; Lave & Wenger, 1991; Martinez & Stager, 2013; Papert, 1980a, 1980b, 1993, 2001; Papert & Harel, 1991; Peppler, 2013; Resnick, 2002, 2008; Sheridan et. al, 2014; Thomas & Brown, 2011.

(Table adapted from Stager, 2014, The Maker Table, <http://www.inventtolearn.com/table/>)

In addition to literature from the maker and digital media learning movements, I also drew from digital media theory, posthumanism and new materialism, thereby entangling 21<sup>st</sup> century learning behaviors (Jenkins, et al., 2009; Twining et al., 2013) with constructionism (Papert & Harel, 1991); artistic development (Burton, 2000, 2009); connected or interest-driven learning (Ito et al., 2013; Peppler, 2013); and a characteristic of digital materiality I came to call *decentered embodiment*. With this neologism I am following digital media theorist Mark Hansen’s (2004) description of an absence (*decenteredness*) that paradoxically enhances

presence (*embodiment*). Exploring this relational effect of digital materiality led Hansen (2015) to declare, “Agency is *resolutely not* the prerogative of privileged individual actors” (p.2, original emphasis). That is, in the digital age, agency is not reducible to an individual will but is rather distributed across networked ecologies. What might this look like in schools? The framework gathers a speculation: Reading the top row of Table 1 from left to right suggests that remixing teacher-centered pedagogy (Column 1) with learner-centeredness (Column 2), and suffusing both with decentered embodiment, might presence teachers and students as co-learners (Column 3).

Actually, decentered embodiment, while paradoxical, is not unusual in our everyday, digital lives. It’s the exhilaration of networked gaming (e.g., one’s first night in Minecraft)—the emotional indeterminacy players experience by being both *inside* and *outside* a game ecology. Less intensely, a similarly incongruous, visceral *and* ephemeral presence gathers from chatting with a far away cousin on Skype. And in schools, third graders might experience decentered embodiment’s paradoxical action at a distance when they pair with a sister school to interweave Greek architecture and 3D modeling by using the Internet. Drawing from similar examples, researchers speculate about the potential of virtual presence to amplify in-person participation and empowerment (Gee, 2007; Sweeny, 2013). Indeed, enacting participatory, digital co-learning has been theorized as underlying a *new ethos* (Lankshear & Knobel, 2011), or a *new culture of learning* (Thomas & Brown, 2011). Descriptions of such practices in classrooms, however, are rare, so it was difficult to know what they might look like. This was the purpose of the digital making and learning framework: without predicting or limiting what might appear in the field, I hoped that mapping the potential effects of digital materiality might help me recognize this new ethos of making-infused learning and knowing, should I encounter it.

**Typology.** As I listened to participants, and followed them from classrooms to the cafeteria to professional development workshops, I began to characterize teaching practices by what teachers said and did. For example, if a teacher used a worksheet during class, or prompted students to invent their own project proposals, I referred to the framework (Table 1) to help me describe the kind of practice I was observing. In this way I noticed that practices were moving toward or away from particular aspects of teaching and learning, for example by exhibiting characteristics associated with traditional schooling (in Column 1), or with maker education (in Column 2 or 3). In these unfolding interpretations, a typology of contact points emerged, which I called the Ways and Challenges (Table 2.1).

TABLE 2.1 THE WAYS AND CHALLENGES: CONTACT POINTS BETWEEN CHANGING TEACHING PRACTICES

<p><b>The Ways</b> Stabilizing digital media making and learning practices</p>	<p><b>The Challenges</b> Resisting digital media making and learning practices</p>
<p>Casual Conversations Sharing and learning together.</p>	<p>Content vs. Making The Fit</p>
<p>Doing Projects Engaging in individual practice.</p>	<p>Assessment</p>
<p>Discovering Iterating Releasing closely held agency.</p>	<p>Anxieties about how teaching is changing with the advent of digital making and learning practices.</p>
<p>Experiencing Student Engagement Vicarious enjoyment of empowerment.</p>	<p>Difficult Conversations</p>
<p>Administrative Disposition Being told what to do.</p>	<p>Not talking about skepticisms, anxieties or concerns.</p>
<p>Following Students' Lead Giving up control to learners' interests.</p>	<p>Lack Of Time Feeling overwhelmed by requirements.</p>
<p>Predispositions of the Teacher Reliving childhood making and building.</p>	<p>Predispositions of Teacher Holding to conduit models of pedagogy.</p>
<p>Self-Directed Learning Exercise of disciplined study.</p>	<p>Lack Of Expertise Inadequate technical know-how.</p>
<p>Reflecting on Experience Individual, meditative, consolidation of learning.</p>	<p>Loss of Control Not having individual autonomy to act.</p>
<p>Workshops Out of School Attendance at extracurricular workshops.</p>	<p><b>Rethinking the Curriculum</b></p>
<p>Professional Development in School School based workshops.</p>	<p><b>Recognizing that changing individual practices imply large-scale structural changes.</b></p>

As I collected more and more statements and observations, the typology helped me further describe practices in relationship to digital making and learning. So, when teachers told me about using making for problem-finding or to amplify student engagement, or about enhancing their own learning by following their students' lead (see Tables 2.2 and 2.3 for examples), I heard their statements as stabilizing the pedagogical characteristics in Column 3 of Table 1. The most common way this began to happen was in casual conversations (top cell, Table 2.2). The most common challenge to that stability was anxiety about the loss of content, or about how making fit into the curriculum (top cell, Table 2.3). Initially, I held the typology of Ways and Challenges as a map of teachers' interactions with digital making and learning; but over time I came to understand practices themselves as actors that enlisted the typology in order to connect, or to refuse to connect with digital making and learning.

**Lunchtime Scenario.** For example, one day in the cafeteria a music teacher told a story about some eighth graders who wanted to use their free period to write a song. She opened the music room and then came back about an hour later. She found them engrossed in rhythm and melodies, though they were having trouble with harmonies. Then another student arrived carrying a violin she had made in the FabLab. Everyone was amazed when she drew the bow across the strings to play a little song—and at the table we oohed and aahed. The storyteller told us that the student with the violin was so happy she almost cried. At that point the storyteller turned to me and said, “That’s what *making* is all about.”

TABLE 2.2 THE WAYS: CONTACT POINTS THAT STABILIZED DIGITAL MAKING AND LEARNING (IN ORDER OF PREVALENCE BASED ON INTERVIEWS AND OBSERVATIONS)

The Way...	Example
Casual Conversations	“A lot of times I need help even figuring out what the realm of possibility is.... I almost see [it] as a face-to-face blogging.” — Aiden, Middle School Science Teacher.
Doing Projects	“We gave them ten paperclips and they could design whatever they wanted...[and] that led to ... really wanting to have more open ended building and making.” — Grace, Elementary Science Teacher.
Discovering Iterating	“It’s really interesting because the paper engineering project is all about iterating and it’s all about prototyping, and maybe that’s why that project ended up being so successful.” — Susan, Middle School Art Teacher.
Experiencing Student Engagement	“The days that most excite me are where the students are incredibly self-motivated, where they’re the ones driving the discussion.” — Tyler, Middle School Media Teacher.
Administrative Disposition	“There’s an embrace of the new. They’re very much into science and technology.” — Amanda, High School History & Humanities Teacher.
Following Students’ Lead	“I don’t need to be a specialist in the application, ...we can work it out together. And the students are pretty into ... helping their teachers along with the tech stuff.” — Susan, Middle School Art Teacher.
Predisposition of the Teacher	“Growing up I just wanted to be in the woods building stuff or in the basement working on projects.” — Kieran, Technology Teacher & FabLab Director.
Self-Directed Learning	“I taught myself Photoshop and InDesign and Illustrator.” — Vanessa, Elementary and Middle School Art Teacher.
Reflecting On Experience	“I think that’s really important for me, as a teacher ...[to] reflect, ...to sort of go through the choices I’ve made.” — Mia, High School Art History & Humanities Teacher.

Workshops Out Of School	"[the workshop] had an impact on my practice. I'm much more interested in letting kids tinker with text and making much more open-ended prompts." — Amanda, High School History & Humanities Teacher.
Professional Development In School	"I think it came from a combination of professional development days and presentations that have been given to us over the last few years." — Tyler, Middle School Media Teacher.

TABLE 2.3 THE CHALLENGES: CONTACT POINTS THAT WEAKENED DIGITAL MAKING AND LEARNING (IN ORDER OF PREVALENCE BASED ON INTERVIEWS AND OBSERVATIONS)

The Challenge...	Example
Content vs. Making	"There's content we want to teach them and skills as well, and that can be at odds with the type of learning that digital fabrication involves." — Isabella, Middle School Science.
The Fit	"I need to know more about the whys about it....Right now it's a method without a point." — Amanda, High School History & Humanities.
Assessment	"And Isabella kept saying, how many points is it going to be worth in your class, [but] we don't really grade on points in here." — Susan, Middle School Art.
Difficult Conversations	"As far as working specifically with teachers, we didn't have enough planning time. So we were never really talking amongst each other." — Susan, Middle School Art.
Lack Of Time	"I don't have the personal time I need in this area.... It's hard when you're a full-time teacher to put in what the course needs, [which is] preparation time and planning time." — Thomas, High School Science.
Predispositions of Teacher	"We've got a group of teachers that are feeling adventurous, ...but they're a minority, to be frank. Most of the teachers at this school are pretty set in their ways." — Kieran, Technology Teacher & FabLab Director.
Lack Of Expertise	"With digital technology moving as quickly as it is, ...you don't really know how anything works all the way through [and] you then don't have the fluency or the expertise in order to help [students] with their frustrations." — Aiden, Middle School Science.
Loss of Control	"Well, that meant giving up control. Right, there's one thing teachers want, it's control of their room." — Amanda, High School History & Humanities.
Rethinking the Curriculum	"Everything's got to be different. ...even starting with grouping kids by age. I think we can start to group kids by interests, and there'd be a whole lot more play going on." — Kieran, Technology Teacher & FabLab Director.

This story enlists several contact points to help stabilize digital making and learning, including *casual conversation*, *experiencing student engagement* and *following students' lead*. I would argue two things: first, this is evidence of digital making and learning gaining traction at the school; and second, the story itself helps generate the conditions for that gain. That is, as a casual conversation, talking about making and doing contributes to establishing ecologies of making and doing, which was clear from listeners' reactions and from the storyteller's final, emphatic statement. But this is where some messiness appears. Another part of the story suggests some pushback: the storyteller's assessment that the students were having trouble with harmony. Here she describes learning that flounders when the teacher isn't there to help, or when she relinquishes control (e.g., *loss of control* from the Challenges). That is, in spite of enthusiastically following her students' lead, and being thrilled with their interest-driven learning, something drags back for the storyteller—perhaps an urge toward a teacher-knows-best trajectory? Her intention is not clear, but the point remains—why say anything at all about a shortcoming?

**Fractional Coherence.** This messiness suggests a *fractional coherence*, Law's (2002) term for the complexities inherent to technical objects, such as a British fighter jet (Law, 2002), or a transportation system (Latour, 1996). With this word Law is trying to describe multiplicities that gather into functional singularities without their constituent parts becoming entirely subsumed by the whole; these paradoxical objects remain more than singular but less than multiple. But when miscommunication, politics, budgetary constraints, or even the research process itself attempts to collapse the multiplicity into a *total* coherence, the dynamic resonances set in play by the multiple interactions of so many components can be stifled, and the object itself falls apart: the jet never gets off the drawing table, or the prototype trains never carry actual travelers. The complex object at the center of this study—digital making and learning pedagogy—appears susceptible to a similar description. That is, at least as exhibited in the lunchtime scenario, digital making and learning is both gaining and failing to gain traction at the school. Following Law (2002, 2004), this indeterminacy suggests that the practice is stabilizing. And further, the typology, as a tool that both describes and constructs practice by holding complex oppositions open and in relationship, increases the likelihood of that stabilization. This in fact is an example of how the typology of Ways and Challenges was useful to me: by retaining the contradiction at the heart of the storytelling experience, the story itself remains intact as an indeterminate though empirical instantiation of practice.

**Two Art Teachers and an Engineer.** The paradox of an indeterminacy that increases stability appeared elsewhere as well. An example comes from contrasting the practices of two art teachers and an engineering teacher. Each practice called on contact points from the Ways, including *casual conversation*, *doing projects*, *following students' lead*, and *discovering iterating*, and from the Challenges, particularly a concern with *loss of content* and *difficult conversations*. Exploring these commonalities highlights a characteristic of digital making and learning's new ethos: teaching as distributed between human and non-human actors, e.g., teacher and materials are symmetrically agential in the enactment of practice. Coming to hold practice in this way was an important finding of the study; it led to descriptions of teaching that do not center on the teacher, and to an understanding of practice as an *enacted encounter with materiality* (bottom cell of Column 3, Table 1).

**Vanessa.** A middle school art teacher with more than ten years experience, Vanessa wanted the school's makerspaces to be used across the curriculum. An insight into achieving this emerged from a story about helping fourth graders understand the scale of their bodies—feet, hands, head—in order to draw pictures of themselves as Revolutionary War soldiers for a stage presentation. My conversation with Vanessa took several detours, touching on math, creativity, scale and proportion, digital 3D design and scanning, and the differences between teaching at various developmental levels. At one point Vanessa found herself speculating about a way to teach drawing so that the hand remained proportional to the body. As she puzzled the implications of her new method she suddenly became excited, saying, “I just came up with that! ...I might try that next year.”

Vanessa's insight is an example of knowledge that appears suddenly and organically, from within the meandering flow of one's work with a material. In this case it emerged from the material of our conversation, becoming present as we explored it. Importantly, Vanessa was not looking for insight; we had not approached the conversation as a problem solving exercise. Rather her innovation appeared as she turned her ideas over in her head, as she was sharing them with me. I am reminded of the way knowing sometimes occurs in an artist's studio, for example, when a flow state (Csikszentmihalyi, 2008) has been reached, or when, after prolonged grappling with a difficult problem, insight suddenly emerges (Irvine, 2015). Here, an object—a way to teach drawing—was shaped by its evolution, and its form appeared by surprise. For Vanessa, this amplified the entanglement of personalized making (the Redcoat figure as a trace of students' own bodies), materials and tools (paint, paper, glue), and cultural

constructs (the American Revolution), and opened a space where students might learn to be historians rather to reproduce or represent an isolated curricular topic.

**Emma.** Head of the art department and a high school art teacher herself, with 20 years experience, Emma told me that she avoided conversations about making because she was skeptical of the maker movement. In an interview that touched on Quantum mechanics, digital animation, literature, politics, and advanced contemporary art, she said she felt peripheral to the conversations around her, as if she was on a different “wavelength” from her colleagues. Sorting through a student’s multi-part pictorial response to artworks by an important contemporary artist, Emma explained that her student had learned “how to think, how to take risks. She learned how to have the courage to keep going, to get herself unblocked.” Gesturing at the variety of work the student had produced, Emma asked me, “How do you Google that?” Her impatience with her colleagues’ infatuation with the FabLab was palpable: “Start with the idea, then go back to the tools,” she said. When I asked how she might explain that to the math department, she laughed and said she didn’t know. “You have to be a little embarrassed,” she said. “That’s when you know you’re on to something good.”

**Thomas.** Formerly a chemistry teacher, Thomas had been assigned to teach an engineering elective for high school seniors. He told me that the students had surprised him with the diversity of their projects: a box that played music based on the Dow Jones average; dice that would Tweet the high roller’s score; a thermos that sensed the level of the liquid inside; and an umbrella that lit up in the rain. But Thomas was concerned; unlike AP Physics and Honors Chemistry, he didn’t know how to evaluate these projects—were they useful enough? Fun enough? In class he asked a student, “Do you have art this year?” Later he wondered how art played into what students needed to know. Most projects seemed inspired by an engineering sensibility, like a coffee cup that sensed the temperature of the coffee, and he told me that he didn’t know how to encourage an artistic sensibility, that he didn’t think he even understood it. Vanessa used to guide him with these questions, but now he was on his own. And he was exhausted. “I am struggling a little bit,” he admitted. “I’m going to assist eleven kids in building their own projects, and they have no idea what they’re going to do? So that’s me making eleven projects.” I asked him what he needed in order to be ready for the next iteration of the class. “A one-year sabbatical,” he said.

**Losing control to gain traction.** A full analysis of the ways these three practices pull toward or back from the ethos of digital making and learning is beyond the scope of this paper, but a brief comparison begins to reveal the kind of learning I often observed. For each participant,

digital making and learning brought out the potential of loss of control—of content, expertise, agency—and each teacher recognized that casual conversation mitigated the difficulty. For Vanessa, learning emerged from the flow of conversation; Emma asserted that learning arrived after a loss of control that came close to embarrassment; and for Thomas, surrounded by runaway student engagement, the need to retain control, if only to assess the learning, was exhausting and nearly debilitating, especially in the absence of Vanessa’s guidance. In each case, learning dynamics reprise decentered embodiment, at least in the sense that these teachers understood that losing oneself to the flow of their practice might heighten learning for their students, but that doing so necessitated risk and uncertainty. The art teachers accepted that trajectory and felt emboldened by it; the engineering teacher, on the other hand, rejected it, though he wondered if “art” might re-invigorate him, even as knew he didn’t understand what he meant by that word. Based on this interpretation of the events I observed and the conversations I participated in, I am moved to wonder about how expertise in arts-inflected trajectories of learning and knowing might be gathered or revealed as pedagogical strategies and tactics (de Certeau, 2011) in teacher education across the curriculum, that is, not only art teacher education.

**Enacted Encounter With Materiality.** This phrase gets close to the learning and knowing brought to presence in these vignettes because it connects two notions of agency that often exclude each other, reprising to some extent, the paradox of decentered embodiment. On the one hand, to *enact* is to work purposefully toward bringing a thing to presence. For example, *City Hall enacted the mayor’s policy on economic relief* implies multiple actors coordinating multiple kinds of work in order to reveal a particular ordering of resources. On the other hand, to *encounter* something is to come upon it by surprise, implying a different kind of directedness. Combining these words suggests a practice constituted by multiple actors that is both focused and open to serendipity, where achievement might arrive unpredictably, like a purposeful surprise, or an intentional accident—an action trajectory that reminds me of Latour’s (1999) proposition that agency in the world is *always* knit through with at least a little surprise.

But further, *with materiality* extends the paradox to encompass an entanglement with tools and materials, such as might occur in makerspaces and FabLabs, or art classrooms. When the description works, as in Vanessa’s and Emma’s vignettes, holding teaching as an enacted encounter with materiality points to the learning sometimes reported by artists, novelists, songwriters, and theoretical scientists, where after prolonged engagement with a particular

material, such as paint or language or melody or mathematics, insight or innovation arrives suddenly or as if by accident. Elsewhere I have described this co-emergent unfolding assemblage of knowing as *material learning* (Cabral & Justice, 2013), and have suggested that new material ‘voices’ can catalyze new ways of thinking. But even when material learning methodologies are foregrounded, innovation is not guaranteed, especially if goals are held so closely that loss of control is impossible, or, to say it another way, if fractional coherence collapses.

On the other hand, in classrooms where students and teachers were open to co-emergent participatory enacted encounters, when practice responded to the ebb and flow of collaborative agency, I observed students and teachers weaving their voices to those of the tools and materials on offer, and surprising innovation or insight sometimes emerged. In those classrooms, in fact, practice became present as a material in itself, and participants as artful co-learners. In such configurations teachers might flourish if they can give over to the materiality of practice, while participants who hold tightly to linear cause and effect objectives might become stymied.

## Conclusions

This paradoxical indeterminacy—where losing a little control suggests a gain of traction—reprises digital materiality’s decentered embodiment. That is, if teaching can be held as co-located participation that paradoxically enhances agency, pedagogical binaries can be described without collapsing into singularities, and practice might remain fractional. As such, one conclusion I draw from the study is that digital making and learning at the study site trended toward an oscillating stability, like the tide coming in and going out, and that teaching practices were evolving in response.

To be clear, with *oscillating stability* I am not saying that digital making and learning alternated between stability and instability, but rather that the kind of stability I observed was an oscillation. I want to describe the *way* that digital making and learning was coming to presence as a dynamic fluttering, a wobbling between traditional practices, maker ecologies and learning ecologies suffused with digital materiality (Table 1). In response to this oscillation, teaching practices might be described as adopting or resisting digital materiality, especially the paradox of decentered embodiment, by using the strategies identified in the typology (Tables 2.1, 2.2, 2.3).

Further evidence for this claim came from an interpretation of a high school history teacher's practice. In her classroom, Amanda danced Roman history and urged students to talk to documents, and to listen for them to talk back. Her practice enacted an open-ended learning and knowing, but she did not consider herself a maker, or an artist. That is, though she had participated in digital making workshops, and supported making and building activities in the classroom, Amanda did not use the FabLab or its machines. And yet she thought that "the maker movement [described] what [she was] doing with text," and that it made her feel "much more open and willing to let alternative things happen in [her] classes." And instead of the anxieties that some teachers felt about giving up some control of curricular objectives, Amanda held history as a "knot of colored string," and expertise as "the feeling of knowing," explaining that the maker movement gave her "increased freedom to make metaphors, and fresh energy to treat old topics in new ways." Clearly, Amanda believed her teaching was changing as it interwove with digital making and learning. And based on observations and interviews I would concur that in the practice that surrounded her, that she accompanied, participated in, collaborated with and curated, an ethos of co-emergent learning and knowing was becoming strong and vibrant. Indeed, I would argue that Amanda's practice had traveled pretty far into the conceptual, pragmatic and situated space of digital making and learning pedagogies (Column 3 of Table 1). More complex and uncertain, however, is the question of how it had achieved this trajectory.

The learning dynamic that I am trying to describe gives rise to a second conclusion, namely, that we need a different kind of language to gather the complexities that digital making and learning pedagogies are bringing to presence in schools. Throughout this study I have struggled with the language of contemporary research methodologies. What kind of learning and knowing practices are these actors enacting? How might I describe them? My tentative answer begins with the typology of Ways and Challenges, but the language of new materialism and posthumanism challenges that response. The difficulty of reforming it, however, tempts me to erase the complexity by hitting the delete key, and to fall back on linear causalities (e.g., A causes B) or normative relationality (e.g., teacher A intends to teach A' which results in B pedagogy). As an artist and art educator I realize that I am not alone in this struggle to articulate co-emergent agency and its effects on practice, as the work of other researchers attests (Castro, 2012; Knochel & Patton, 2014; McClure, 2010; Sweeny, 2013; Thumlert, 2015). From farther afield, I also draw on the eloquence of Bennett (2010) as she puzzles through the difficult political implications of vibrant matter (see especially chapter 2, *The Agency of Assemblages*). And closer to home, at least in terms of the empirical nature of my study, I am

reminded of Walkerdine's (2007) difficulty in describing the relational dynamics of boys' and girls' video game play; and of Sorensen's (2009) difficulties with the recalcitrant language of Enlightenment materiality in her study of digital game environments in Danish elementary classrooms. Both of these researchers grappled with disruptive metaphors in order to grasp what was going on, and both also turned toward methodologies that held complex empiricism as a critique of causality. And yet, after gathering all of these examples to my side, how might descriptions of teaching practice that don't center on the figure of a teacher actually contribute to teacher education or to educational reform?

I'm wary of proposing a simple answer to the difficult question of how Amanda—or any teacher—came to participate in a practice that embodied the ethos of digital making and learning. Casual conversations and a willingness to loosen control of outcomes certainly played a role. I would argue, though, that the paradox of a non-maker teacher adopting a maker ethos suggests an ecology of practice that the digital making and learning community has not yet begun to articulate. Also, though Amanda never referred to herself as an artist, the entanglement of deep expertise and playful engagement with her material (the material of history) that I observed in her practice, or, in the practice that enframed her, reminded me of poets, musicians, painters and scientists I have known. As such, following Law's (2004) logic of overlap and juxtaposition, a third conclusion of the inquiry is the proposition that if pedagogical narratives can hold binaries open—for example, by not collapsing dichotomies like content/not content, knowing/feeling, or material/immaterial—learners might come to enact new metaphors of knowing, perhaps changing paradigms in the process. Making metaphors, in fact, was an important component of Amanda's practice, and, I would argue, fully interwoven with its enactment. This raises a concluding question: what role does metaphor-making play in make-to-learn ecologies, and how do we educate teachers to enact that particular kind of expertise?

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