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BRINGING INVENTION EDUCATION INTO MIDDLE SCHOOL SCIENCE CLASSROOMS: A CASE STUDY

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This paper reports an exploratory case study on broadening youth participation in invention education by supporting teachers' efforts to bring invention education into middle school science classrooms. Invention education has been suggested to be highly promising for engaging and empowering youth in science, technology, engineering, and mathematics (STEM) learning; sustaining their interest; and preparing them to become future inventors and innovators. Students who are diverse by race, ethnicity, and gender, however, have traditionally been under-represented among STEM degree holders, which is ultimately reflected in who patents technological inventions. The integration of invention education into STEM coursework in students' early years and across their years of schooling may be an effective approach for creating greater diversity among STEM graduates and patent holders in the U.S. Few studies, however, are available to inform understandings of this approach to teaching and learning. Greater insights are needed in effective approaches to teaching young people to think and work as inventors, the design and development of invention education curriculum, and the unique design considerations needed when developing invention curriculum for science classes offered during the regular school day. This study contributes to the literature by analyzing one teacher's experiences with modifying and implementing a widely-used afterschool invention curriculum called Junior Varsity (JV) InvenTeams Chill Out! for 7th grade science classes. The teacher in this study cited his ability to present information through multiple channels, enrich students' understanding, and produce excitement in classrooms as examples of the benefits of invention education. The study also makes visible the challenges he encountered during implementation of the curriculum, including encouraging students' creativity, classroom management, and covering the mandated standards. Findings from this study can inform the design of invention curriculum and teacher professional development programs that aim to promote invention education in middle school.

Key words: Middle school science; Invention education; In-service science teachers; JV InvenTeams

INTRODUCTION

There has been a longstanding inequity issue in the science, technology, engineering, and mathematics (STEM) innovation workforce in the U.S.: Women represent only 12% of U.S. innovators, while minorities represent 8% of U.S.-born innovators (1-4). Research has suggested that the under-representation may be related to factors such as family, community, and neighborhood. White men from high-income families are more likely to receive patents and become innovators than the average person in the population (1). People who were exposed to

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innovation through family, neighborhood, and environment during childhood are more likely to innovate than those who were not (1). Innovation, the attempt to move the first occurrence of an invention into practice (5), has been viewed as a central driving force of economic growth (6,7). Since minorities will continue to comprise a large proportion of the U.S. population rise—with nearly 40% of the population projected to be Black or Latino by 2060 (8)—it is imperative to provide opportunities for all youth to engage in technological invention activities that prepare them to ultimately become innovators.

One promising approach to mitigate the inequity is to bring invention education into schools — in particular, middle schools — because the middle school years are an important time in forming students' attitudes toward STEM, and exposure to invention activities could potentially influence their future career interest in STEM innovation. Integrating invention education with science coursework can ensure that all students are exposed to invention learning activities in their early adolescence because science classes are mandatory for middle school students. Opportunities for learning to invent, however, remain scarce in middle school despite the potential benefits to students and efforts by program providers to support such opportunities in formal and informal learning environments. More research is needed to understand barriers that are inhibiting broader implementation and how to prepare and encourage teachers to adopt invention education in their classrooms. This paper reports findings from an exploratory study where 7th grade physical science students learned heat transfer with a hands-on, project-based invention curriculum. Over 300 students from the same school district in the northeastern region of the U.S. spent three weeks learning invention, science, and engineering concepts through a modified version of Junior Varsity (JV) InvenTeams Chill Out! curriculum. The Chill Out! curriculum was originally developed for out-of-school time implementation by the Lemelson-MIT (LMIT) Program, a sponsored program in the School of Engineering at MIT. Students learned heat transfer and applied their understanding to invent lunchboxes in the Chill Out! unit. The invention activity extended understanding of the STEM concepts by allowing students to invent solutions to everyday issues associated with heating and cooling.

The purpose of this study is to investigate the challenges teachers faced during the classroom enactment of the Chill Out! unit. We employed a case study methodology (9,10), illuminating the case of one representative teacher (Mr. T) and his experience of implementing the Chill Out! unit in his four science classes with a student population diverse by race, ethnicity, and gender. To make the unit more accessible and relevant to students from under-represented populations (e.g., English learners), we modified the curriculum by adding visual representations to explain jargon and reducing the reading load (note that a detailed description of the curriculum customizations can be found in another paper in this special issue, entitled "Culturally Relevant Science: Incorporating Visualizations and Home Culture in an Invention Science Curriculum").

We chose to focus on Mr. T's experience because he attended eight hours of professional development with the other 7th grade teachers implementing the in-school invention education curriculum and because of his knowledge of physical science, which we perceived as a strength that would support the classroom implementation. The professional development, co-led by the researchers and LMIT staff, featured an introduction to invention education and an overview of the curriculum with suggestions for implementation tactics and hands-on activities. Printed curriculum guides and all hands-on materials were provided by the research team during the early fall of a new school year. Mr. T organized the materials in preparation for implementation in late fall. Two researchers observed classroom enactments, collected invention artifacts, conducted interviews before and after the implementation, and organized debriefing meetings with Mr. T periodically throughout the classroom run. The research questions addressed were:

- What were Mr. T's perceptions of the benefits and challenges with regard to teaching invention in his middle school science classes?
- What modifications, if any, did Mr. T make to the invention curriculum as he implemented the curriculum in his middle school science classes?

- How did Mr. T's initial experiences as an invention educator and science teacher influence Mr. T's thinking about his own teaching practices?

RATIONALE

Potential Benefits and Challenges of Invention Education

Invention education is a novel approach to active learning through interdisciplinary thinking in educational settings. It encompasses the critical components of both scientific inquiry and engineering design processes (e.g., formulating a hypothesis, experimenting, designing, and iterating) and yet differs from them, largely in how youth identify the problem they are solving and what they do once the problem is solved (11). Invention education typically features an open-ended problem discovery phase at the beginning of a project to foster the development of the mindset of inventors who see the world as problems waiting for solutions and then select a problem that they are passionate about. The young inventors identify a problem, formulate solutions, iteratively design the solutions, and build prototypes while keeping the user's/beneficiary's/customer's need central to their decision-making. They apply their skills, knowledge, and understanding of the problem as they consider the next invention problem.

Learning approaches centered around creative, project-based activities, though not necessarily invention education, have proliferated with the maker movement and due to the compatability of project-based learning (PBL) with the Next Generation Science Standards. The maker movement has yielded numerous maker spaces and labs in museums, libraries, universities, and schools, reflecting increased interest among educators and students in using familiar materials to deconstruct, reconstruct, and innovate (12,13). A wealth of research on PBL has suggested theoretical foundations for this approach to teaching and learning, which we drew on as we conceptualized the potential benefits of invention education. First, the strong emphasis on hands-on activities can lower the barrier to participation, making invention projects highly accessible to all students, especially those who are of low academic levels (14). Second, solving problems from everyday lives can be highly appealing to students who are turned off by traditional paradigms of formal science education (15). These youth often view the practices performed in science classrooms as too far away from those conducted in their families and communities. Invention enables them to witness the close relationship between STEM and their lives, actively sparking creativity and interest. Third, invention projects typically are interdisciplinary in nature, providing ample entry points and solution paths for students with different expertise (16,17), promoting collaboration, and reinforcing integrated STEM learning (18).

Despite the increasing prevalence of making and PBL among educators, there still exists an unequal representation of females participating in invention activities, as evidenced by one national grants initiative for high school inventors. Participation data over the past ten years from the Lemelson-MIT InvenTeams grants initiative indicate that 35% of the students are female and 65% are male (n = 2,403), even with the initiative's continuous efforts to promote invention education among female students. A research study with InvenTeams students found that factors discouraging female students' participation in the invention experience included stereotypes of inventors, high time commitments, and a lack of prior knowledge, exposure, understanding, and engagement in invention (19). More strategies and efforts are needed to promote invention education among all youth.

Integrating Invention Education with STEM Coursework

In this study, we brought invention education into the school day to promote invention education and broaden participation. Embedding invention in school coursework, e.g., science and technology classes, offers the largest possible audience and provides early access to students who have been traditionally under-represented in STEM and invention, thus precluding them from innovation—the driving force of economic development. Inclusion in the school day also directly addresses the issue of students self-selecting into or out of the STEM learning experiences necessary for invention in out-of-school settings (20,21). Further, this is consistent with recent economic findings that an early exposure to invention and innovation is critical to including these activities in students' adulthood and careers (1).

Getting schools to offer invention education within the school day, however, is not easy. The literature on implementing PBL learning in classrooms has suggested many challenges teachers face when teaching such projects in classrooms, including shifts to a constructivist approach to adopt student-centered instructional strategies, classroom management issues, the creation of different types of assessments, and support for student collaboration (22-24). Teachers need to transition from traditional instructional methods centered around knowledge transmission towards the student-centered, constructivist approach. They need to tolerate the ambiguity and flexibility of the dynamic student-centered learning environment, recognize and accept the shift of their role from a lecturer to a facilitator, and promote student-driven inquiry and learning.

Besides the challenges inherent in PBL noted above, teachers often are faced with a dearth of both invention curriculum for in-school settings and effective instructional practices. The field of invention education is relatively young, and there are not many invention curricula available in the U.S. One notable exception is the JV InvenTeams curriculum developed by the LMIT Program and piloted in 2014. As previously mentioned, this invention curriculum was designed to be implemented in out-of-school time learning spaces. Invention activities often require more time than is available during the school day and may not align with the school district's mandated standards. To successfully integrate invention education into school coursework, teachers need to select an invention curriculum that is aligned with the district curriculum standards and modify it for their diverse student population; adjust their own teaching methods; and perhaps even change their teaching beliefs. It is due to these myriad of obstacles that invention education in schools has been relatively underexplored.

This study aims to fill in this important gap by investigating the challenges in-service teachers faced during the implementation of the aforementioned JV InvenTeams curriculum in their classes. Four 7th grade science teachers revised and implemented one JV InvenTeams curriculum called Chill Out! in their classes. The research explores how the teachers' ways of thinking of and teaching with invention curriculum changed and what factors supported and constrained the classroom implementation. The findings reveal teachers' perceptions of invention education and offer insights into the design of invention curriculum and professional development programs to better fit the needs of middle school science teachers to broaden students' participation in invention education.

CHILL OUT! CURRICULAR UNIT

The Chill Out! unit used in this study was developed based on the JV InvenTeams activity guides developed by the LMIT Program. Built upon the program's fifteen years of experience of supporting the work of young inventors, the JV InvenTeams unit guides were intentionally designed to support the acquisition of STEM knowledge, skills, and mindsets that are crucial to preparing young people to begin their work as inventors. LMIT has provided support, including professional development, to 148 groups of middle and high school students since 2015. The guides have engaged over 2,000 students and 148 educators to develop confidence in their hands-on technical skills and minds-on STEM knowledge while considering inventing solutions to real-world problems. The JV InvenTeams guides were designed to provide experience for middle school and early high school students to invent solutions and hence build their confidence to carry out more open-ended inventing efforts in their upper high school years and beyond. Three of the JV InvenTeams student groups progressed to the competitive level of receiving an InvenTeams grant. This was through a national grant initiative known as InvenTeams that LMIT has offered for 15 years in which high school students identify problems in their local communities and receive $10,000 to conceptualize, design, build, and test working prototypes of a technological solution to their problem. Eight of the 243 InvenTeams have received U.S. patents.

While JV InvenTeams guides have been popular and successful among youth and educators, they had previously been used in out-of-school settings. The teacher in this study, Mr. T, was one of four teachers who worked together to modify the Chill Out! unit by prioritizing the contents and activities that aligned well with their district's curriculum standards (see Table 1). The modifications made it more suitable for inclusion in the middle school science classes. In total, the teachers planned to spend 10 days (two school weeks) on the Chill Out! unit. Their modifications included:

- an emphasis on the science concepts involved in the unit, e.g., heat transfer, thermal energy, insulation, conduction, convection, and radiation;
- less focus on the invention extension activities. In the original curriculum, students are expected to spend at least two hours on brainstorming how the newly acquired knowledge and skills can be applied to other every day examples, using the SCAMPER brainstorming technique (25,26) and completing an invention worksheet that required students to think about the invention plan and beneficiaries. The modified version only engaged students in brainstorming new invention problems as time permitted;
- a simplified invention challenge at the end of the unit where students would convert self-sourced shoeboxes into lunchboxes. This removed much of the hands-on skill building of how to create lunchboxes; and
- added homework activities to engage all students, especially students from diverse cultural backgrounds.

Mr. T spent three weeks on this Chill Out! unit and added activities and formative assessments based on students' feedback and responses, e.g., instructions on how to work with team members and how to respond to peers' criticisms (detailed information can be found in the "Mr. T's Invention Education Curriculum Modifications" section). All the invention education activities planned and listed in Table 1 were taught in the same sequence during his implementation.

METHOD

Research Design

A case study methodology (9,10) was used to investigate the research questions. The case study method was especially beneficial given the purpose of this exploratory research and the small sample size involved in this study. We conducted semi-structured pre- and post-interviews with Mr. T, soliciting his opinions on the invention curriculum before and after the classroom implementation and held five debriefing conversations with him to capture the real-time changes and adjustments during the implementation. Through the reconstruction and analysis of the opportunities for learning enacted in the classroom, we aimed to make visible one teacher's views of the modified invention curriculum, his perceptions of the challenges and benefits of implementing the curriculum in a middle school science course, and the ways his experiences with teaching the curriculum have impacted his own views of teaching.

Participants

This research project, as noted above, began with a purposeful sample of four teachers for the exploration of the research questions. The criteria for selection of the teachers included the following: 1) teachers who had no prior experience of implementing an invention curriculum in classrooms, 2) teachers who were willing to participate in the study and devote extra time to the modification and preparation of the implementation, and 3) teachers of students with diverse backgrounds. Teachers received a stipend for their participation. In this paper, we reported findings from one teacher, Mr. T, a veteran teacher in the school district, because of his strong background in physical science. He is a white teacher of 7th grade science in a public school in the northeastern region of the U.S. He has taught middle school science for seven years and had no experience of teaching an invention curriculum or other PBL projects. The classes he taught were medium in size, ranging between twenty to twenty-six students. His school has a diverse student population, with 24.2% of students being English language learners and 46.1% coming from minority groups.

Table 1. Revised Activities for Students to Perform during *Chill Out!* in 50-minute Classes

	Theme	Activities
Day 1	Invention introduction	• Complete invention warm-up activities, Grab Bag Inventing, and Cell Phone Stand Design Challenge • Play "Four Corners" game to help students form teams where the members have diverse experience • Ask students to bring shoeboxes to school for the later invention project
Day 2-3	Explore science concepts of heat, heat transfer, convection, conduction, and radiation	• Complete hands-on labs that aim to teach convection, conduction, and radiation • Discuss problem solving and invention in the context of food safety and transportation
Day 4-5	Explore science concepts of insulation, insulator, conductor, and biomimicry	• Explore the thermal properties of various materials • Explore how the blubber of Emperor penguins minimizes the amount of heat loss to cool ocean water • Hands-on lab that teaches insulators
Day 6-8	Design work: build a lunchbox using shoeboxes	• Design, build, test, and revise a lunchbox using shoeboxes that will keep cold food from warming up and warm food from cooling down
Day 9	Remove heat using Peltier tiles	• Learn about evaporation, evaporative cooling, and thermoelectric effect • Experiment with Peltier tiles • Build a Peltier cooling unit that is made of a Peltier tile sandwiched between two heat sink fans
Day 10	Peltier prototyping and invention extension	• Brainstorm ways they might use Peltier tiles in their inventions of lunchboxes • Design and add a Peltier cooling unit to the lunchbox invention, test out their lunchboxes, and provide feedback to other teams • Extend the invention experience to other everyday examples

Data Collection

We conducted semi-structured interviews with Mr. T before and after the implementation of the Chill Out! unit. The interviews lasted approximately 20 minutes and were conducted during school hours. The interviews were recorded and transcribed for data analysis. The interview protocol was pilot tested prior to data collection.

The pre-interview questions focused on eliciting Mr. T's prior teaching experiences, practices, and views about invention education through a series of questions: 1) How did you teach heat transfer previously? 2) Have you used invention curriculum, project-based learning, or design projects in your teaching before? and 3) How do you think the Chill Out! unit is different from your regular curriculum? What do you think are the potential benefits? What learning and teaching difficulties might teachers and students face? The post-interview questions aimed to engage Mr. T in reflecting on the implementation, by asking: 1) What do you think students have learned? 2) What are the benefits of invention education compared to the traditional curriculum? and 3) What challenges or difficulties did your students or you meet during this classroom run?

In addition, we conducted debriefing meetings with Mr. T once every three days, documenting his thoughts and changes made to the curriculum during the implementation. All debriefings included the same four questions: "What worked? What didn't work? What modifications did you make? What modifications do you plan to make for the next run?" In total, Mr. T spent 17 instructional days on the Chill Out! unit. We held five debriefing meetings with him, all of which were recorded and transcribed to capture what happened during the implementation. The interviews, debriefings, and field notes constituted the corpus of data used in our analysis.

Data Analysis

Analysis of the data followed a constant comparative method (27). The inductive process of data analysis started with the researcher gathering information through open-ended questions and field-notes. These were put into themes and categories that became broader through analysis (28). Specifically, to answer the first research question on teachers' views of the invention curriculum, we combined Mr. T's responses to the interview questions before and after the implementation. The second research question on Mr. T's modifications to the invention curriculum was addressed by analyzing his responses to the debrief-ing questions on the changes he made and planned to make. The analysis of the third research question on the impact on Mr. T's views of his teaching prac-tices focused on his reflection after the classroom implementation.

RESULTS AND DISCUSSIONS

Overall Implementation Results

Mr. T implemented the Chill Out! unit in his classrooms for 17 days. During interviews with Mr. T, he described his experience as a success. Like many teachers, Mr. T defined success in terms of his students' behaviors and activities (35). In the post-interview, he mentioned that his students not only reached all the learning goals he established on science concepts of heat transfer but also developed a deep understanding of relevant ancillary concepts, including invention and biomimicry through the hands-on application of skills and knowledge, as was evident in the final invention project—a lunchbox. In particular, Mr. T felt that all the hands-on activities allowed the students to recognize the failure of their misconceptions, providing opportunities for him to help correct the wrong ideas: "I think it was easier for them to see some of their misconceptions when something didn't or did work as long as there was someone there to explain why the material used wasn't as effective or was expected."

Mr. T also noted the high engagement and enthusiasm of students, saying, "They were excited to see how they did. And they were listening intently to why things worked or why things didn't.... And they were pretty receptive to the lunchbox building assignment. They were excited to see who won [the invention competition] and were looking forward to doing it again even though we told them, already, that we were only gonna do one building assignment." Some of his students spent their spare time on the lunchbox invention project: "I was happy to hear that some of them took their project home and wanted to do a good job on it. This one, for example, is a picture [see Figure 1] of one student's final project. She put a lot of time on it. She had the project drawn over the weekend when I said it was optional for you to do extra work. She was really excited to get it completed."

Views of Teaching with Invention Curriculum in Science Classrooms

Mr. T described himself as a typical science teacher who liked using visualizations, simulations, and explanations in his teaching. When teaching heat transfer, he would start with direct instructions on the vocabulary or terminology of heat transfer and then conduct demonstrations of the concept to arouse students' interest. Afterwards, he would engage students in laboratory explorations of various heat transfer phenomena and have them explain their observations. He described his teaching method this way:

> When I teach heat transfer, I usually start with some amount of direct instruction. I like to have them have the vocabulary words a little bit ahead of time. Sometimes I'll start with a demonstration and ask for them to come up with some type of explanation that talks about why heat would be transferred from one place to another... It [the demonstration] would depend. Sometimes it's like

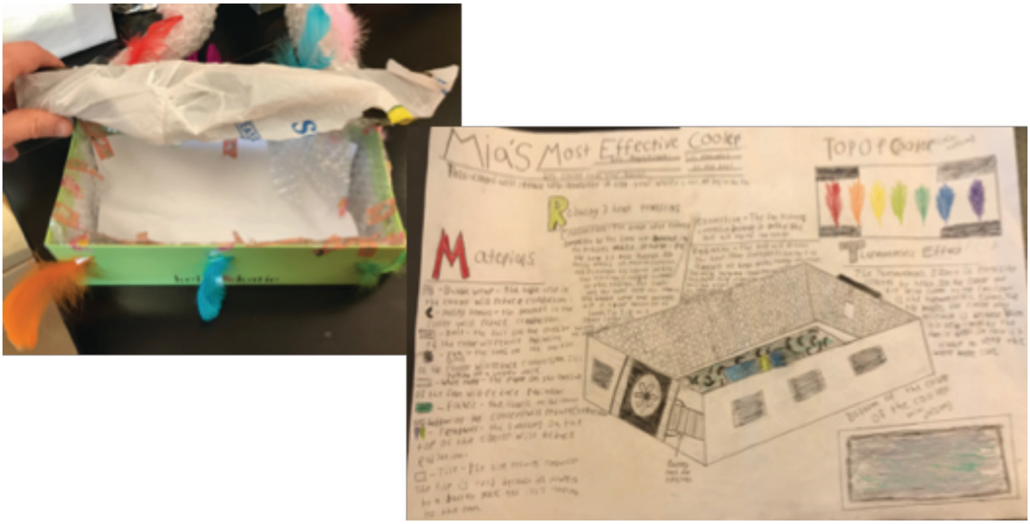

Figure 1. One student's lunchbox invention and her poster.

> just putting their hand on the table and asking, 'Why does the table feel cool? What's actually happening?' Where other times, I'll show them a demonstration at the front of the room of the movement of fluids inside of like a big clear container. In the movement of the fluid going up and going down, they can kind of see why is it doing that. What's going on. They have to do a little bit of thinking. Usually, from there, is when I'll do vocabulary, and then we'll take them over to the lab stations and start doing some of the actual exploratory stuff for heat transfer.

He would try to engage students in scientific inquiry and scaffolded knowledge building activities to develop a deep understanding of the science concept. Mr. T indicated that he typically does not include much hands-on design and no invention activities in the teaching. His students may discuss the application of the science concepts but are not engaged in design or construction work. He explained, "We talk about why things happen the way that they saw, not so much the actual application of those things in building."

Mr. T expressed excitement about the invention curriculum and indicated a belief that invention education would benefit students more than traditional science curriculum. His responses to the pre- and post-interview questions revealed his perceptions of three types of strengths that he associated with the invention curriculum:

1. Presenting information through various channels to foster a richer understanding of the concept, e.g., explanation of the science concepts, laboratory exploration, application through construction, etc. Mr. T indicated that this would be especially beneficial to students who have difficulties in reading and learning with traditional class materials since "[the] information is presented in a bunch of different ways. I think it's more supportive for students that maybe direct instruction is a little bit challenging for them or just focusing class materials is more confusing."
2. Engaging students in applying their ideas through invention. Mr. T indicated that this would require students to integrate the science with existing knowledge and apply their ideas in an invention. The higher order thinking and application skills involved in the task would engage students who are of higher academic levels and who may become bored with traditional classes. Mr. T elaborated, "Also, there's definitely a little bit of students using their own ideas and applying concepts than just kind of exploring and kind of thinking about or analyzing the

situation. That extra step, I think, would be good for some of our higher-level learners."

3. Enriched information on the science concepts. The Chill Out! unit was designed to foster the development of minds-on and hands-on skills that support invention. It included not only explanations of the science concepts underlying the invention of lunchboxes that both maintain heat and cool but also information on related concepts, such as biomimicry and thermoelectricity. Mr. T indicated that the information would enrich the curriculum content and engage students who may be interested in the relevant information.

Besides these potential benefits, Mr. T expressed five reservations about introducing invention education in science classrooms based on his experience. These reservations were:

1. A lack of effective teaching strategies to spark students' creativity. He stated that most middle school aged students are used to the traditional didactic instruction where they are passive receivers of knowledge. They probably do not have much prior design or invention experiences and may not be able to devise solution ideas or realize the solution through construction. Mr. T witnessed that some students needed to search online for inspirations of drawings and worried that students might not be able to come up with their own ideas. He said, "I think for some, I don't think they're used to coming up with ideas on their own. A lot of times, we tell them, 'I just want you to draw something,' Kids are looking to use their computers for a picture of something. They come up with the idea maybe, but they're not actually trying to do it all themselves, so I'm a little bit nervous that creativity might challenge some a little…. I know it's exciting for them, but ... it could be a little bit scary."
2. Managing students working at different paces. Invention education would engage youth in creating their own inventions, which inevitably would lead to students working at different paces. Mr. T indicated that this would be a challenge to any classroom teachers who are working with over 20 students simultaneously. He observed, "I'm a little bit nervous they're [students are] going to get done really fast, while other students may take a longer period of time to get completed. If they're just sitting around and kind of not doing anything, I'm a little bit nervous that there's not going to be ... there's going to be some lag time between different student abilities."
3. Managing students of different reading ability. The Chill Out! unit, originally designed with out-of-school education and students at various levels (ranging from grades 6 to 10) in mind, included detailed descriptions of lots of information. Mr. T deleted many readings in his preparation for implementing the curriculum in his class. He, however, expressed concern that, even after these changes, the heavy reading load would pose great challenges to his students and his teaching, as there were English language learners in almost all of Mr. T's classes. The differences in reading ability could result in difficulties in classroom management. He noted, "When I was looking through it, I think there's quite a few words. It's a little bit overwhelming.... I'm not sure sometimes they are students who struggle because the material's too challenging for them, and other times I think it is some type of language barrier, where they just may not be able to access the curriculum as quickly as other students around them."
4. Balancing between providing scaffolded instruction and allowing for open-ended invention work to sustain students' interest and freedom. Mr. T expressed concerns related to how to best scaffold student inventing and learning through explicit and direct instructions. Finding a balance between prioritizing what is important to students and providing just enough support would be critical to ensure the success of invention education. Mr. T envisioned the problem before implementation of the curriculum in his class and had planned some solutions. He said, "I might ask how they can improve instead of telling them how to improve. For certain students, it's a really easy fix where you just kind of say, 'What would you do if for example, the cell phone stands [an invention warm-up design activity], what would you do if the speakers

weren't loud enough? What could you add to your cell phone stand that would be better?' … That direction, I don't think, really cheats the system. It helps them while still gives them a chance to be creative, just kind of points them in a new direction, says, 'What can we add onto this to make it better?'" Instead of providing direct instructions on improving their inventions, Mr. T planned to ask questions to prompt students to recognize the flaws in their designs and engage in autonomous iterative refinement of their inventions.

5. Tension between covering standards and spending more time to promote deeper learning. One challenge Mr. T encountered was that invention projects typically take more time than regular curriculum. As mentioned earlier, he ended up spending 17 days (three and a half weeks) instead of the planned 10 days on the Chill Out! unit. Although he was excited about the results and planned to continue with the unit during the next school year, he acknowledged this challenge of brining invention into classrooms: "In terms of hitting the standards, I think it really only addressed maybe one, one and a half, two at most of what we were doing in class. I don't think we could do this for every single one, it would take too much time, however, it would be a really good idea to continue to do something like this because I think the kids really enjoyed hands-on work."

Mr. T's statements reflected a positive attitude toward invention education yet also raised some concerns. Three of his five reservations addressed the requirement for teachers to shift from the traditional way of delivering knowledge toward student-centered teaching, i.e., believing in, facilitating, and promoting student-driven learning in invention. One reservation focused on curriculum optimization for all learners. The final reservation related to Mr. T's requirement to meet the district's curriculum goals. The need to meet district curriculum goals presents a challenge for the implementation of invention education in the regular school day.

Mr. T's Invention Education Curriculum Modifications

Besides the modifications the teachers collectively made in the planning phase of the project, Mr. T made additional changes throughout the implementation. We analyzed data, classroom observations, and debriefing meetings, and we categorized the modifications. These modifications are described below.

Modifications to Existing Activities to Make Invention More Accessible

A majority of the modifications focused on the curricular activities in the guide spoke to a need, according to Mr. T, for the guides to be more relevant for these middle school aged youth with diverse backgrounds and varied levels of English. For instance, Mr. T modified one activity that provided a list of problems that the students could design solutions for. Instead, Mr. T asked students to create a pool of problems in the classroom and then they voted on the problem that they wanted to work on. His students identified and chose the problem that many students do not bring pencils to school. As he explained, "We skipped the portion of the [activity], but I asked them to find and solve a specific problem for me, and think pair share back to me. The specific problem they all chose was that students don't bring pencils to class, what would you design so that students would bring pencils?"

Mr. T's students devised various solutions and shared them with the whole class, indicating high interest and enthusiasm in their invention problem:

> We had everything from crazy magnetic strips that would always keep the pencils in the classroom to sirens if the pencils left, to kids that wanted to put Alexa, the little sound thing back….that Amazon thing in their locker and it would set a reminder that would say "Hey, did you take a pencil today?", and you would have to say yes and take one off of the duct taped wall, or something. They said the taped wall with the pencils stuck to it. And we had kids that just said write a name on it, and other kids that are saying put it in your pocket. So those are the responses, and I thought that that was a pretty good idea.

Afterwards, the whole classes critiqued the feasibility of the solutions, which enabled students to recognize and understand constraints of invention:

> We did go into one of the details to talk about different solutions they have…. like some of these inventions are really good ideas but they may not be really feasible. But other inventions are would be a little bit too obvious and maybe wouldn't be all that effective. ….. I think this is more beneficial [than the activity] as these are their [students'] own problems and ideas.

As researchers and as the program developers (both the guides and the professional development), we interpret Mr. T's modifications as being beneficial in multiple ways. First, the modifications provided students with the freedom to identify their own invention problems and supported the development of a sense of ownership of the invention. Second, the process of finding problems and choosing one to work on is consistent with the work of inventors in the real world, where they work on problems they select and that they are passionate about. Third, choosing a problem that students are familiar with and have experience with can help develop empathy and ownership of a problem, two crucial aspects to ensure the success of inventive work (29-31).

New Activities to Foster the Development of Relevant Invention Skills

Besides adapting existing activities in Chill Out! to better engage students, Mr. T created new activities to embrace the learning of relevant skills and knowledge. Such activities were often developed instantaneously, driven by the implementation results of previous curricular activities. For instance, upon the completion of one invention activity, Mr. T realized that many of his students did not know how to present or critique their inventions. They were not receptive to other's criticism and did not know what to do. He designed an activity where students were required to present to other groups and provide feedback to other groups' inventions. He provided instructions on how to present (e.g., being nice) or critique. As he described:

> So I put all of their inventions out on the desks over here. They had to walk around, and they had to choose one that they wanted to present for. From that they had to provide a glow and a grow, or a positive and negative. They had to present. I said you have to present something and you have to be nice because other people are going to present yours, and why would this [presentation] be important when you're inventing. Some of the kids got kind of the purpose there, so what things could improve, I think really met some of these questions and inventions, and a lot of times, kids had pretty good ideas as to 'mine had this, and maybe this one didn't,' how could they improve upon that portion?

He also instructed students on why being receptive to others' criticism is important, how to deal with criticism, and how to collaborate with other team members during inventing:

> I was talking about accepting other people's ideas, and how it doesn't always feel good when someone criticizes your work and you have an explanation for it, but it's an important part of working in groups. I thought that was something that's really important after I heard a lot of the kids in some of the classes who would ask me, 'Hey, I just wanna do my own. My group doesn't want to do what I wanna do.' And I was like, well, why. You need to work with and stuff.

Such modifications were developed in real time based on the results of previous activities. This modification fostered the development of important 21st century skills, such as presentation and collaboration, that are critical to invention.

Reuse of Existing Teaching Materials

Our observation demonstrated that Mr. T customized and repurposed his existing teaching materials for use with the new curriculum instead of relying solely on the new guide. One modification Mr. T made was to convert the lab explorations on heat transfer in the Chill Out! unit into live demonstrations. The students first investigated conduction, radiation, and convection using labs activities previously designed by Mr. T, which were different from the activities in the Chill Out! unit. Then Mr. T conducted the labs in the Chill Out! unit as whole-class demonstrations and asked his students to observe and discuss the differences between the labs and the demonstrations. At the end of the activity, students wrote reflection notes in their scientific notebooks, summarizing the key science concepts addressed in the labs and demonstrations.

This finding is consistent with the literature on how teachers adopt new curricular materials. Integrating the existing materials into the new curriculum may have contributed to Mr. T's confidence in the curriculum and may have aided his perceived value of both. Moreover, his confidence and valuing of the revised curriculum may have supported his adoption and use of the invention curriculum in his classes.

New Assessment Tools for Teaching Invention

One important aspect of formal education is to assess student acquisition of skills and knowledge. The Chill Out! unit included resources for students' self-assessment of performance. Mr. T found the self-assessment inadequate for assessing student science learning and, therefore, utilized four types of assessment tools to evaluate student learning: 1) quiz, 2) concept map, 3) worksheet, and 4) poster design. He adopted the quiz and concept map from his previous teaching materials, focusing on assessing student understanding of the underlying science concepts, e.g., conduction, convection, radiation, and insulation. He designed and utilized the worksheet and poster presentation to capture students' inventive thinking and their processes of working like inventors. In particular, the worksheet required students to write an essay upon the completion of the prototype design, describing their design rationale, materials used in the lunchbox invention, and reasons for choosing certain materials. The poster design task asked students to reflect on the critiques they received from other student groups, plan for design iterations, and document their thoughts. Figure 2 shows an example of the poster made by a student group called Gleep Glorp. In the poster, students created a technical drawing of the lunchbox showing the top and side views, labeled materials used in the invention, and described how heat transfer can be minimized. Mr. T also designed a rubric for the posters (Table 2) to score students' posters. The worksheets and posters were used to assess how students developed and iterated their invention solutions.

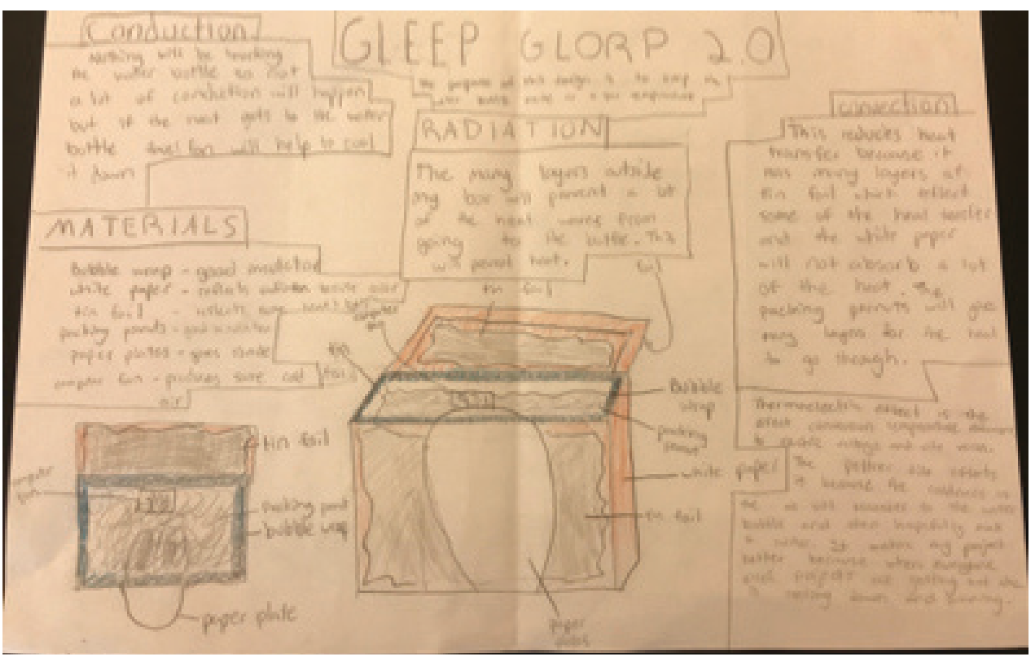

Figure 2. An example of a student poster describing their lunchbox invention.

Changes to Mr. T's Teaching Practices

Teaching invention requires a shift from traditional teaching methods focused primarily on the transmission of knowledge to more open-ended facilitation that encourages students to actively acquire and apply science knowledge to invention activities. Teachers need to tolerate the ambiguity inherent to the process of invention while providing skill and academic support to individual students as needed. One change Mr. T noted was that he gave more oral directions instead of asking students to read the textbooks: "I gave more oral directions, or written directions on the board more than they actually did in the [guides]. They can easily follow and would look at the board if they forgot."

Another change is that Mr. T frequently asked students to brainstorm invention ideas and explanations. He recommended having students brainstorm and write down their thoughts because "they [students] love the brainstorming and I can quickly know what they are thinking and where they struggle.… I feel like the brainstorming session might be more helpful if they had a space for them to answer [in the guide]." These changes in Mr. T's teaching indicated that he may have recognized the need to change from didactic teaching toward a more student-centered approach, where students are given more flexibility and freedom to work on their own inventions.

The shift in Mr. T's pedagogical approach aligns with Guskey's Model of Teacher Change (35), which posits that the experience of successful implementation is more effective in changing teachers' attitudes and beliefs than professional development. According to the model, to promote innovative approaches in schools, teachers need to first gain evidence of improvements in students before they make a change. In Mr. T's case, he tried the Chill Out! unit, witnessed students' engagement and improved learning, and started to consider more open-ended, hands-on invention activities for his students. At the end of this project, he expressed enthusiasm for implementing the unit again next year, volunteered to serve as a coach for the afterschool STEM club in his school that uses other JV invention curricula developed by the LMIT Program, and admitted that he has "started thinking about the changes he could make next year." After two to three rounds of implementation and customization of the invention education curriculum, it is highly likely that Chill Out! will become part of Mr. T's curriculum.

CONCLUDING REMARKS

Curriculum designers, researchers, policy makers, and teachers are striving to design effective and useful supports for engaging youth, in particular those of under-represented groups, in STEM and preparing them to enter the STEM workforce pipeline. Frequently, this involves the design of an innovative approach that offers appropriate scaffolding, inspiring STEM experiences, and connections to extensive and diverse resources (32). Invention education is one of the highly promising approaches. Implementing it during the school day would greatly broaden youth's participation in STEM and help address the under-representation of women and minorities among those who ultimately patent technological inventions and become innovators.

Yet, integrating invention into STEM coursework is not easy. A variety of factors might influence in-service teachers' willingness to consider novel approaches, including administrative support, local relevance to material already being used by the teacher, and the degree of comfort a teacher feels in trying new instructional methods and materials as well as teaching perhaps new content (33). To achieve practical utility and widespread diffusion, it is critical to understand teachers' perceptions of invention education and their needs when using it in classrooms in addition to offering responsive support. This exploratory study analyzed one teacher's experience of implementing an invention curriculum in middle school science classrooms to better understand teachers' subjective realities—what works, what is too risky, what does not work, and what changes or modifications are necessary.

The results provided evidence of the benefits and challenges Mr. T encountered when implementing an invention curriculum among 7th grade students from diverse backgrounds. He valued the hands-on invention experiences, the varied ways of presenting information, and, ultimately, the high enthusiasm of the students. Meanwhile, he faced challenges, such as managing students with varied levels of academic achievement, creativity, and reading ability; finding

Table 2. Mr. T.'s Scoring Rubric for the Students' Posters of the Lunchbox* Inventions

Scoring Level	Material Explanation	Reducing All Types of Heat Transfer	Application of Thermoelectric Effect	Sketch	Presentation
5: Accom-plished	Lists all materials and completely explains the reasons why each was used and why each was located in that position	Clearly explains the 3 types of heat transfer and details ways that the cooler reduces each type	Features the technology we explored in class and gives explanation of how it makes the cooler more effective	A neat and accurate model of the cooler that includes color and labels furthering the audience's understanding	Shows complete understanding of the cooler and presents major points clearly. Includes extensions to the content
4: Compe-tent	Lists all materials and explains some of the reasons why each was used and why each was located in that position	Clearly explains the 3 types of heat transfer and details some of the ways that the cooler reduces each type	Includes the technology we explored in class and gives explanation of how it makes the cooler more effective	A neat and accurate model of the cooler that includes some color and labels	Shows complete understanding of the cooler and presents major points clearly
2 or 3: Develop-ing	Lists most of the materials and explains some of the reasons why each was used and why each was located in that position	Somewhat explains the 3 types of heat transfer and details some of the ways that the cooler reduces each type	Handwritten text is present that is partially helpful to the understanding of the reader	A messy but accurate model of the cooler that includes some color and labels	Shows some understanding of the cooler and presents most of the major points clearly
0 or 1: Beginning /Not Present	Lists some materials and poorly explains some of the reasons why each was used. Does not explain location	Poorly explains the 3 types of heat transfer and details few of the ways that the cooler reduces each type	Handwritten text is present that is not helpful to the understanding of the reader. No text present	A messy and inaccurate model of the cooler that includes some color and labels	Shows little understanding of the cooler and presents few of the major points clearly

*Mr. T refers to the lunchbox invention as a cooler in his rubric.

a balance to provide appropriate support to students during invention; and completing the invention curriculum within limited class time. Mr. T made instantaneous adjustments to the curriculum during classroom enactment, including making revisions to existing activities to make invention education more accessible and relevant to all students, preparing students with relevant skills such as teamwork and presentation, adapting and reusing his existing teaching materials for invention education, and developing new assessment tools for classroom purposes. He also noted that he adopted more student-centered teaching practices, such as encouraging students to brainstorm and explain their ideas. By the end of the implementation, Mr. T expressed more confidence and interest in adopting invention education in his science classes partially because of the excitement it added to his classes. He planned to further customize the invention curriculum for his teaching in anticipation of experiencing big Eureka moments during the next implementation. He concluded the first experience this way:

> I think there was a lot of excitement but it maybe wasn't a eureka moment. They [The students] were excited to get things completed. They were excited to see how they did. And they were listening intently to why things worked or why things didn't. But I don't know if it was something like a eureka moment. It wasn't like a 'Oh, now I've got it.' Like a complete understanding turnaround. I think some of the stuff that we provided was exciting because it was more hands-on, and so it was more like a joyful learning moment … [rather] than something like a eureka moment.

The case of Mr. T resonates with both Guskey's Model for Teacher Change (35) as well as Roger's five-stage diffusion of innovation process (34), where the teacher must first become aware of invention education (Stage One: Knowledge), develop an opinion or attitude towards it with respect to its value and possible use (Stage Two: Persuasion), and decide whether to try the new change or reject it (Stage Three: Decision). Afterwards, the teacher employs the innovation to a varying degree depending on the situation to determine the usefulness of invention education (Stage Four: Implementation) and finalizes his/her decision to continue using and customizing it (Stage Five: Confirmation). Through these stages, teachers can develop a solid understanding of the content and structure of invention curriculum, visualize its fit within their current curriculum framework, make and iterate specific plans, and implement it in their classrooms. Mr. T. moved through all five stages of diffusion with the invention curriculum in one year. This five-stage diffusion of the innovation process and Mr. T's work can inform professional development programs and efforts to attract and support more teachers to implement invention education in their science classes.

Further, the results of this study provide valuable insights to curriculum designers to help alleviate the under-representation of students from diverse backgrounds in STEM education by implementing invention education in schools. Mr. T's case reflects the needs, challenges, and desires that other teachers may face when adopting invention education in science classrooms. Developing an understanding of in-service teachers' concerns can inform designers' efforts to lower the barriers to adoption by (re) designing invention education curricula for classroom use in ways that are responsive to teachers' needs.

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