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CULTURALLY RELEVANT SCIENCE: INCORPORATING VISUALIZATIONS AND HOME CULTURE IN AN INVENTION-ORIENTED MIDDLE SCHOOL SCIENCE CURRICULUM

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This study examines the benefits of a middle school “invention” curriculum—an inquiry and project-based approach to teaching science that gives students opportunities to learn ways of thinking like inventors. In this article, we focus on modifications made to this curriculum to make it more accessible to English language learners (ELLs). Visualizations, visualized formulae, and science literacy activities were added to help ELLs access the subject matter more effectively. “HomeFun” activities were added to provide opportunities for students to connect knowledge from their home cultures to key aspects of the curriculum. The article reports findings from our research surrounding students’ experiences with the ELL-modified invention curriculum. We used a case study method, gathering data in two classrooms from two different middle schools in the northeastern U.S. Data included classroom observations, interviews, journals, and artifacts. We analyzed the data inductively. We also analyzed five focal students’ HomeFun assignments in detail. We found that the focal children — all children of immigrants — used positive statements when describing their experiences with the modified invention science curriculum and reported that it helped them work through the text and make personal connections to the science subject matter. Students also reported that the visualizations, the science literacy, and the HomeFun activities helped them learn science and provided connections to their home cultures. We draw conclusions about the benefits of invention-oriented curricula and visualizations for teaching science and the importance of making science culturally relevant.

Key words: Invention; Project-based learning; Visualizations; HomeFun activities; Culturally relevant science

INTRODUCTION

Immigrant students, together with the children of immigrants, represent a large and increasing share of the U.S. K-12 population (1). These students, who often speak languages other than English at home, have to learn academic English at the same time as they learn subject matter (2,3). This is difficult, and it often leads to academic struggles for students who do not reach their potential.

One instructional strategy that has been shown to increase students’ subject matter knowledge involves drawing upon what Gonzalez, Moll, and Amanti (4) call students’ “funds of knowledge.” This approach requires educators to help students make

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connections between the subject matter being taught and the knowledge and skills from the students' home cultures. Boutte & Johnson (5) note, however, that science teaching seldom employs students' funds of knowledge and what Ladson-Billings (6) calls "culturally relevant pedagogy." In this study, we examine the benefits of teaching middle school science by combining culturally-relevant pedagogy (drawing on immigrant students' funds of knowledge) with project-based learning activities that expand students' engagement with science concepts while also requiring them to think and work as inventors.

This new approach to teaching science is part of an ongoing effort by Boston College, the Lemelson-MIT (LMIT) Program, and a school district in the northeastern U.S. to respond to the needs of a growing immigrant student population. The efforts have been informed by research that indicates that (a) students learn English better when language learning happens along with subject matter learning (3,7) and (b) doing science through hands-on and inquiry-based approaches can enhance students' scientific understanding and their second language development (8). The joint work has involved modifications to one of eight Junior Varsity (JV) InvenTeam curriculum guides (Chill Out!) developed by the LMIT Program—a curriculum designed to help students learn science while they work as apprentice inventors under the guidance of a teacher. The existing curriculum supported inquiry-and project-based approaches to learning focused on helping students learn to think like inventors while learning about science. Partners altered the curriculum in three ways to make it more accessible to English language learners (ELLs). First, pictures and visualized formulae were added to make key concepts more accessible to ELLs. Visualizations can help ELL students understand complicated science concepts by making them more concrete (1,9). Second, we created "HomeFun" activities that asked students to use knowledge from their home cultures to illustrate curricular concepts. HomeFun activities were designed to connect knowledge from students' home cultures to the subject matter, following a funds of knowledge approach. They prompted students to engage their families in dialogues that explored family histories and cultural backgrounds in order to complete the school assignments. Third, we added new procedural writing activities to support the development of science literacy. Prior research has shown that science literacy activities can help students engage in class, extend their thinking, and deepen their understanding (10,11). Science literacy activities ask students to apply scientific knowledge rather than simply describing scientific concepts (12).

The modified curriculum was implemented in two middle school classrooms, which served as the sites of study for examining three research questions:

1. How do middle school students perceive and experience an ELL-modified invention curriculum?
2. How do middle school students respond to visualization as they work to comprehend science concepts?
3. How do HomeFun activities in a modified invention curriculum help middle school students learn science and develop their science literacy?

Invention-Oriented, Project-Based Science Learning

Invention involves "making observations, posing questions, examining books and other sources of information, planning investigations, using tools to gather, analyze, and interpret data, proposing answers, explanations, and predictions, and communicating the results" (13). By engaging in these activities while working on their own inventions, students have opportunities to build literacy skills and acquire knowledge. There has been limited research on invention as a pedagogical tool. Saxon et al. (14) reported that invention camps helped students improve their understanding of subject matter in science, history, mathematics, and art as well as develop teamwork skills. Such invention programs sometimes occur in competitions or invention contests at the end of semesters in some schools (13,15,16). The limited research done on these programs indicates that student participants can develop high-level problem-solving skills and become better at cooperation. A more recent study describes a high school science course that improved students' science skills (17). However, few invention programs have been adopted as part of the standard curriculum used by schools during the regular school day.

For purposes of this study, we define invention project-based learning (IPBL) as helping students understand science concepts by creating a tangible invention through inquiry-based and hands-on project-based learning. IPBL follows familiar principles of project-based learning, building curriculum around key science concepts, the processes and practices of scientists, and hands-on activities and problem solving that draw upon curricular knowledge, but it also involves picking problems and engaging in activities that can lead to a technological solution. We know that project-based learning helps students learn science (18-20). We also know that project-based learning in science can help immigrant students learn content (21). Hands-on activities can make science more accessible to ELLs because they do not require as much linguistic input. Finally, we know that incorporating science literacy activities in curriculum can enhance students' subject content learning and literacy development (3,7,22).

Our IPBL activities build on this knowledge and existing research findings for each of the components of the program. Few studies, however, have been conducted in classrooms where project-based learning in science is coupled with engaging students with the development of inventions and curricular resources that incorporate science literacy, visualizations, and culturally-relevant knowledge in order to involve children of immigrants more effectively.

Visualizations in Science Learning

Visualizations have been widely used in science education for many years (23). Employing visualization is an effective way to help students understand scientific concepts (24). Visualizations have been shown to promote students' scientific understanding and engagement. Chang Rundgren and Yao (9) describe how visualizations can be beneficial in terms of knowledge, attitude, and skills. Visualizations enhance students' cognitive knowledge and intellectual abilities. They also incorporate affective and psychomotor dimensions. Cognitive benefits include (a) making abstract knowledge and ideas concrete, (b) translating scientific ideas between macro, micro, and symbolic levels, (c) showing how processes work, and (d) allowing students to model processes. In the affective domain, visualizations can help students (a) pay attention, (b) they can induce positive emotions, and (c) they can entice students to engage in an interactive visual environment. In the psychomotor domain, visualizations can (a) enhance students' spatial skills, (b) externalize students' ideas, and (c) enhance their communication skills. When visualizations are used to foster students' representational competencies, they are more able to learn science content and apply it to their lives.

Culturally Relevant Science Learning

A cultural incongruence between school and home can lead to educational problems (25,26), as students from non-mainstream backgrounds are inadvertently excluded or underestimated. To support diverse learners, Ladson-Billings (6) proposes culturally relevant pedagogy. This involves "using the cultural knowledge, prior experiences, frames of reference and performance styles of ethnically diverse students to make learning encounters more relevant to and effective for them" (27). Gonzalez, Moll, and Amanti (4) describe a type of culturally relevant pedagogy in which students bring "funds of knowledge" from their home cultures and integrate this into subject matter learning. Martin (28) argues that instruction should involve deep content knowledge, strong pedagogical content knowledge, and culturally relevant pedagogy. This approach can highlight students' diverse cultures, enhance their achievements, build on their cultural competencies, and encourage them to critique current social inequities.

Johnson (29) describes how two middle school teachers became culturally relevant science teachers, showing how a teacher can foster students' conceptual understanding by incorporating home culture literacy and language practices. Seraphin (30) describes how literacy activities can be used to create culturally relevant science learning. She shows how an indigenous student involved herself in an inquiry science project by writing about her traditional culture, thus creating personal connections to science learning, taking ownership of the learning, and improving her critical thinking. Writing about their own cultures allows science students to deepen their literacy and science learning. Studies like these show the potential of culturally relevant science teaching, and we need more work that explores this potential.

METHODOLOGY

We used a multiple case study method (31) to explore how middle school students perceived and experienced the modified JV InvenTeams curriculum together with the science literacy and HomeFun activities.

Context

The modified curriculum was taught at two middle schools in a public school district in the northeastern U.S. The unit was incorporated into the science curriculum taught during the regular school day when seventh grade students were learning about heat transfer. This was the first time LMIT program staff had an opportunity to explore ways the curriculum might need to be adapted for use in formal education contexts rather than in the informal learning settings for which it was originally designed.

Participants

We implemented the program with seventh graders in two schools (teacher Jay's and teacher M's classes). This study focuses on teacher Jay's class. Through purposive sampling (31), we selected five focal students who were children of immigrants (Table 1). Four of the five students were bilingual. The others all spoke English fluently, except for one, whose proficiency was advanced intermediate. Teachers evaluated their written English as lower than their oral proficiency.

Procedure

We implemented the program in five stages between November and December 2017 in teacher Jay's class:

1) Professional development for teachers: We led several meetings with teachers to select focal classrooms and discuss the logistics of the curriculum.
2) Ordering equipment: We ordered necessary equipment for the projects.
3) ELL modification: We modified the JV InvenTeam curriculum for ELLs by adding visualizations, creating HomeFun activities, and designing science literacy tasks.
4) Implementation: Students worked with the curriculum, developing their inventions and writing about them.
5) Celebration: Students and teachers presented the inventions and selected the best invention in a competition.

Material

The curricular topic was "heat energy." The JV InvenTeam Chill Out! guide that addresses this topic has six chapters that focus on heat temperature and movement: 1) Invention Introduction; 2) What Is Heat; 3) Keep Your Cool; 4) Removing Heat; 5) Peltier Prototyping; and 6) Invention Extension. Students are asked to create their own lunch boxes to keep lunch foods both cool and hot using the scientific knowledge they learn in the curriculum (e.g., convection, conduction, radiation). Visualizations were added to provide extra help for ELLs, including icons, visualizations, and visualized formulae (Figure 1).

Seven HomeFun activities that drew on home cultures and traditions were designed as supplements to the curriculum. These activities promoted culturally relevant pedagogy and also fostered science literacy (Table 2).

In this study, we focus on data from the Day 1 and Day 4 HomeFun activities (Figure 2). The Day 1 assignment asks students to write about notable inventions from their home countries or towns. The Day 4 assignment asks them about clothing used to keep warm or cool in their home countries or towns. Both assignments encouraged working with family or community members. Students often spoke with their grandparents while doing these activities.

Table 1. Demographics of Selected Participants

	Karl	Angeline	Karina	Monica	Bryan
Grade	7th	7th	7th	7th	7th
Gender	Male	Female	Female	Female	Male
Home Country	Scotland	Haiti	Italy	Italy	Italy

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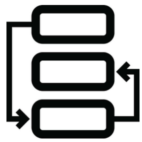
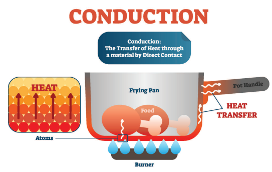
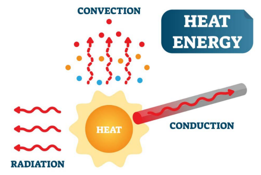
<tr><td>Images</td><td>
created by Arhtur Shlain from Noun project</td><td>
</td><td>
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*Images, pictures, icons, and other visuals are adopted from various open source sites. The evaporation visualized formula was created by the research team.

Figure 1. Samples of visualizations and visualized formula.

Data Collection

We collected four kinds of data: a) classroom observations, b) semi-structured interviews before and after the program, c) researcher's journals, and d) artifacts (e.g., HomeFun assignments, the lunch boxes that students invented).

- *Observations:* During the program in Fall 2017, the researchers observed classroom activities and kept field notes.
- *Three semi–structured interviews:* We conducted interviews with five children of immigrants. Each interview took place during lunchtime for about 30 minutes. We also conducted a follow-up interview, in which we conducted member checks to verify responses.
- *Researcher's journals:* One of the research team members kept a researcher journal throughout the implementation process. He also drew and took pictures of student activities.
- *Artifacts:* We collected writing samples from the HomeFun assignments, and we analyzed the five focal students' HomeFun assignments.

Data Analysis

We analyzed two sets of data: a) the interview data, observations, and researcher journals and b) the students' HomeFun assignments. The first set was analyzed inductively (32). We used coding categories derived from the literature (e.g., culturally relevant, project-based, etc.) and open coding. The second phase involved axial coding, in which codes related to each other are put into subcategories and then combined to form new thematic categories. We reviewed emerging concepts and clustered them with similar concepts. At the third stage, we compared new themes across the five participants and identified

Table 2. The List of HomeFun Activities

HomeFun activities in the modified JV Invention program

Day 1. Famous inventions from my home country/town or elsewhere
Day 2. Comparing engergy, heating, and cooling used in different countries and places & "K-W-L: What I Know; What I Want to Know; What I Learned"
Day 3. Bilingual photo essay
Day 4. Clothing that keeps us warm or cool
Day 5. How we keep cool in my home country/town
Day 6. Inventions that make life at home fun or easy
Day 7. How we heat or cook things in my home country/town & stories of inventions that improved our lives
Day 8. Concept maps about inventions & real world and local needs & vocabulary journal

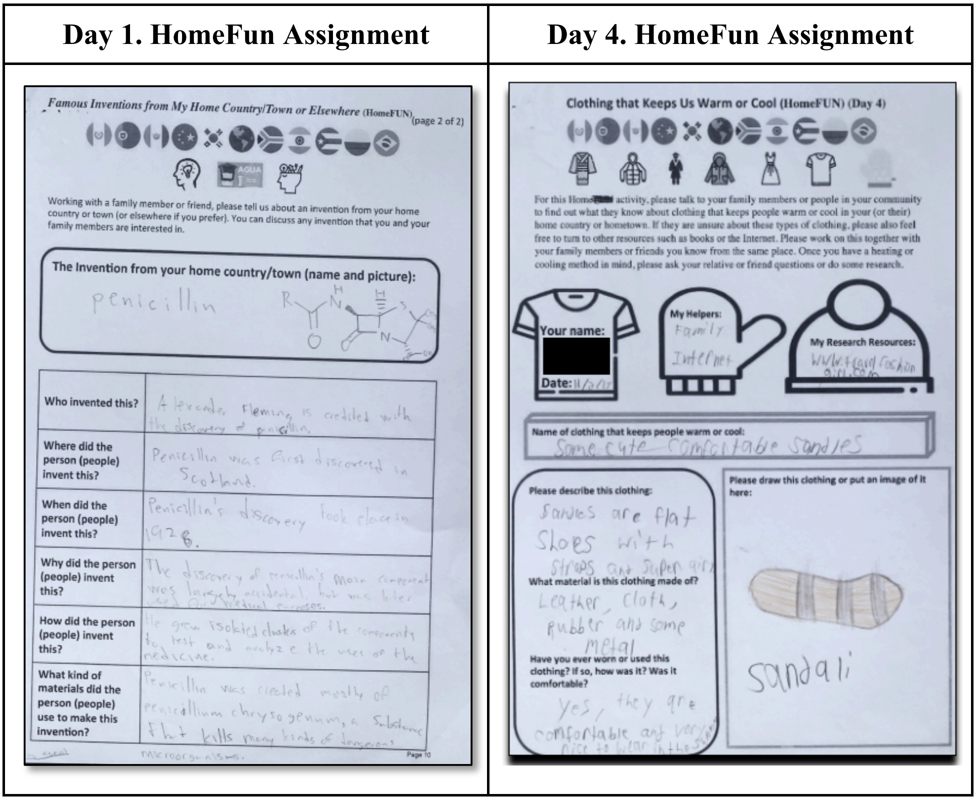


Figure 2. Samples of HomeFun activities.

Table 3. Criteria Used to Analyze HomeFun Activities

Presentation	Culture	Writing	Science
• Organization • Illustration	• Choice of topic • Connection to science • Engaging representation (illustration) • Interaction with family and community	• Vocabulary • Language function (instrumental, regulatory, interactional, personal, representational, heuristic, or imaginative) • Appropriate grade writing • Interaction with family and community • Subjectivity (tone & voice)	• Science content accuracy • Exploring science concepts • Science content knowledge • Data sources

emergent themes. We also analyzed other qualitative data, including observation notes and reflective journals, using the same coding procedure. We triangulated across data sources, comparing the coding across researchers, and we identified robust patterns.

To analyze the second set of data — the HomeFun assignments — we adopted and modified the analytic framework from Saint-Hilaire's science curriculum work (33) combined with Donahue's account of culturally relevant science (34) (Table 3). We describe hereafter how we also drew on Halliday's model of the primary functions of language (35) and Li and Kim's (36) functional approach to ELL writing. Drawing on these four sources, we divided our analytic categories for analyzing HomeFun activities into four types: 1) presentation, 2) culture, 3) writing, and 4) science.

Our research team included members from diverse backgrounds (e.g., a science professor, doctoral students, native English speakers as well as ELLs). In order to triangulate, we collected multiple data sets and analyzed the data accordingly (32). We also conducted member checks in the third interview with participants. By gathering multiple data sets and using diverse data analyses, we increased the trustworthiness of the study (37). All research team members and teachers reviewed the data analysis.

FINDINGS

We summarize the findings with sections for each of the three research questions.

Children of Immigrants' Personal Connections to Invention Learning

Research Question 1: How do middle school students perceive and experience an ELL-modified invention curriculum?

Four out of five focal students described the process of designing and creating their own inventions as "really fun" and "challenging." They mentioned the importance of hands-on, inquiry-based learning, authorship in invention learning, and connecting culture to science as well as challenges in connecting their abstract ideas to their concrete inventions.

All students actively engaged in the invention-oriented, project-based learning and used words to describe their experiences that indicate they enjoyed creating lunch boxes. Bryan, who made a lunch box by applying a thermal principle that was part of the curriculum, emphasized the strength of hands-on and inquiry-based learning. He said, "I liked it a lot because it's very hands-on, it's more about you and like, it's your perspective on it. It asks more questions about you specifically, compared to information." His account suggests he was particularly engaged by this project because he could create based on his needs and perspectives. Karl agreed, saying that the activity "definitely makes it a lot more… interesting and it feels like you are learning more. It feels like you learn more because you're learning about two different things [science and invention] at once, and you can connect them."

Monica was proud of her authorship while learning through invention. She said that the invention program helped her to "accomplish something with myself" and "try being more independent and learn [science] at the same time." Bryan also liked how he was able to choose his own style of invention: "My favorite part was making the cooler because projects are fun to make, because it's more like you get to choose what to make and your style."

Students also mentioned their science learning with family members. Karina said, "I told them [my family members] about it [my invention], like how everything was going and they helped me more on the background stuff with it so I can get more information on it. So they helped me with the HomeFun activity." She continued, "They [family members] liked my idea. They just, they want to make sure that I did like a good job on it so that like it ended up working well for everyone." Monica also emphasized the importance of connecting to one's culture. Monica said, "It [invention] is related to culture, so… cause… they (each community) don't have the same culture, you have to make it different ways to apply to their culture."

Often students encountered challenges while designing inventions. While trying to make their abstract ideas work in the concrete material, students tried multiple attempts, discovered problems, and designed solutions. For example, evidence suggested that Karl and Angeline understood the scientific concepts, but both indicated that it was hard to design the lunchbox. Karl said, "Definitely [it was] hard to apply a lot of the knowledge like…finding the best way to use a lot if materials like… what materials would be the best to use." Monica said, "Things took apart, I've got confused on how to fix it without destroying the entire thing. So it was fun, but I had to figure it out." Karl also tried out several different approaches. He said, "You have to try again and have to like think in a completely new way." Overall, students made positive comments about the projects and the ownership that they were able to take. They also persisted through the challenges.

Employing Visualization in Invention-Oriented Science

Research Question 2: How do middle school students respond to visualization as they work to comprehend science concepts?

ELLs said they benefited from visualizations and visualized formulae. The illustrations and extra descriptions helped them to understand science concepts more clearly. One of the participants said, "visualizations help me to understand 'heat transfer' and that helped us to build a cooling device better" (e.g., Figure 3). Visualizations helped students identify which step they were at and how that step was related to others in the invention process.

Karl said, "Those [visualizations] I think are really helpful. If you're like, having trouble doing something, because then you can put a name to an image that you can see. And you can see where things are in relation to each other. Better than themselves. [Visualizations] make better than words can." Monica also echoed, "It helps you understand how it works. If it's just words, you don't really get a complete visual cause you never seen it before you learned about it before, so you understand it easier." In general, students found visualizations particularly helpful when they were confused or needed to understand the procedures required.

Since students went through multiple complicated steps to create their inventions, as Karl said, "students need to figure out the whole procedure, at the same time, the exact and specific stage they are getting on." Students' statements indicated that the visualizations helped them follow the process of experimenting and making inventions and helped them understand scientific concepts. Karl continued, "It can be about evaporation. You can go through the textbook. These things… radiation… for each step procedure; it's easier because then you know exactly… where you're getting that. I think it help so. Helped [me] a lot."

Photos, images, visualized formulae, and icons were all helpful to students. Students also drew images in their HomeFun activities. For example, Karl drew the chemical formula for penicillin (Figure 4). Angeline, who was often confused during the invention program, told us that photos enabled her to see "what they are doing," such that "she would get and understand it." Her comments suggest that the ability to compare her work to an example represented in the photo helped her feel more confident and enthusiastic. Thus visualizations could not only communicate content, but they also helped to keep students engaged while learning.

Karina illustrated how she understood the concepts of conduction, convection, and radiation by interpreting the visualization (Figure 3) as follows: "It shows me like what it like it's trying to say. Like how the radiation is down- is down in the bottom and the convection is like inside. Makes it easier." This statement indicates that visualizations and visualized formulae helped Karina understand scientific concepts and procedures more clearly.

Writing Home Cultures in Invention-Oriented Science

Research Question 3: How do HomeFun activities in a modified invention curriculum help middle school students learn science and develop their science literacy?

To understand middle school students' science and literacy learning during HomeFun activities, we adopted four categories from Saint-Hilaire's curriculum evaluation framework (33) and Donahue's cross-cultural analysis (34). We report the findings according to these four categories: presentation, writing, culture, and science.

Presentation

Students successfully incorporated drawings and explained accordingly. All students followed the format requested in the assignment. They engaged, explained, explored, elaborated, and evaluated the

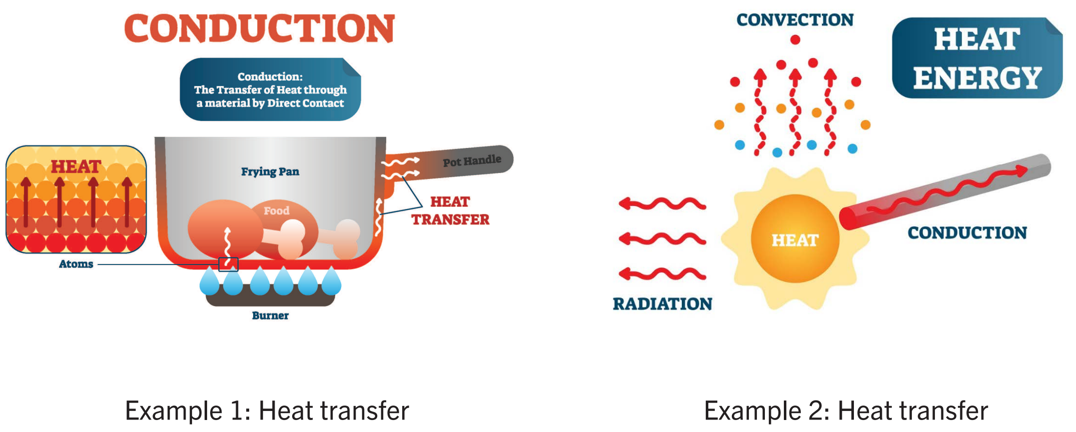


Figure 3. Examples of visualization.

topics they were presenting (22). They also provided images, graphics, or other resources. Most of the students drew the objects (see Angeline's drawing), though Karl shared penicillin's chemical formula instead (Figure 5). He said using science from the curriculum and connecting it to the topic he chose made him "learn more because I am learning about two different things at once, and I can connect them." Students also communicated about their learning by presenting facts and experiences.

Culture

Students chose various cultural artifacts from their home cultures. In HomeFun activity 1, students chose penicillin, Weymann Fabric Bodies, pizza, radio, and dentures. For HomeFun activity 4, they explored kilts, t-shirts, multicolored jeans, and sandals (Table 4). Most felt that it was "good to get to know inventions from my home country." For example, Angeline mentioned that "it was cool" to know there is a great invention (Weymann Fabric Bodies) from Haiti. Three students (Karina, Monica, and Bryan) selected Italian inventions (pizza, radio, and dentures), Karl chose penicillin from Scotland, and Angeline chose Weymann Fabric Bodies from Haiti (Table 4).

In HomeFun activity 4, students selected clothing associated with their home countries. While Karl and Monica chose more traditional clothing — kilts and sandals — Angeline and Karina chose more contemporary t-shirts and multicolored jeans (Table 5). Karina had a strong memory of multicolored jeans from a visit to Italy, in contrast to the jeans she was used to in the U.S. She said:

> When I was there [in Italy], I noticed that they didn't really wear plain blue jeans; a lot of them have different colors, like green. The U.S. has it [multiple colored jeans] but it's more common for them [Italians] to wear different colors than normal plain color. I liked having more colors

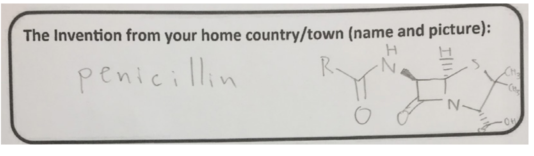
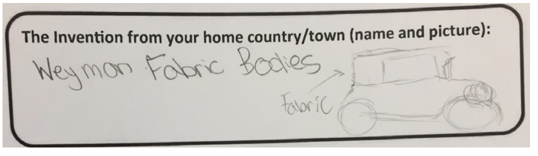
Karl's drawing	Angeline 's drawing
	

Figure 4. Samples of students' drawing.

Table 4. Topics of HomeFun Activities

Student	Karl	Angeline	Karina	Monica	Bryan
Home country	Scotland	Haiti	Italy	Italy	Italy
Day 1: Famous inventions from my home country/town	Penicillin	Weymann Fabric Bodies	Pizza	Radio	Dentures
Day 4: Clothing that keeps us warm or cool	Kilt	T-shirt	Multicolored jeans	Sandals	n/a

> sometimes on my clothes. Sometimes it's just as fun as I want myself to look good."

Angeline emphasized the similarities between Haitian-style t-shirts and U.S. versions:

> I start about how sometimes like they [Haiti and United States] are close, it like inside somewhere to like the United States. I was, kind of surprised, I didn't- because sometimes like there were like some tradition that are close to something, but I didn't know that they would like come close because like, I never would really like pay attention to like, um, the stuff that like happens in my parents' culture.

Four students worked with their family members and expanded their learning by working with relatives at home. They produced various images from this work. The topics students selected for the activity related to their home cultures. Most students' families engaged in the process of completing HomeFun activities. Students said HomeFun activities increased interaction with family members. Bryan told us:

> Like my parents, when I asked them about this, I asked if they knew any invention out of the top of their heads from Italy. They said they knew about dentures because my mom's grandfather he told my mom before that dentures was made in Italy.

Artifacts from students' work demonstrate connections to their home countries and their home cultures. After completing the invention program, Karl and Monica said that they felt even more connected to their parents' home countries. Karl began to refer to Scottish history, saying that "Our history… My family, where they're from… I can feel like I can connect to that. It's a lot of history… a lot of it really interests me because… here's a lot of interesting things… It's our history." Monica also felt that she was "part of Italian culture….You could think of more capability, because Italians did it too so you feel like you can do it too… cause you are the child of them… you are part of their culture." Bryan added that he wants to be a "good reflection for Italy." He said, "I thought it [inventing dentures] was pretty cool. It shows that it comes a long way… because now dentures are all over the world. I want a good reflection for Italy; dentures was made there. It's pretty cool."

Students' statements suggest that engaging in the activities made them feel proud of themselves as well. Karina said, "I was proud of my work. I like when I made I could help a bunch of people, not just myself, like only thinking of myself; it can like help a bunch of people like do it on their own or take what I did and use it." Monica came to identify herself as an inventor, saying that "Making your own invention like means…like you get to help other people by making things to help them; but technology or like cooler is like making cool water hydration and that… That's what coolers mean. That's a thing." Making their own inventions made students think that they can create useful objects if they have enough scientific knowledge and know appropriate procedures. Furthermore, students' words suggested an awareness that they could contribute to society by inventing things.

Science

Table 6 presents the results of our content analysis of HomeFun activities, in which we examined science content accuracy, science content knowledge, and data sources.

Table 5. Students' Responses to HomeFun Activities 1 and 4

Students' responses	HomeFun Activity	Karl	Angeline	Karina	Monica	Bryan
Origin of the topic chosen	Day 1	Scotland	Haiti	Italy	Italy	Italy
	Day 4	Scotland	Haiti	Italy	Italy	n/a
Engaging representation/ illustration	Day 1	Formula of penicillin	Drawing of fabric bodies	Drawing of pizza	Drawing of radio	Drawing of denture
	Day 4	Drawing of kilt	Drawing of shirts	Drawing of pair of jeans	Drawing of sandal	n/a
Interaction with family, community members	Day 1	Not mentioned	Not mentioned	Not mentioned	Not mentioned	Family members
	Day 4	His mother	Me, myself, and I	Family members	Family members	n/a

All students used evidence from diverse sources—especially internet texts and family members—to explore scientific concepts. They described inventions from their home countries and used scientific content to explore aspects of these inventions. The students drew on various science content knowledge from chemistry (e.g., penicillin), materials science (e.g., Weymann Fabric Bodies & dentures), food science (e.g., pizza), and physics (radio) as they described the relevant inventions. Karl, for example, drew on his knowledge of molecules and the elements that compose them to research and then draw out the chemical formula for penicillin.

Writing

All students made comments that support the notion that the science literacy components were helpful in learning science. Monica said, "It was good because like I learned how to write with science, and it helped me like understand what we were doing more." Others claimed that the writing activities helped make the science culturally relevant. As Karl said in his earlier quote, he "learned more" because the program connected culture to science, since they "learned about two different things at once, and they can connect them."

Students also made comments that suggest that they enjoyed learning about ways inventions emerge from an intersection of culture and environment. The statements indicate that the intersection of culture and environment helped to contextualize science and to make it more engaging. Karina said "I want to learn more about like their [Italy] kind of science and like how they live compared to ours like that kind of like life, because it's a different life over there and different times and everything. I want to know more about that."

The four elements of our HomeFun writing analysis were vocabulary, language function, appropriate grade level, and subjectivity (voice and tone). Table 7 gives examples of these. We will review each of these four areas in turn.

- *Vocabulary:* As summarized previously, they used various vocabulary related to their topics.
- *Language function:* As we might expect, most students used language representationally, stating or explaining the facts about their topics. They also occasionally used other functions of language. Sometimes they hypothesized, offer ing a conjecture or theory about a topic. Bryan, for example, used common sense to hypothesize about the functions of dentures for Italians a century ago. Once in a while, they used language to express something personal about their families and their identities—as Angeline did when she talked about her family history. They also occasionally used language imaginatively, making a judgment and putting themselves into a situation. Karina did this when she imagined what it would feel like to wear items of clothing.

- *Appropriate grade-level writing:* Their writing style was brief and focused on information. Students tended to write short and often incomplete sentences. Students mostly answered the questions. Karl's and Monica's writing samples were appropriate for seventh grade, but the other students' writing samples were short or incomplete.
- *Subjectivity:* Students completed HomeFun activities with various tones: descriptive, evaluative, explorative, or explanatory. When they wrote about scientific inventions, they often used an evaluative tone (Karl, Angeline, and Karina). When they explained about their daily lives, they used words that were casual and cheerful, writing descriptively. Their writing took a neutral stance when writing about scientific matters, while they chose to write in expressive voices when describing individual experiences.

They described their HomeFun activities using either cheerful (Karina and Monica) or neutral (Karl and Angeline) terms. They chose the tone and voice of their writing depending on their goals. The tone or voice reflected in Angeline's choice of words changed in our analysis of words used before and after her invention. She told us that she did this invention program because "I have to do it" in the initial interview. But then, in her HomeFun activity 1, she indicated that she was pleased to discover that Weymann Fabric Bodies had been an important invention made by a Haitian scientist ("that's my dad's country"). She then told us that "They [HomeFun activities] are pretty good. I got to learn something that I didn't know." These words demonstrate how her orientation to the work had changed and that the work reinforced her pride in being Haitian.

Table 6. Content Analyis of HomeFun Activities

Science Content	HomeFun Activity	Karl	Angeline	Karina	Monica	Bryan
Science content accuracy	Day 1	Fact	Fact	Fact	Fact	Fact
	Day 4	Insufficient explanation	Experience	Fact & Experience	Fact & Experience	n/a
Exploring science concepts	Day 1	Demonstrating facts	Demonstrating facts	Demonstrating facts	Demonstrating facts	Demonstrating facts
	Day 4	Demonstrating facts	Making observations and comparisons	Making observations	Making observations	n/a
Science content knowledge	Day 1	Chemical composition of penicillin	Use of flexible materials for car structures	Chemical composition of food	Transmission of radio waves	Materials science
	Day 4	Insulation of heat by clothing	Heat transfer facilitated by clothing	Clothing style accomplished through color variation	Heat transfer facilitated by clothing	n/a
Data sources	Day 1	Not mentioned	Not mentioned	Not mentioned	Web link: history.com/topics/~	Family members & Internet resources
	Day 4	His mother & Internet resource (Google)	Internet resource (website)	Parents	Fashion blog: travelfashiongirl.com	n/a

DISCUSSION AND IMPLICATIONS

These results show that the middle school students who were immigrants and ELLs benefited from the invention-oriented, project-based curriculum, including the visualizations, HomeFun, and science literacy activities. We summarize the implications in three sections: 1) creating young inventors through invention-oriented, project-based learning, 2) culturally relevant science, and 3) the impact of visualizations.

Creating Young Inventors through Invention-Oriented, Project-Based Learning

The results showed that invention-oriented project-based learning afforded students new opportunities to engage with the science curriculum. Middle school students worked to learn science concepts and used them to create their first inventions—lunch boxes. For example, after learning about "heat transfer," including concepts like conduction, convection, and radiation, students used these concepts to invent a smart lunch box for themselves. Students expressed interest in learning these concepts and deploying them in their inventions. They connected the knowledge and concepts they had learned with a concrete invention problem (13) and used what they learned about the ways inventors think to conceptualize and build their lunchboxes.

Table 7. Four Elements of HomeFun Writing Analysis

	Day	Karl	Angeline	Karina	Monica	Bryan
Vocabulary	Day 1	Penicillin Penicillin chrysogenum Substance microorganisms	Weymann Fabric Bodies		Long-distance wireless telegraph A 50-foot tether Antenna	Denture Culprit The Etruscans
	Day 2	Thermal insulator Conduction Cashmere	Polyester	Thread Fabric	Sandals	n/a
Language function	Day 1	Representational, stating or explaining: "Penicillin was first discovered in Scotland."	Personal, expressing individuality: "Port-au-Prince, Haiti (that's my dad's home country)."	Representational, stating or explaining: "He was called to make a pizza for the king and queen."	Representational, stating or explaining: "Marconi and his team invented the radio in London, England."	Heuristic, hypothesizing: "People used these because they would have no teeth if they didn't."
	Day 2	Representational, stating or explaining: "Woven in a pattern known as tartan."	Heuristic, hypothesizing: "I am taking a guess and saying polyester is made of…"	Imaginative, making judgments and entertaining: "It was nice, it dressed up the outfit more, it was comfy."	Representational, stating or explaining: "Sandals are flat shoes with straps and super airy."	n/a
Appropriate Grade writing	Day 1	Academic writing	Briefly written	Briefly written	Academic writing	Incorrect answer
	Day 2	Briefly written (evaluation)	Briefly written	Briefly written	Briefly written	n/a
Subjectivity (Tone & voice)	Day 1	-Evaluative -Scholastic	-Descriptive -Neutral	-Evaluative -Scholastic	-Explanatory -Neutral	-Exploratory
	Day 2	-Descriptive -Neutral	-Evaluative -Neutral	-Descriptive -Cheerful	-Exploratory -Cheerful	n/a

They used positive terms to describe the experience and words that suggest that they gained confidence along the way.

Several of the middle school students made statements that suggest that they had come to identify themselves as "inventors." With this identity shift came a sense of agency, as they became active inventors instead of passive learners. Some began to describe themselves as working to improve human life through inventions. These emergent new identities as inventors helped them develop both competence and confidence. As they began to think of themselves as inventors, some students also began to describe science and work as inventors as a way to improve their lives and society.

The work students did in this project aligned with Next Generation Science Standards standards in supporting "three dimensional learning" — developing an understanding of core disciplinary ideas, participating in science and engineering practices, and exploring crosscutting concepts (38). For instance, students in this project learned about "heat transfer" and the related concepts of convection, conduction, and radiation. They connected it to their daily lives by studying topics like how clothing can keep them warm and how a lunch box can keep their food cold. They participated in practices characteristic of science by making their own inventions and working with others to generate, prototype, and then test ideas.

While learning science, students also improved their language learning. For example, they were able to practice various functions of language, such as representing, hypothesizing, and imagining. They had to formulate scientific ideas verbally with classmates and engage in productive dialogue. Teachers encouraged students to use multiple registers both orally and in writing. On occasion, teachers encouraged students to focus explicitly on how language functions in science, and this helped them learn to speak and write more like scientists (39). These teachers also used culturally sustaining pedagogies (27), working to connect the subject matter to students' home languages and contexts.

Culturally Relevant Science

We modified the invention curriculum by incorporating HomeFun activities that invited students' home cultures into the science classroom. By engaging in HomeFun activities, students were afforded opportunities to learn more about inventions from their home countries (such as a cooling and/or heating system from their ancestral homes). Students learned about important, relevant topics in science and associated the concepts with their home cultures.

The students' words reflected in the activities suggest a positive stance toward their home cultures. For example, Angeline noticed that one inventor was born in Haiti even though he invented radio while living in London. Since she is Haitian, she was very eager to learn about Haitian inventors. All the children of immigrants strongly identified with various inventions from their home countries and reflected on how inventions from their countries, such as sandals, shirts, and jeans, connected to their current experiences in the U.S.

Incorporating their home cultures in this way facilitated students' academic learning, increased communication with family members, and increased pride in their identities (40). This reinforces conclusions of Seraphin's (30) work, in which curriculum that connected literacy and science learning fostered mastery of subject matter as well as students' pride. Students' experiences doing HomeFun activities achieved culturally relevant teaching of science, as described by others (21).

The HomeFun activities also facilitated students' science literacy. Students were able to organize and articulate their thoughts through these activities. All students in the class were afforded an opportunity to benefit since the program was incorporated into the regular science curriculum, as opposed to an after-school extracurricular activity or a one-time event such as a science competition that might not be available to some students. Given the dearth of invention programs in K-12, and the fact that existing programs mainly involve competitions and camps (13,15,16), our research shows invention education can make science more relevant, enhance students' engagement, support the development of pride in their home cultures, and motivate students to contribute to society by creating their own inventions. Intentional efforts to recognize students' cultures as funds of knowledge (41) contributed to students' active engagement in learning. In this case study, in which the teacher paid attention to what students were bringing to the classroom and treated their backgrounds as assets (39), students moved beyond simply learning rudimentary skills as they developed academic writing and scientific literacy.

Impact of Visualization and Visualized Formulae

Employing visualizations can help students understand science content better. Students described how, when they felt confused, visualizations helped facilitate their understanding. As reported in previous studies (9,42), visual representations can be pivotal in fostering understanding of science. In contrast with previous studies examining visualizations in the science classroom, we used different types of visualizations, including icons, visual components, visualizations, and visualized formulae. Visualizations and visualized formulae proved to be helpful for all students. It can be difficult to represent scientific processes visually, but the potential impact on learning is clear.

Incorporating invention curricula into a regular science curriculum in middle schools can facilitate students' learning of science and development of science literacy. When students built their own lunchboxes, they demonstrated their ability to connect science concepts to concrete, tangible inventions. In the next phase of this study, we will examine ways teachers had to re-think their ideas, choose different materials, and re-envision their class activities in order to teach students to invent. Ways of teaching young people to work as inventors while learning science is an under-explored field. Further research is needed to inform the development of new teaching strategies and teacher preparation programs that support educators' take-up of invention-oriented, project-based science learning.

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