Tofel-Grehl, C., Jex, E., Searle, K., Ball, D., Zhao, X., & Burnell, G. (2020). Electrifying: One teacher's discursive and instructional changes through engagement in e-textiles to teach science content. *Contemporary Issues in Technology and Teacher Education, 20*(2), 293-314.

Electrifying: One Teacher's Discursive and Instructional Changes Through Engagement in E-Textiles to Teach Science Content

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This paper shares findings from the first of its kind quasi-experimental mixed methods study exploring the potential impacts on teacher instruction through engagement with making and e-textiles. Because engagement in hands-on inquiry has demonstrated strong promise for increasing student interest and engagement in STEM careers, finding curricular approaches that engage students in project-based learning remains important. As such, the Maker Movement and making has gained traction as a possible effort to improve such outcomes. This study shares outcomes from analyses of one teacher's first engagement with teaching eighth-grade science through e-textiles. Four of his classes were taught using his traditional science curriculum while four of his classes were taught with an equivalently designed e-textiles curriculum. Findings indicated that his instruction during e-textiles classes was different in terms of classroom discourse opportunities and engagement. Specifically, students taught in classes with e-textile were afforded more opportunities to engage their own questions with the teacher and engage on a more personal level with him.

In many ways, teachers are gatekeepers for students in their classes. Teacher belief, instructional approach, and content knowledge all serve to open and close windows of opportunity for students (Klassen & Tze, 2014; Lumpe, Czerniak, Haney, & Beltyukova, 2012; Seashore, Dretzke, & Wahlstrom, 2010). Because teachers are frequently the authorities of learning within their classrooms, their thinking and approaches afford students varied opportunities to engage and identify with science, technology, engineering, and mathematics (STEM) learning.

Within school classrooms, a myriad of factors interact to foster or stifle student interest and engagement with STEM content. Encouraging findings indicate that students are more engaged with STEM learning when hands-on and constructionist learning makes its way into the classroom (e.g., Tofel-Grehl, Fields, Searle, Maahs-Fladung, Feldon, Gu, & Sun, 2017).

Often, such activities in science classrooms engage technology as an instructional and motivational tool. However, improvements in outcomes based on technological interventions are as variable as the technologies and pedagogies engaged (Tamim, Bernard, Borokhovski, Abrami, & Schmid, 2011). Because engagement in hands-on inquiry has demonstrated strong promise for increasing student interest and engagement in STEM careers (Gibson & Chase, 2002; Kong, Dabney, & Tai, 2014; Lazonder & Harmsen, 2016), finding curricular approaches that engage students in project-based learning remains important. As such, the Maker Movement and making has gained traction as a possible effort to improve such outcomes (Halverson & Sheridan, 2014).

The Maker Movement, an eclectic field of researchers, hobbyists, and disciplinary specialists engaging in tinkering and imaginative project design, has historically remained outside of classrooms due to temporal, fiscal, and pedagogical constraints. However, as more research demonstrates the feasibility of making in classrooms (e.g., Buechley, Peppler, Eisenberg, & Kafai, 2013; Fields, Lu, & Kafai, 2017; Tofel-Grehl et al., 2017), classroom teachers are beginning to explore more ways to bring making's high-enthusiasm projects into their classrooms to engage standards based learning.

One such technology is electronic textiles (e-textiles). These projects engage students in circuit construction using conductive thread instead of wire, wearable sensors, and LEDs. These projects can be highly varied and personalizable, making them particularly engaging for students (Kafai, Fields, & Searle, 2014), as well as effective vehicles for student learning (Litts, Kafai, Lui, Walker, & Widman, 2017; Tofel-Grehl, Ball, & Searle, in press).

To date, however, little is known about the impacts of maker activities on teachers and classroom instructional practice. Because of the essential role teachers play in influencing student classroom experiences, we argue in this paper that engagement with making in classrooms has direct impacts on teacher classroom instruction.

Given the unique affordances of making established in the literature we hypothesized that teacher instruction would be different around maker activities. We specifically analyzed potential changes in one teacher's interactions with students by comparing instruction during e-textiles making projects and business as usual teaching of the same content. Of specific interest are the affordances for teachers and students that can shape classroom discourse (i.e., those spoken and physical manifestations of communication that are enacted for the purposes of interacting with another individual; Gee, 2000).

Because making disrupts the normal dynamics of didactic classroom instruction (Howell, Tofel-Grehl, Fields, & DuCamp, 2016), further shifts in classroom discourse ought be explored. Classroom discourse directly impacts student experiences and understanding, as it provides a key mechanism to foster connections and meaning-making (Lemke, 1990; Michaels, O'Connor, & Resnick, 2008; Seah & Yore, 2017). For example, teachers' use of effective questions in classroom discussion is associated with higher levels of student achievement (Clark, Harbaugh, & Seider, 2019; Schoen, Cebulla, Finn, & Fi, 2003). Similarly, students' responses and questions to each other and the teacher are important tools for assessing their evolving understanding of content (Cazden, 2001; Simon, Erduran, & Osborne, 2006).

Previous research indicates, however, that relatively few teachers are proficient in using rigorous and effective questioning strategies that promote extended student engagement in classroom discourse (Banilower, Smith, Weiss, & Pasley, 2006; McCarthy, Sithole, McCarthy, Cho, & Gyan, 2016). This case study examines one teacher's shifts in classroom practices associated with the curricular use of e-textiles in his eight-grade physical science class with a close look to the discursive practices.

Discourse in the Science Classroom

Current discourse research within science education primarily focuses on meaning-making and argumentation. Rather than viewing classroom discussions as providing evidence of concept attainment, these studies work from the assumption that the discussion itself builds meaning and understanding (Duschl & Osborne, 2002; Warfa, Nyachwaya, & Roehrig, 2018). Through discussion, students build their understandings and co-construct knowledge (Duschl, Erduran, Grandy, & Rudolph, 2006). This coconstruction of knowledge stems from a learning community in which students use evidence to build theoretical models and concepts not yet presented by the teacher, and the teacher acts as a moderator and facilitator rather than a knowledge giver (Driver, Newton, & Osborne, 2000; Tang, 2017).

The classroom community's discursive practices provide the structure and motivation for communication and support student goal-setting related to classroom activity (Kiemer, Groschner, Kunter, & Seidel, 2018). Furthermore, because changes in teacher talk can directly impact student learning through explicit modeling of argumentation and argument building (Erduran, Simon, & Osborne, 2004), exploring curricular approaches that may influence teacher talk can elucidate changes for students.

As inquiry-based learning becomes more common in science classrooms, teachers find a widening disparity between the various obligations they face. Teachers now need to provide greater access to students to drive discussions and curricular agendas (Driver et al., 2000). However, greater emphasis on testing drives rigorous standards of learning, which hinder teacher comfort with open discussions within science classrooms. On one hand, teachers want to allow students to drive the course of their own learning; on the other, they fear that not enough of what they believe is real science will happen to prepare their students for testing (Haney, Lumpe, & Czerniak, 2003; Tofel-Grehl & Searle, 2017).

Access and Engagement

Classroom dynamics are also fraught with issues of access. Teachers speak freely; students normally require teacher nomination to obtain the right to speak (Ardasheva, Howell, & Vidrio Magnaña, 2016; Cazden, 2001). These discourse patterns create complex power dynamics between students and teachers. Through these participation frameworks, students engage in deliberate behaviors to garner teacher attention. However, student nomination is a direct engagement process that is not comfortable for all students, due either to lack of confidence or a discrepant cultural model of appropriate engagement (Gallimore & Goldenberg, 2001; Vetter, Schieble, & Meacham, 2018).

When socially normalized discursive actions are at odds with learning, students and teachers struggle to create cogent systems of effective communication. Consequently, efforts at instructional reform have long called for increased democratization in classrooms, encouraging teachers to foster student discussion through inquiry rather than focus on content delivery through lectures (Campbell, Zhang, & Neilson, 2011; Shaffer et al., 2014).

Science education has been referred to as a "second socialization or specialist enculturation into a sub-community" (Lemke, 2001, p. 298). Learning the social and content language of science enculturates students and seems to be at the heart of the systemic disenfranchisement of minority groups. Particularly with the push toward inquiry-based learning, teachers deem students with different types of discursive identities as lacking in reasoning and scientific thinking skills.

Michaels and O'Connor (1990), for example, worked with Haitian immigrants to substantiate the belief that teachers inferred cognitive ability from discursive interactions. Students who offered little in the way of classroom talk received marks indicating lower cognitive ability. However, in Haiti, normative discourse patterns for teachers and students do not provide for student elaboration. Reasoning-based discussions were not important within that educational framework. Therefore, when asked direct questions, students from Haiti responded but did not offer elaborations or justifications for their reasoning.

Such discursive divides directly influence students' sense of belonging and their attitudes towards science itself . Students report that they "speak science" at school and engage in "normal talk" at home and with their peers. The process of discursive assimilation occurs on a spectrum from "oppositional discursive status" to "proficient discursive status," in which students can move between their normal discursive patterns and those expected within the science classroom (Brown, Reveles, & Kelly, 2005). If students identify themselves as at odds with or in opposition to the discursive patterns of their science classrooms, their inclination to seek out further science experiences decreases.

Affordances of Making

Making offers a form of hands-on, project-based instruction that, at its core, is different than most other hands-on projects. Because of highly varied outcomes and solution paths for maker projects, the normal classroom model where all correct answers are the same disappears. Because projects and designs are so highly personalizable, youth engage with the work differently than other projects (Tofel-Grehl et al., 2017)

E-textiles, for example, offer unique characteristics that may enable students who do not self-identify as strong science students to engage better with the content. As e-textiles design incorporates crafting techniques such as sewing and knitting, it can provide access to STEM content and engagement for a variety of student populations traditionally underrepresented in those disciplines. Kafai, Searle, Martinez and Brayboy, (2014) proposed a culturally responsive approach that connected community funds of knowledge and STEM activities in a culturally relevant way to engage American Indian middle school students in computational activities.

Crafting practices have a long history in many indigenous communities, making the use of e-textile activities as a means for connecting programming and computational thinking a more effective teaching tool. This activity created a strong connection between the American Indian's local knowledge and practices and further enabled students to perceive themselves as "successful stakeholders of the digital age" (Kafai et al., 2014, p. 245).

Similarly, Calabrese Barton, Tan, and Greenberg (2017; see also Calabrese Barton & Tan, 2018) found that the participation of youth from traditionally underrepresented communities in an urban STEM-focused makerspace program supported meaningful engagement linked to personal and collective histories. Engaging in making legitimized access to and use of tools and design processes usually accessed only through conventional STEM participation.

Such results have also been documented through comparative studies. In a quasi-experimental study of e-textiles' impact on student engagement and motivation (Tofel-Grehl et al., 2017), students in the e-textiles condition reported significantly greater perceptions of their teacher's and family's care about their learning of science than did peers in a business-as-usual control condition. E-textiles students also reported that their peers had a more positive image of science, in general, and were more encouraging of their efforts in science than were participants in the control condition. These shifts in perception were also accompanied by a greater likelihood of taking projects home to share them with their families.

Research Questions

While studies of making with e-textiles have carefully examined the modes of engagement facilitated for students, none so far have examined the changes in teacher practice that may accompany and foster these shifts. Examination of the discursive affordances of e-textiles based instruction can inform the field's understanding of the opportunities to make meaningful changes to student experiences. As such, this study described here addressed the following research questions:

1. How, if at all, did discourse and other instructional practices differ between the instruction of e-textile projects and traditional projects?
2. What differences, if any, did the teacher experience or perceive between teaching e-textiles curriculum versus traditional circuitry curriculum?

Methods

This case study illustrated the ways in which teaching with maker space technologies changed the instructional discourse of one teacher. Using e-textiles as the making technology, we examined the differences in classroom talk and engagement from both teacher and student perspectives. The teacher taught the same science content four periods each day — two using his conventional approach and two using making — for two cohorts of students in the same school year (i.e., four total classes using e-textiles and four using the conventional approach). This arrangement facilitated contrastive qualitative analyses based on observations and interviews, as well as a quasi-experiment to compare quantifications of observed behaviors using the Reform Teaching Observation Protocol (RTOP; MacIsaac & Falconer, 2002) scores.

Site and Sample

The school. The school site selected for this study was the sole public middle school of the town. King Street Middle School (KSMS; a pseudonym) serves an economically diverse rural town in the Western United States. With 550 students enrolled, the school reports 70% of students to be Caucasian, 26% to be Latinx, and 4% to be of other racial or ethnic backgrounds.

Student proficiency scores roughly fall into these same percentages; approximately 78% of students score in the proficient or above range in both their mathematics and reading standardized test scores. The school reports just over 20% of all students participate in the free and reduced lunch program.

The teacher. The teacher involved in this case study approached members of the research team about employing e-textiles in his eighth-grade science classes. His willingness to participate made his classroom a productive context for piloting the development of a secondary science curriculum using e-textiles. Mr. Williams (a pseudonym) taught all sections of middle school science at KSMS. With more than 10 years of teaching experience at the school, Mr. Williams was certified in the Project Lead the Way science curriculum and was working toward completion of his National Board Certification in science.

His interest in e-textiles as a mechanism for teaching science stemmed from a professional development experience offered by his district the previous year. He connected with a member of the research team through involvement with this professional development project.

The classes. The classes selected for inclusion in the study were those taught by Mr. Williams. To more effectively isolate and understand the effects of e-textile projects on classroom science learning, only half of the classes he taught participated in the e-textile projects and are referred to as the treatment group. The other half acted as a comparison group and proceeded with the traditional projects he used to teach electricity and circuits. These classes were established by the school through their normal scheduling and class assignment procedures.

Across all classes, the scientific content of the lessons remained uniform in order to isolate the impacts of the e-textile projects (see discussion of curricular unit development). Four sections used e-textiles materials to build model circuit projects while the other four, the comparison group, used traditional materials, consistent with the teacher's practice across previous years.

The students. Students who participated in the study were enrolled in the eighth grade at KSMS and participated in Mr. Williams' science class as part of either the first or second cohort, based on scheduling constraints of the school. A total of 155 students participated and were reflective of the overall demographics of the school.

Curricular Unit Development

We developed the e-textiles unit addressing electricity and circuits in cooperation with Mr. Williams, who determined the specific content to be covered. The process of developing the unit and specific lessons was intentionally collaborative and iterative in nature. Mr. Williams focused on his state's standards that were directly modeled after the NGSS.

His prior classroom instruction efforts drew upon his own teaching experience and training for his National Board Certification when determining the content and sequence of the content lessons. Because we sought to ensure instructional equivalence of the targeted content between the control and treatment groups, the content of the lessons were designed to be identical. In short, instructional equivalency was at the front of the design process; students in both treatment and control had the same number of projects, received the same amount of direct instruction, and were provided the same amount of project construction time. Both sets of students were provided the option to bring their work home with them to ensure equivalency of access and work time.

Last, when members of the design team realized that debugging was an inherently important aspect of student work in e-textiles, we designed an equivalent debugging activity for the control group to provide them a comparable activity.A detailed outline of the curriculum can be found in Tofel-Grehl & Fields (2015) and Tofel-Grehl et. al. (2017). To meet the needs of the school and expected learning standards, the unit designed lasted 4 weeks. Ten discrete content lessons were developed and coupled with four specific learning activities. Table 1 provides detail regarding the scope of the lessons.

Table 1 Unit Outlines for Control and Treatment

Lesson	Control Classes: Traditional Curriculum	Treatment Classes: E-textiles Curriculum
1	Lecture: Introducing Electricity and Electron Transfer	Lecture: Introducing Electricity and Electron Transfer
2	Lecture: Introducing Circuits and Circuitry	Lecture: Introducing Circuits and Circuitry
3	Lecture: Conductivity and Simple Circuits–Exploring Conductive Materials	Lecture: Conductivity and Simple Circuits–Paper Circuit Intro
4	Conductivity, Insulation, and Polarization–What Makes an insulator & other questions activity.	Conductivity, Insulation, and Polarization–Paper Circuit Project continued
5	Parallel Circuits- Bread Boards and Alligator Clips	Parallel Circuits- Paper Circuits and Bracelets
6	Series Circuits and Circuitry Construction Bread Boards and Alligator Clips	Series Circuits and Circuitry Construction-Paper Circuits and Bracelets
7	Switches and Short Circuits- Short circuit activity focused on debugging	Switches and Short Circuits- Bracelets
8	DC Motors Project	Bracelet construction
9	DC Motors Project	Bracelet construction continued
10	DC Motors Project continued	Bracelet construction continued

Data Collection

Data were collected over 2 months, as follows:

Interviews. Interviews with the teacher happened intermittently across the 2 months of data collection. He was interviewed prior to the start of teaching to capture his expectations and beliefs about the upcoming unit, as well as during and after to capture his reactions and emerging perspectives during instruction. He also participated in reflective interviews following the completion of the relevant instruction.

Observations. Video recordings and in-personobservations of classroom interactions took place approximately 4 hours per day for 36 school days across both conditions. Field notes, including hand-transcribed transactions relevant to the research foci, and open coding occurred during live observations.

Artifacts and student interviews. Artifacts were photographed during and after construction. Students were queried about their process and reflections on learning through both treatment and control. Some students in the treatment groups were queried about family perceptions after initial analysis of findings associated with family interest were noted.

Data Analysis

Understanding the actions and behaviors of the teacher involved in this study was multilayered. We applied a grounded theory framework (Lincoln & Guba, 1995) to establish trending discursive and pedagogical patterns within the teacher's instruction. Within this larger framework, we utilized an analytic induction approach (Erickson, 1985) to examine iteratively multiple forms of data and distill themes of instructional action and change for Mr. Williams.

To assess the extent to which differences in classroom practice were consistent across traditional and e-textiles implementations, videos of classroom teaching were also coded by four raters blind to condition using the RTOP (MacIsaac & Falconer, 2002). The RTOP items focus on five major pedagogical issues: (a) lesson design and implementation, (b) instructor's use of content knowledge, (c) degree of student inquiry, (d) classroom culture (degree to which student-student communication was encouraged), and (e) student-teacher relationships.

For the current study, the content knowledge items were excluded. Thus, the four sections included 20 observable items scored from 0–4 based on the frequency and extent to which the behavior occurred. During rater training with 10% of the sample videos, pairwise interrater agreement for every possible pair exceeded 85% on each item. Using principal components analysis, these items all loaded significantly onto a single factor (eigenvalue = 12.0), with standardized loadings between 0.661 and 0.856. As such, a single factor score (item mean) was used as the dependent variable to enhance reliability.

The treatment condition was dummy coded as a fixed factor with e-textiles instruction coded as 1 and the comparison condition coded as 0. Data were analyzed with SPSS 25 software using a linear mixed model that accounted for nesting within class period to assess the impact of treatment condition on RTOP score.

The differences found in the video analysis between instruction in control and treatment classrooms were then the subject of interview discussions and reflective practice conversations with the classroom teacher. These conversations clarified our understandings of the teacher's intent and actions within the classroom context. From these understandings and the reformed practice areas outlined in the RTOP protocol, three themes of teacher practice reform were developed.

Qualitative analysis was conducted using MaxQDA qualitative analysis software. Initial coding was completed using broad categories, such as examples of instruction, examples of student engagement, and on and off task student behaviors. The initial themes were chosen based on the overarching goal of the RTOP assessment of identifying "reformed teaching" practices. These initial themes were then analyzed to identify subcategories within each broader theme, and each theme and subtheme were assessed to determine the extent to which they might differ between e-textiles and conventional classes.

Findings

Quantitative Findings

Results of the linear mixed model analysis indicated a significant effect of treatment on the RTOP factor score with $b = 0.483$ ($t = 3.27$, $F = 10.71$, $p = 0.002$; 95% CI: [0.188, 0.777]). The mean score across 35 observations of the treatment condition was 4.00 ($SD = 0.541$), and the control mean across 37 observations was 3.52 ($SD = 0.696$).

In short, the qualities of the teacher's interactions with students during e-textiles instruction reflected significantly greater levels of fostering inclusive learning communities, shaping the direction of lessons based on student ideas, student inquiry, student-student communication, and student-teacher interactions where the teacher engaged in a supportive, rather than directive, style with students. Item-level mean scores and standard deviations by condition are reported in Table 2.

Table 2 Mean RTOP Items Scores by Condition

RTOP Protocol Question		Control		Treatment	
		M	*SD*	*M*	*SD*
1.	The instructional strategies and activities respected students' prior knowledge and the preconceptions inherent therein.	3.49	.804	3.97	.664
2.	The lesson was designed to engage students as members of a learning community.	3.73	.902	4.09	.818
3.	In this lesson, student exploration preceded formal presentation.	3.54	.803	4.14	.772
4.	This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.	3.62	.924	4.09	.612
5.	The focus and direction of the lesson was often determined by ideas originating with students.	3.38	.953	3.89	.867
11.	Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.	3.27	.990	3.97	.857
12.	Students made predictions, estimations, and/or hypotheses and devised means for testing them.	3.38	.861	3.57	.979
13.	Students were actively engaged in thought-provoking activity that often involved the critical assessment of procedures.	3.68	.884	3.97	.707
14.	Students were reflective about their learning.	3.35	1.136	4.03	.954
15.	Intellectual rigor, constructive criticism, and the challenging of ideas were valued.	3.76	.641	3.94	.838
16.	Students were involved in the communication of their ideas to others using a variety of means and media.	3.89	.906	4.31	.631
17.	The teacher's questions triggered divergent modes of thinking.	3.27	.871	3.69	.900
18.	There was a high proportion of student talk and a significant amount of it occurred between and among students.	3.70	.909	4.14	.733
19.	Student questions and comments often determined the focus and direction of classroom discourse.	3.43	.689	3.89	.758
20.	There was a climate of respect for what others had to say.	3.76	.796	4.17	.707
21.	Active participation of students was encouraged and valued.	3.70	.939	4.11	.758

22.	Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.	3.35	.824	3.74	.780
23.	In general, the teacher was patient with students.	3.62	.794	4.26	.817
24.	The teacher acted as a resource person, working to support and enhance student investigations.	3.14	.855	3.94	.684
25.	The metaphor “teacher as listener” was very characteristic of this classroom.	3.35	.857	4.14	.772

Qualitative Findings

Qualitative analysis was conducted in two stages. First, a broad level open coding of Mr. Williams’ interviews was conducted to obtain a better sense of his perceptions of his teaching. After that, observational data, including video recordings of his instruction and field notes, were used to thematically code across qualitative data sources. The integrated coding scheme is presented in Table 3, reflecting 13 initial themes and five distilled themes.

Initial coding. In discussing his teaching, Mr. Williams frequently commented positively about the introduction of e-textiles into his classroom. A veteran teacher with 10 years of experience teaching this grade and content area, he felt that e-textiles improved his ability to reach his students. As he stated, “Quite frankly, the change was beyond my predictions!”

Mr. Williams also said he felt that the students who were typically disengaged from learning science in his class were Latinx English language learners (ELLs). Interviews with him prior to teaching the novel e-textiles curriculum indicated that he believed his low performing ELLs would continue to perform poorly, but that the more average achieving students would be the ones from whom he would see better engagement.

Mr. Williams was later surprised, as he reported to the research team members, that his ELL students demonstrated greater involvement and a higher frequency of assignment completion. While learning outcome tests indicated that ELL students did not score significantly higher on their posttests than other groups of students, they did perform on par with their non-ELL classmates — something Mr. Williams adamantly stated he had not seen before in all his years teaching at the school. He attributed this change to his students’ interest and personal values placed on crafting. As he noted, and many students confirmed in their interviews, many of his ELL students had family members who worked with either circuits or sewing as part of their jobs.

Table 3 Qualitative Themes and Findings

Initial Themes	Exemplar From the Data
Distilled Theme: Teacher-Led Direct Instruction - Observed in control more often.	
Teacher gives direction to students regarding group work, remaining on task, etc.	"Rotate your negative line up. From underneath, sew around three times and use the flat stitch." -Williams, 4/30, period 4
Teacher gives direct instruction one procedures of task.	"That is a short."- Williams, 5/1, period 6
Distilled Theme: Teacher Questioning Strategies - Verification of understanding observed equally but the answers to questions occurred more in treatment.	
Teacher questioning on specific content topic to verify student understanding.	"Why do we have this squiggly line [in light bulb drawing]? What's inside? A resistor." -Williams, 4/30, period 6
Teacher answers student questions.	"Talk among yourselves and resolve your disagreements between answers."- Williams, 4/30, period 6
Distilled Theme: Teacher Engagement with Students - Observed in treatment more often.	
Teacher engages with students not on content.	"I cannot be complementary enough!"- Williams, 4/30, period 4
Teacher praises students or student effort.	"I am so flattered you asked me for help instead of Krista. Let's figure it out."- Williams, 4/30, period 4
Teacher problem solves with students.	"Shessid, this is going to be an amazing light up shoe."- Williams, 4/30, period 3
Distilled Theme: Student Engagement - Observed in treatment more often.	
Students' identity leads to affinity with projects or work.	"Why are you so good at sewing?"- white student. "Because we are Mexicans!"- Aldo, 4/30, period 4
Students share personal stories or aspects of the work.	"I like doing electricity. It's fun. I like learning to sew more better." -Francisco, 4/30, period 6 "I was sewing on the bus going home yesterday." -Lila, 4/30, period
Distilled Theme: Student Driven Discourse and Learning. - Observed in treatment more often.	
Students ask questions for clarification of content.	"Can we start work?" Paulo, 4/30, period 4

Initial Themes	Exemplar From the Data
	"My mom is so proud of me." -Manuel, 4/30, period 4
Students ask non-content, task-oriented questions.	"Does my work look good, Mr. Williams?"- Issabella, 4/30, period 4
Students ask questions to problems solve activity	"I need your help, Mr. Williams." Edward, 4/30, period 4
Students ask questions about access to more time for working on class assignments.	"Mr Williams, it lit up but it is dim."- Shessid, 4/30, period 3

Shifts in Mr. Williams' teaching were observed during the e-textiles unit, though he did not initially notice or recognize these shifts. For example, the nature of the classroom discourse he engaged in shifted when he taught e-textiles based lessons. Classroom observations and review of video found shifts in questioning techniques and opportunities for student conversation.

In control classrooms, for example, Mr. Williams tended to ask more direct questions that required students to produce a definite right or wrong answer. However, in treatment classrooms, his questions rapidly became more open, asking students for explanations or justifications of their thinking. Mr. Williams, when presented with evidence of the shift in classroom discourse, initially stated that it was the project-based learning opportunities afforded him and the students that led to the changes in classroom discourse. However, when this assertion was challenged, because the control groups also had project-based learning opportunities designed to be content-equivalent, Mr. Williams asked, "Well then, why did I ask and answer more questions with those kids?"

Teacher engagement with students. Across treatment and control conditions, Mr. Williams used several different mechanisms to engage with his students. Broadly speaking, he engaged with both groups over content, with comments such as "Remind us what a resistor does." These comments were coded as having a high focus on content topics or knowledge transmission. However, with treatment groups, a noticeable difference in the tenor and type of conversations occurred.

While Mr. Williams engaged with students over content, he also spent a larger proportion of his time talking about social or outside-of-school issues with his e-textiles students. At times, those questions pertained to the projects at hand, but most often they did not. These conversations occurred during sewing and construction time, when students were engaged in the project but no discrete content lecture was occurring.

He was also observed being more complimentary and encouraging of students when they were working on their e-textiles projects than with students working on traditional circuit projects. As he said to one student, "I cannot compliment you enough!"

Further evidence of his engagement with students was observed in his positionality in the classroom. During e-textiles instruction, he was more often seen at student desks looking over projects with them. In control classes, he was more often observed at his teacher table. Given these observations, we can reasonably assert that more positive and engaging interactions occurred between the teacher and students in the treatment classes than in the control classes.

Teacher questioning strategies. As is typical in many classrooms, Mr. Williams used questions to assess student understanding of content. This questioning occurred in treatment and control classes equally. However, the discourse in the treatment classrooms also contained many more questions from Mr. Williams to students that were based on student-initiated questions or concerns. Consequently, he engaged in much more answering of students' individual questions during e-textiles instruction.

While Mr. William's general frequency of questioning and directing remained fairly consistent across the 4 weeks in the control group classrooms, a steady decrease in the number of teacher-driven questions and specific direction to the treatment groups were observed, with little during the last week when compared to the first. This result could be explained by the fact that for much of the last 2 weeks of the unit the treatment group classrooms were highly engaged in the e-textiles activities, and their classroom activities were more student led.

Furthermore, as classes proceeded in their units of study, Mr. Williams relied more on peer talk or pair-and-share in his treatment classes. For example, in checking comprehension around resistors, he stated, "Talk among yourselves and resolve your disagreements between answers." This statement shifted the discourse from teacher-led to student-led and proved powerful with student responses, which appeared both more detailed and longer.

At another point, Mr. Williams noted that he did not see an immediate solution to a student's challenge and suggested she "should ask a friend to help [her] solve it." This ceding of the authoritative role of knowledge giver was only observed in the treatment classes.

Independent student engagement and identity. Perhaps the most noteworthy shift between treatment and control was the level of student engagement. Students designing and building e-textiles projects were, by both teacher report and observation, more deeply invested in their projects and engaged in the class content. While it makes intuitive sense that students allowed to design projects of their own creation would be more engaged, the student engagement was not constrained narrowly to project construction. Students were also observed to be more engaged and asking more questions during conversations about science content.

Within the e-textiles classes, students asked more questions of their teacher and worked more collaboratively with each other to solve problems. The students asked many questions about short circuits in their projects, and they also asked questions about how the science could impact the design and options for their work. Additionally, several students articulated personal association with the work and the content.

One student, Francisco, who had been identified by Mr. Williams as someone who did not enjoy science class stated that he “like[d] doing electricity” and was gaining confidence in sewing. While engaging in the project activities, students expressed ways that they felt crafting connected with their heritage. Another student of Mexican heritage joked that some of the students were good at sewing because of that heritage. Consistently across the e-textiles unit, students appeared engaged, asked more questions, and articulated their own empowerment toward driving this learning experience.

Discussion

The findings presented in this article illustrate the potential affordances maker technologies can offer to act as fulcra for instructional change within standards-driven classrooms. While most research into maker technologies has focused on out-of-school spaces (e.g., Sheridan, Halverson, Litts, Brahms, Jacobs-Priebe, & Owens, 2014), the current study offers an example of shifts in classroom teacher instruction and discourse associated with teaching through maker technologies.

The emergent discursive shifts over the course of the e-textiles unit notably stood in contrast to the more traditional, authoritative discourse Mr. Williams maintained over the same time period for conventional project-based activities. Further, the shifts were not narrowly constrained to pedagogical engagement. With student freedom to customize design features in personally meaningful ways during e-textiles work, the teacher’s interactions with them seemed to follow suit and broaden to engage their personal lives beyond course content. Thus, a reciprocal engagement occurred, where students were empowered to make connections between course content and their personal identities. Mr. Williams was likewise encouraged to broaden the scope of his engagement with his students and provide more latitude for them to act as peer authorities during problem solving with challenging content.

Particularly noteworthy is that Mr. Williams’ perceptions of his ELL students’ engagement shifted over the course of the e-textiles unit. Not only did their test scores not systematically differ from their English-proficient peers in contrast to his previous experiences, but Mr. Williams’ discursive shifts seemed to facilitate productive engagement around course content that was recognized by both him and the students. As with the broader shifts in teaching approach that led to significantly higher RTOP scores reflecting increased overall student autonomy, these students were apparently better able both to see themselves as productive contributors and to be seen as such.

While the findings reported here are promising, limitations inherent to the current design warrant further research. First, the case study design permitted a deeper exploration within a single context, yet it cannot inform questions regarding the generalizability of the findings. Similarly, the collection of data during a single curricular unit within a single academic year does not permit exploration of the extent to which observed differences might be sustained beyond the end of the unit or the role that cohort-specific effects might play.

A chasm of disconnect often exists between the worlds of informal maker spaces and real-world classroom content instruction. On one side, maker space technologies, touted as innovative and dynamic ways to engage learners' enthusiasm, provide students with complex problems surrounding design and function. Such projects, seemingly ideal for addressing the multifaceted and deep level goals of the new *Next Generation Science Standards* (2020), frequently fail to make their way into the classrooms. On the other side, the open-ended and personalizable projects associated with such activities may appear disconnected from the day-to-day constraints of classroom practice.

Our research suggests that the gap between promise and practicality may be more one of perception than of reality. Further, preservation of this dichotomous framing may hinder valuable opportunities for teachers to shift their discursive practices in ways supported by the affordances of making projects and materials.

Acknowledgments

The work reported herein was supported National Science Foundation Grant No. 1542801. The findings and opinions expressed in this report do not reflect the position or policies of the National Science Foundation.

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