



## English learners' science-literacy practice through explicit writing instruction in invention-based learning

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### ABSTRACT

This study explores how three English learners, also referred as L2 learners, improve in science literacy in an invention-based learning (IBL) project. IBL, a project-based learning invention, asks students to respond to problems by inventing. Through the lens of sociocultural theory, our multiple case studies examined how middle school L2 learners demonstrate scientific concepts and science literacy by inventing a lunchbox that keeps food cool. We collected participant interviews, observations, and field notes, and we analyzed these inductively. We also analyzed participants' writing samples based on Garcia, Chiappetta and Fillman's science-literacy framework. Students demonstrated comprehension of scientific concepts and processes, ability to use scientific thinking skills, and capability to apply knowledge to real-life experiences. As a result, although L2 learners experienced some struggles during the writing process, students' language skills and conceptual learning developed. In addition, students perceived writing as an essential skill for learning science.

Since the late 1950s, science literacy, “the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity” (National Research Council, 1996, p. 22), has been a critical element in K–12 curriculum in the United States (Chiappetta & Fillman, 2007; DeBoer, 2000; DeWaters & Powers, 2006; Millar, 2006). Cognitively demanding curricula and activities that require higher order thinking are more engaging for students from all levels and backgrounds (Newmann & Wehlage, 1995). The need to develop a high quality and intellectually motivating curriculum led educators to use science literacy as a way to improve curriculum. For instance, in comparison to the traditional approach of memorizing scientific concepts, new approaches emphasize meaning making and higher order thinking processes that draw connections between scientific concepts and real-life experiences (National Research Council, 1996; Organization for Economic Co-operation and Development, 2013).

Developing cognitively challenging and higher order thinking skills demands curriculum reform. Many researchers suggest writing as a tool to enhance science literacy among students (Florence & Yore, 2004; Hand & Prain, 2006; McClune, Alexander, & Jarman, 2012; Prain & Hand, 1996). Through the process of transforming intangible ideas into concrete form, writing shapes and deepens students' conceptual understanding of science and enhances organization, clarification, and reten-

tion of knowledge (Rivard & Straw, 2000; Warwick, Stephenson, Webster, & Bourne, 2003). Through processes of explanation, interpretation, and reconstruction, students can develop science literacy and content knowledge through writing (Carrier, 2005; McClune, Alexander, & Jarman, 2012; Schleppegrell & Colombi, 2005).

However, despite the critical role of writing in science (Fang, Lamme, & Pringle, 2010; Florence & Yore, 2004), educators rarely incorporate writing into science curriculum. Instead, teachers often use writing as an assessment tool to evaluate students' knowledge (Rivard, 1994; Sampson, Enderle, Grooms, & Witte, 2013). Most students in secondary science education seldom have opportunities to express their understanding of scientific concepts and engage in deep thinking through writing. As a result, students become receivers of knowledge rather than active contributors and producers (Rivard, 1994; Sampson et al., 2013). In addition, without explicit writing opportunities, many students find it difficult to articulate their ideas and thoughts on paper (Sampson et al., 2013).

Invention-based learning (IBL) is a project-based learning (PBL) model for teaching science, emphasizing that students learn and extend knowledge through hands-on and problem-solving inventing activities that give “students opportunities to learn ways of thinking like inventors” by inventing (Kim et al., 2019). Following PBL principles, IBL promotes a learner-centered environment where students hold ownership

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of the learning through inventing. As an extension of the Lemelson MIT Invention Program, IBL provides students time and space to design and build by applying scientific knowledge and hands-on experiences such as building a lunchbox right after learning ‘heat transfer’ science concepts in the “Chill Out” program. The purpose of science-literacy instruction in the Chill Out project is to enable students to use writing as a learning tool to facilitate their scientific understanding. For example, students learn heat-transfer concepts and obtain science knowledge through this project, and they apply these concepts to real-life experiences. They invented a lunchbox, a project that involves all the necessary science concepts (i.e., convection, conduction, and radiation) to keep the lunchbox cool.

This IBL project offers unique opportunities to learn how science concepts work in real life. Teachers use explicit language and write mini-lessons, and students question and compare their inventing experiences with curricular concepts when writing a lab report about their invention. As English language learners, also referred as L2 learners, connect knowledge and experience on paper, student comprehension develops and expands. Thus, the invention program incorporates language and writing lessons and instruction.

Gibbons (2008) argues that when teaching language and writing skills, traditional curricula often incorporate “lower level drill-and-practice activities and a focus on basic grammatical forms excised from authentic contexts of language use” (Gibbons, 2008, p.157), activities that are neither intellectually engaging nor challenging to L2 learners. However, with stimulating inventing experiments, L2 learners and English-speaking students collaborate to develop scientific comprehension and literacy skills.

The only recent IBL study explained how invention-based learning improves culturally relevant science learning of L2 learners (Kim et al., 2019), but it did not discuss the language and writing components. In this study, we focus on L2 learners whose primary language is not English. Our L2 learners are self-identified bilinguals from diverse background who are fluent in both home language and English. We describe how incorporating explicit language-writing instruction in an invention program enhanced L2 learners’ science-literacy development and application.

## Theoretical framework

Sociocultural theory argues that educators should support the development of language through meaningful social practices (Brisk & Parra, 2018). Based in a sociocultural perspective, we examined science-literacy development of L2 learners whose primary language is not English in the context of IBL. Vygotsky (1978) argues that interpersonal and social interaction form the basis of learning and that humans use symbolic tools such as language and numbers to interact with themselves and others. As a medium, language allows learners to co-construct, scaffold, and negotiate meaning among group members, and the writing process serves as a mediating tool to transfer, construct, and solidify knowledge (Goodman, 1987; Lantolf, 2000; van Lier, 2002; Vygotsky, 1978).

Several implications follow from sociocultural theory in helping students develop science-literacy skills through writing. First, writing must be coordinated with the invention activity such that knowledge building occurs through collaboration and social interaction; the writing process should allow students to develop, transfer, and reconstruct knowledge gained from invention activities (Engle, 2006; Engle, Lam, Meyer & Nix, 2012; Vygotsky, 1978). For students to use writing as an active means of transferring and reconstructing knowledge, the writing task should link to their invention experience and provide opportunities to interpret, analyze, and reflect on their experience (Engle, 2006; Perkins & Salomon, 2012; Wagner, 2010). Building strong connections between the invention and writing allows L2 learners to transfer knowledge and reconstruct it in writing (Engle, 2006; Engle et al., 2012; Perkins & Salomon, 2012; Wagner, 2010). Such a connection confirms that writing

is an essential part of learning science (Carter, Ferzli, & Wiebe, 2007; Jiménez-Aleixandre et al., 2000; Yore, Bisanz, & Hand, 2003; Yore & Treagust, 2006). Through writing and social interaction with peers, students actively contribute knowledge instead of passively receiving information (Engle, 2006; Engle et al., 2012).

Second, implementing language instruction, such as how to write and what language to use in the genre for the purpose and targeted audience of the writing (Purcell-Gates, Duke, & Martineau, 2007; Wingate, 2012), is critical. Educators should provide appropriate feedback and scaffolding as L2 learners engage in writing and building literacy skills (Purcell-Gates et al., 2007; Wingate, 2012). Without appropriate instructional support and guidance, using writing as a mediating tool for science learning may not be an achievable goal for L2 learners (Aguirre-Munoz, Park, Amabisca, Boscardin, 2009; de Oliveira & Lan, 2014; Martin & Rose, 2005).

## Literature review

### Writing instruction

Literacy skills, including reading and writing, are absolutely essential for students to acquire and extend academic knowledge in science (Fang et al., 2010). Without the ability to read for comprehension and write for expression, students’ understanding may be limited and may lack the complex background knowledge needed to engage in critical thinking (Carrasquillo, Kucer, & Abrams, 2004; Fang et al., 2010). However, the National Assessment of Educational Progress reading-assessment average score in 2017 indicated that students in Grades 4 and 8 are below a proficient level in reading. In addition, 2011 writing-assessment scores indicated that only 23% of eighth-grade students are at or above the proficient level in writing (National Center for Education Statistics, 2017). The results are even worse for L2 learners, that is, those whose first language is not English. The 2011 writing-assessment report shows that only 1% of language learners met the expectation at or above the proficient level of writing and 65% fell below the basic level of writing (National Center for Education Statistics, 2011). Nonetheless, L2 learners’ literacy and language development is crucial for them to understand content-area texts. Without appropriate instructional support and guidance, writing to learn science may not be an achievable goal for the low to intermediate literacy levels of L2 learners (de Oliveira & Lan, 2014; Martin & Rose, 2005) and “may not serve well students with intermediate and high levels of general English competency in developing higher levels of academic-English proficiency” (Aguirre-Munoz et al., 2009, p. 298).

An emerging body of research indicates the effectiveness of explicit instruction in language in content areas (Bruna & Gomez, 2009; de Oliveira & Lan, 2014; Fang et al., 2010). Yore and Treagust (2006) state that “learning how to talk, write, and read science frequently requires the embedding of explicit language tasks and instructions into science inquiry” (p. 296). Reading and writing in science requires understanding of the specific genre and language predominantly used in science, such as in informational and expository texts. Explicit language and writing instruction enables students to comprehend different genres of writing such as a report, precis, and essays. Thus, to build literacy in science, educators must incorporate language instruction throughout the content-area instruction for L2 learners (Fang et al., 2010; Herman, 2013; Yore & Treagust, 2006). The Invention-based learning (IBL) we incorporated into language and writing instruction enhanced student learning of various science concepts and applications to real life (Kim et al., 2019).

### Invention-based learning (IBL, a type of project based learning) and writing

Traditionally, project-based learning (PBL) was a learner-centered learning pedagogy where teachers become facilitators of projects while

students learn by solving real-life problems (Guo, Saab, Post, & Admiraal, 2020; Markham, 2011; Thomas, 2000). Investigating scientific phenomena, generating ideas, and building scientific concepts through activities (Moje, Collazo, Carrillo, & Marx, 2001) is an excellent way to engage students in science learning. PBL, with teacher support, allows students to learn beyond memorization and to find their own solutions to problems (Guo, Saab, Post, & Admiraal, 2020; Hickey, 2014). PBL challenges students to inquire and engage in problem-solving activities to “meld prior knowledge and experience with new learning and develop rich domain-specific knowledge and thinking strategies to apply to real-world problems” (Blumenfeld et al., 1991, p. 371).

Many studies demonstrate the potential of PBL to enhance student learning in diverse manners (Blumenfeld et al., 1991; Foulger & Jimenez-Silva, 2007; Thomas, 2000). Incorporating writing in a PBL environment makes sense. Langer and Applebee (1987) state that “The act of writing facilitates a logical, linear presentation of ideas, and to the permanence of writing. ... Written language not only makes ideas more widely and easily available, it changes the development and shape of the idea themselves” (p. 3). Even though the process of writing helps shape and develop conceptual understanding, it is a complex and cognitively challenging activity that requires organization, clarification, and articulation of knowledge (Calkin, 2018; Florence & Yore, 2004; Rivard & Straw, 2000; Warwick et al., 2003). Critical thinking and communication skills that are fundamentally embedded in PBL help students develop foundational knowledge and experience that becomes the basis of student writing (Rivard & Straw, 2000; Warwick et al., 2003).

As a type of PBL, IBL, an instruction pedagogy for teaching science through inventing activities, supports students in understanding science concepts and knowledge through problem-solving activities, prior to writing. Unlike PBL, IBL takes an invention education approach to project-based learning (Zhang, Estabrooks, & Perry, 2019). This approach focuses on building an inventor mindset and searching for new possibilities to solve problems (Zhang et al., 2019). IBL engages students by asking them to solve real-life problems by creating their own inventions (Kim et al., 2019). IBL creates a problem-solving environment where students make decisions throughout the inventing process. By incorporating prior knowledge and the experience into writing, students internalize the reasoning behind science concepts and enhance their scientific understanding (Blumenfeld et al., 1991; Fang et al., 2010; Kim et al., 2019; Langer & Applebee, 1987). In this innovative learning environment, students can use writing as a tool to apply material learned to real-life situations to inquire and search for possible solutions. This process involves “knowledge transfer” (Bransford, Brown, & Cocking, 1999).

#### Science-knowledge transfer

Many researchers have explored the notion of transferring knowledge from one context to another using terminology such as knowledge transfer, transfer of science learning, knowledge transforming, and knowledge-constituting process (Engle, 2006; Engle et al., 2012; Hayes & Flower, 1980; O'Connor & Michaels, 1993; Perkins & Salomon, 2012; Scardamalia & Bereiter, 1987). Bransford, Brown, and Cocking (1999) argue that knowledge transfer occurs when one has the “ability to extend what has been learned in one context to new contexts” (p. 39). For instance, according to Simons (1999), knowledge can be transferred in various ways: “from prior knowledge and skills to new learning, from new knowledge and skills to new learning situations (learning now preparing for later learning), and from new knowledge and skills to applications in work and daily life (learning for practice)” (p. 578). As this project involves multiple methods to address the same scientific concepts, students accomplish knowledge transfer by developing and connecting prior knowledge to a new context.

For three decades, while researchers have shown that science literacy is crucial in shaping conceptual understanding and retaining knowledge (Florence & York, 2004; Langer & Applebee, 1987; Rivard

& Straw, 2000), most prior studies have described the development of science-literacy incorporation in conventional instruction-based settings (e.g., Chiappetta & Fillman, 2007; DeWaters & Powers, 2006). Rarely have researchers studied invention-based science curricula. None have combined the study of invention with exploration of how incorporating explicit language and writing instruction into science teaching provides a tool to encourage knowledge transfer and helps English-language learners understand science concepts, attain knowledge, and apply those concepts in creating an object for real life.

In this study, we explored how middle school English-language learners developed their science literacy and scientific understanding through writing in an IBL science-curriculum unit. The following research questions guided the study:

- 1 How do three L2 learners perceive writing in IBL?
- 2 How do three L2 learners' writing experiences demonstrate understanding of science concepts and the application of knowledge to the real world?
- 3 How do three L2 learners develop science-literacy skills and science concepts through writing in IBL?

#### Methods

For this study, we used a multiple-case-study design to explore three L2 students' perceptions of writing and science-literacy development through writing in an IBL project (Creswell, 1998; Merriam & Tisdell, 2016). We treat each L2 learner as a case. With the case as “the primary instrument for gathering and analyzing opportunities for collecting and producing meaningful information” (Merriam, 1998, p. 20), we collected data on multiple dates using multiple data-analysis methods to establish study trustworthiness (Lincoln & Guba, 1985; Patton, 2002).

#### Context of study

The context involves collaboration between two research universities—Boston College and Lemelson/Massachusetts Institute of Technology (MIT)—and a public-school district in the northeastern part of the United States, where educators implement and study IBL curriculum. The invention curriculum, Chill Out, was developed by Lemelson-MIT. Chill Out units introduce students to the concepts of heat transfer, such as conduction, convection, and radiation.

The school district has a high number of students whose first language is not English (49.2%) and students with special needs (55.3%) (Massachusetts Department of Elementary and Secondary Education, 2020). As a team, we implemented the Chill Out IBL curriculum unit, during regular school hours in seventh-grade science classrooms for approximately 4 weeks in the fall semester.

The Boston College team modified the curriculum for L2 learners, incorporating various visualizations and provided the science-literacy teaching curriculum, teaching materials, and resources as part of the unit. We conducted a workshop and a meeting with a volunteer teacher participant, Ms. Smith on the science-literacy component prior to curriculum implementation. Ms. Smith implemented the Chill Out curriculum in the heat transfer unit in her 7th grade science classroom. English was the primary language of instruction for the three L2 learners.

#### Participants

With Ms. Smith's help, we selected one of her four seventh-grade classes for focused observation, interviews, and artifact collection. To explore how L2 learners developed science literacy and scientific understanding through writing, we selected three L2 learners based on their (a) availability during lunch hours, (b) status as L2 learners, and (c) completion of the project. All participants were children of immigrants and spoke their first language (L1) at home with family members (see Table 1). Victor and Elia's first language is Spanish while Lily's first

**Table 1**  
Demographics of participants.

Name	Victor	Lily	Elia
Grade	7 <sup>th</sup>	7 <sup>th</sup>	7 <sup>th</sup>
Gender	Male	Female	Female
L1	Spanish	Haitian Creole	Spanish

language is Haitian Creole. The three students are proficient English speakers who exited English as a Second Language (ESL) program and no longer receive ESL services. Even though the students are no longer receiving ESL services, students are classified as L2 learners in this study because they learned English as a second language (Stölten, Abrahams-son, & Hyltenstam, 2015). Piller (2002) states that L2 learners are “multicompetent language users and that their competence differs from that of monolinguals in principle”, thus, even the expert L2 users should be measured differently from monolinguals (Piller, 2002, p. 180). According to Stölten et al. (2015), there has been multiple ways to determine the naiveness of L2 learners and one of them is based on self-identification. In this case study, all three students self-identified themselves as L2 learners and bilinguals, describing that they are fluent in English and another language as their mother tongue.

#### Task: Intervention chill out program

The Chill Out Unit, developed by JVInvenTeams from Lemelson-MIT, involves the application of heat-transfer content from the middle school science curriculum to the invention of a lunchbox: <https://lemelson.mit.edu/curriculum-invention/jv-inventteams-chill-out>. The Chill Out unit supports teachers and students to learn and apply heating and cooling in creative ways. The goal of the Chill Out unit is consistent with IBL’s framework and processes that foster inventor mindsets by providing students a wealth of opportunities to explore science through hands-on activities and developing inventions. This is the first time the program was adapted for a middle school science class. Students learned scientific ideas about heat transfer, such as conduction, convection, and radiation, first, then participated in various science labs. The science teacher, Ms. Smith, is an experienced teacher who is in her third year of teaching this class. She taught the main features of science report and its use of language. The writing lessons focused on language and genre of science report writing.

The lunchbox project procedure includes groups of three or four participants. Ms. Smith assigned students to groups before the project. She prepared materials such as shoe boxes, aluminum foil, packing peanuts, wax paper, rubber, styrofoam, paper, cloth, and more. She allowed students to bring other insulating materials from home. The process is to (a) learn science concepts about heat transfer, including convection, conduction, and radiation, as part of the science curriculum; (b) design the lunchbox, with drawings and explanations; (c) obtain materials from the resource area; (d) construct the lunchbox according to the design, attempting to maintain a constant internal temperature when exposed to a heat source; (e) draft a report describing the lunchbox invention and experience; (f) test the invention and discuss successes and potential changes; and (g) receive mini-lessons on the report genre. Ms. Smith provided explicit writing instructions on the genre and language used in procedures and reports; the teacher explained the purpose, element, and structure of writing. The language lesson provided information on language features such as voice, adjectives, and conjunctions (see Appendix A.). After the mini-lesson, Ms. Smith asked students to highlight subjects, verbs, adjectives, and sentences that could be combined with conjunctions. Students thoroughly reviewed highlights of the draft and revised language features based on the mini-lessons. Ms. Smith walked around the classroom to provide extra support.

Students consistently interacted and collaborated in class during the invention-making process. Ms. Smith placed students into groups of

three or four and students worked in groups throughout the inventing process. Group collaboration engaged students, encouraging them to share, elaborate, and demonstrate their reasoning about the experiment and investigation. With the explicit writing instructions and language instructions focusing on vocabulary, students created a lab report, which can be a challenging writing task (Fang et al., 2010). As a result, writing became a mediating tool to construct knowledge drawing on their social interactions and collaboration experiences, in a way that made learning more tangible. The three L2 participants were in the same class and in the same group.

#### Data collection

We collected data through multiple sources: (a) writing drafts, (b) interviews, (c) observations and field notes, and (d) artifacts. We obtained IRB approval from the institution and followed the guidelines carefully.

- 1 Writing drafts: We collected two sets of participants’ writing for analysis: a first draft and a final draft. The writing drafts are the work of an individual student.
- 2 Interviews: We conducted two semi-structured interviews with each participant. Each pre-interview was about 10 minutes and post-interviews were about 30 minutes. The first interview focused on L2’s demographic information, beliefs about science and invention. The second interview covered their experiences, reflections, and writing samples.
- 3 Observation field notes: One researcher observed a class three to four times per week regularly, as a participant observer (as in Merriam, 2009) during the entire Chill Out unit. The researcher observed all students in class, established rapport, recorded observations, and consolidated the information.
- 4 Artifacts: We collected artifacts such as participants’ initial lunch box design and pictures of the final versions of lunch boxes. The initial lunch box design and pictures of the final versions of lunch boxes were group artifacts. Each group produced different lunch boxes with unique designs and insulation materials.

#### Data analysis

We analyzed the first data set, L2 learners’ writing samples, in two ways: we analyzed how L2 learners revised the language in their writing and we analyzed how L2 learners developed their conceptual knowledge and applied their scientific knowledge to the real world. Further, we analyzed students’ interview data. We transcribed the interviews and analyzed the transcripts inductively.

First, we analyzed the same student’s writing for language choice and usage. We inductively analyzed the L2 learners’ before and after writing samples to discern their scientific understanding in relation to the knowledge of language appropriate in science. For instance, we coded and analyzed each type of revision—such as “change from everyday language to language reflecting scientific concepts”—across students’ essays.

Second, we examined their acquisition of science concepts based on the modified Garcia (1985) and Chiappetta and Fillman (2007) science-literacy framework and inductively analyzed L2 learners’ writing samples using the four science-literacy categories: (a) science as a body of knowledge, (b) science as a way of investigating, (c) science as a way of extending knowledge, and (d) science as a way of extending knowledge to interact with society. We searched for evidence of the four categories in each student’s writing. We present the categories and subcategories in Table 2.

Third, we inductively analyzed interview and field-note data (Lincoln & Guba, 1985; Merriam, 1998; 2009) with a research question in mind: “How do L2 learners develop science literacy and scientific understanding through writing?” We first conducted open coding to

**Table 2**

Categories and subcategories used to analyze how students demonstrated and extended conceptual knowledge.

Science as a body of knowledge	Science as a way of investigating	Science as a way of extending knowledge	Science as a way of extending knowledge to interact with society
Presence of facts/ concepts/ laws/principles/ - Concept(s) must be described in at least one full sentence in order to be considered a concept  - Making connections between concepts and experiment  - Lunch box experiment illuminates a concept and describes related phenomena	Scientific method or other investigative procedure - A discussion of the scientific method, materials, or any other investigative procedure is demonstrated - Manipulative skills and process skills are presented  - Manipulative skills such as measuring, weighing and drawing are used - Process skills in science, such as analyzing, observing, and classifying are included	Scientific thinking and discovery  - Scientific thinking and discovery are included  - Illustration of thinking processes such as cause and effect, interpretation, and explanation - Presents methods of science and problem solving (method and process)  - Gives evidence and proof	Making connection to real-life  - Usefulness and value of science and invention to society  - Indicates appreciation of benefits gained from science and invention)

capture key words and concepts from student interviews. Then we combined these to form thematic categories such as “writing for reconceptualization,” “strengthening understanding of scientific concepts,” and “emerging ideas by highlighting words and phrases” that indicated students’ experiences and perceptions. After writing possible themes next to each category, we reviewed the transcripts and field notes again to check the themes and codes, such as “writing-positive-reconceptualization.” We established the trustworthiness of the study by adopting triangulated data and continuously cross checking among researchers (Lincoln and Guba, 1985). Two team members worked to review the data, and their coding was almost identical. We resolved the few differences through dialogue between researchers. We also compared and contrasted L2 learners’ writing and interview transcripts with their initial lunch box designs, with the lists of used materials and the pictures of final lunch boxes.

## Results

This study focused on L2 learners’ development of conceptual understanding and science literacy in writing and their perceptions and experiences when writing about invention in science class. The L2 learners in this study are proficient in both their first language and English. They self-identified as bilinguals, fluent in both languages. Their English language proficiency levels are similar to L1 students. All three participants appeared fluent in oral English and competent in reading and writing.

### L2 Learners’ perceptions and experiences in writing

The three students shared the perception that writing is an important skill to acquire in the field of science:

**Elia:** I do think writing is important in science because like writing is like a lot important thing we have to do. I don’t know why but in science like writing it down what you do like a lot of scientists draw down notes like while they were doing the experiments, like what is happening. So I do think it’s important all the time.

**Lily:** because most likely you’re supposed to do a report on what you find in science and about your experiment.

**Victor:** I think so ’cause if you are older and you don’t really like say you want to have a job as doing science you need to write a report on something and you didn’t really do that as a child when you were younger and you didn’t have much practice and you could have difficulty.

However, students had mixed feelings and opinions toward their inventing experience. Students used words to describe their experience like “good,” “fun,” “challenging,” “a little bit frustrating,” “really awesome,” and “really cool.” They explained that the invention experience

was challenging, but also had positive feelings and attitudes toward it. For instance, Victor explained that the invention process was fun but frustrating at the same time. Elia added, “It was a good experience, really cool like building a new thing that I’ve never learned before and I feel like a challenge but it was like really awesome at the same time.”

All three L2 learners mentioned that writing was challenging, yet it enhanced their understanding of scientific concepts and invention experiments. Victor explained that the challenges of writing were “time-consuming” and took “a lot of thinking,” while Lily and Elia mentioned that they faced challenges such as finding appropriate words, accurately describing their findings, or finding scientific concepts. Despite the difficulties, all three found writing helpful in building their understanding of scientific concepts and experiments. Lily described writing in this way: “We understood our experiment more because we could like write an essay about how these concepts occurred in deeper definition” and “we got to increase our mindset and how we view our writing.” Similarly, Elia said that writing was helpful because she relearned the concepts. The following quotation shows how Victor perceived writing as a helpful tool:

Well, it made me understand more about convection, conduction and radiation and like objects that are good conductors ... because I sometimes understand more when writing about it or reading it instead of learning from somebody else. ... I understand more clearly of preventing heat energy works.

Victor explained his experience:

Before I was a little bit nervous on writing this because I wasn’t really like the concepts and some of the words were like a little bit confusing for me and after that as I like just wrote I wrote what I thought. ... And as I wrote I understand more about the concept and the words.”

Lily shared the experience of emerging ideas while explaining a paragraph about connecting the concept of radiation to the use of sunscreen:

Well, it really just popped into my head when I was writing the rough draft, because it seems like really likely, because every day some people use sunscreen during hotter days ... because before, I didn’t know about, I didn’t know much about how to prevent like what from transferring, or like heat transferring through liquid gas, and then after I realize more of that idea and my writing got better.

Students described how writing helped them engage in deeper thinking. While Elia explained she was able to relearn the concepts through writing, Lily said that she was able to understand ideas better because she was given a chance to explain how the scientific concepts occurred “in deeper definition.”

Victor described how writing took a long time and he had to engage in “a lot of thinking.” L2 learners indicated that the time and thinking

**Table 3**  
Victor's revision.

Name	Type of revision	Before explicit writing instruction	After writing explicit instruction
Victor	Change from everyday language to language reflecting scientific concepts (word choice)	1. Thermal equilibrium is when heat energy will flow from an <u>area of</u> high temperature to low temperature until the two objects are at the same temperature.	1. ...thermal equilibrium [which] is when heat energy will flow from an <u>object with</u> high temperatures to <u>one with</u> low temperatures until the two objects are at the same temperature.
	Adding evaluative language to provide emphasis.	2. In conclusion the challenge was trying to keep the water bottle cold.	2. In conclusion the <u>real</u> challenge was trying to keep the water bottle's first temperature close to its final temperature.

**Table 4**  
Lily's revision.

Name	Type of revision	Before explicit writing instruction	After explicit writing instruction
Lily	Change from everyday language to language reflecting scientific concepts (at the word level).	1. During this project we radiation occurring when the heat lamp <u>shined</u> its light on the top of the box.	1. During this project radiation occurs when the heat lamp <u>emits</u> its light on top of the box.
	Change from everyday language to language reflecting scientific concepts (at the word level)	2. ...basically <u>anything</u> that involves with the sun to a solid, liquid, gas.	2. ...basically any <u>prevention</u> that involves with the heat of the <u>sun</u> to a solid, liquid, or gas...
	Change from everyday language to language reflecting scientific concepts (Voice shift from familiar voice to authoritative voice)	3. <u>The steps we took to prevent heat from reaching the water bottle through the process of radiation is by covering the top of the box with white paper instead of dark colored paper because darker colors absorb more heat and light colors reflect more heat.</u>	3. <u>To prevent heat from reaching the water bottle through the process of radiation, the top of the box is covered with white-colored paper instead of dark-colored paper because darker colors absorb more heat while lighter colors reflect more heat.</u>

spent in writing enhanced and clarified their understanding of scientific concepts. They articulated how writing about the invention required them to recall, revisit, and reconstruct core scientific concepts in the experiment. Throughout the process, students were able to reconceptualize and strengthen their understanding of scientific knowledge.

Even as L2 learners mentioned writing as a challenging task, they recognized an increase in their understanding during the writing process and experienced the discovery of new ideas. The three students also made a strong connection between writing and understanding science. For instance, two L2 learners extended and connected their experience to the science profession, as they believed it was important for scientists to write a report and record their experiments during the invention process, as they did.

#### *Text analysis of L2 learners: Scientific understanding in relation to language use*

All three L2 learners made revisions after the explicit instruction; however, the type of revision varied. Results included (a) changes from everyday words to scientific concepts (e.g., word choice), (b) shifts of voice (e.g., authority voice), and (c) evidence of knowledge transfer in their writing (e.g., application of scientific knowledge to daily activities).

Victor's paper contained all three types of revisions. By using a noun semantically connected to the scientific concept—thermal equilibrium—Victor revised a phrase, "an area of" to "an object with," thus changing language from everyday use to scientific language. The word "area" is an everyday language word that provides a less specific image of heat transfer compared to the word "object." The replacement shows that Victor's understanding of thermal equilibrium has become more accurate and scientific. The second revision was in evaluative language. Victor added "real" in front of the word "challenge" to emphasize the difficulty of his experiment. Even though including evaluative language did not significantly improve the content, his intention was clear. See Victor's revision in Table 3.

#### *Table 4 and 5.*

Like Victor, Lily changed language from everyday to specific language that made science concepts explicit and enhanced accuracy. Two changes were in vocabulary and one was in voice. For example, Lily

changed from "shined" to "emits" to more accurately describe the action of radiation and from "anything" to "any prevention" to provide a clear referent. When explaining the purpose of covering the box with white paper, Lily changed the voice of the sentence from a familiar and casual voice to an objective and authoritative voice, to be more appropriate in her science writing. In the first draft, she used a pronoun, "we," more familiar in everyday language. In her revised draft, she used the sentence with a non-finite verb, "to prevent," to write causal and effective sentences to describe the science experiment. After initially using familiar concepts and everyday words, Victor and Lily advanced their language choices to be more scientific.

Elia made three types of language revisions. Among the three, two were made to improve accuracy. She changed the construction of a noun group from "the air outside the water bottle" to "the air outside the water in the bottle" to provide an accurate description of phenomenon. Although her first word choice "water bottle" refers to a type of bottle, the revised phrase "water in the bottle" refers to the water itself. This revision demonstrated the change in her understanding of the scientific phenomenon, convection, in the experiment. Her initial description of heating up "the air outside the water bottle" does not directly relate to the heat transfer from gas (air inside the water bottle) to liquid (water). Her initial explanation relates more to conduction, heat transfer through a solid, because the air outside the water bottle will not affect the water temperature directly, though the temperature of the bottle will. This indicates the development of her understanding between the two drafts. In addition, replacing an unclear referent, "they," with a specific referent, "materials," showed her intention to increase the accuracy of the description. In addition, changing everyday language to scientific language, such as changing "prevent" to "blocked" and "touching" to "reaching," also showed her intention to more precisely describe the phenomenon.

Lastly, by adding the quantifier "most" to the sentence, Elia corrected her prior understanding of heat transfer in the lunchbox experiment. Her revision from "they [materials] prevent the hot air from touching the cold water" to "the materials blocked most of the hot air from reaching the cold water in the bottle" indicated the new information that the materials could not completely prevent the heat from reaching water.

The changes in student writing revealed two types of development, in language and scientific comprehension. The result shows the L2 learners

**Table 5**  
Elia's revision.

Name	Type of revision	Before explicit writing instruction	After explicit writing instruction
Elia	Change in construction of the noun group to improve accuracy in meaning Referent "they" to "the material" Change from everyday language to language reflecting scientific concepts ("prevent" to "blocked" and "touching" to "reaching") Adding a quantifier: most	1. ...when <u>the air outside the water bottle heats up</u> .  2. <u>they prevent the hot air</u> from <u>touching</u> the cold water.	1. ...when <u>the air outside the water in the bottle heats up</u> ..  2. <u>the materials blocked most of the hot air from reaching</u> the cold water in the bottle.

increasing their ability to explain the phenomenon with precision and accuracy in their writing. For instance, the use of scientific language and objective voice instead of everyday language and familiar voice dramatically improved the accuracy of their meaning in context, and employed scientific concepts. Choosing accurate words offered them the ability to more precisely describe the scientific experiment. Since writing reflects knowledge of language and content, by describing the phenomena accurately and scientifically in writing, students demonstrated their understanding of the scientific phenomena.

#### *Science as a body of knowledge: Scientific knowledge and understanding*

All three L2 learners' writing demonstrated their conceptual understanding of scientific phenomena such as heat transfer, convection, and radiation, and their roles in the invention experiment. Victor first defined heat transfer and thermal equilibrium, then applied them in describing his invention experiment:

And heat transfer is the transfer of energy from a higher temperature object to a lower temperature object. ... Thermal equilibrium, which is when heat energy will flow from an object with high temperatures to one with low temperatures until the two objects are at the same temperature. ... Heat transfer and thermal equilibrium are involved in this project because when heat transfers from the light to the water bottle they will both be the same temperature, as time passes by, which is thermal equilibrium.

His application of heat transfer and thermal equilibrium to his invention experiment showed how his understanding of those two concepts extended beyond memorizing definitions. He understood those two concepts scientifically, then applied them in the experimental setting. Lily and Elia also demonstrated their understanding of a learned scientific concept. Lily wrote, "During this project radiation occurs when the heat lamp emits its light on top of the box" and Elia explained that "throughout this project convection occurs when the air outside the water in the bottle heats up, the air that is heating up due to the heat lamp, transfers to the cold water causing the water to heat up."

Lily's description of the experiment setting revealed her understanding of radiation as heat transfer through light. Elia was also able to explain how convection occurred during the experimental process. This indicated that Lily and Elia's understanding of the concepts went beyond simple memorization; they digested the concepts and were able to apply them to their invention.

#### *Science as a way of investigating: Scientific thinking skills*

The students' writing demonstrated their engagement in scientific investigation and thinking. Both Victor and Lily paid close attention to the results of other groups' water-bottle temperature testing. Their writing provided a space to compare the lunch boxes and allowed them to investigate and inquire into the possible reasons behind success and failure:

**Victor:** All in all, the project was moderately successful because ... the difference between the beginning and final temperatures of

the water bottle was only a remainder of 4.6 degrees Fahrenheit which is not such a drastic dispute ... an observation was that because of adding white-colored paper the project was more successful since three out of the top four rankers had white-colored box.

**Lily:** Some other boxes that contained aluminum foil or other conductors had a greater difference from the beginning temperature of the water bottle to the final temperature than other boxes with more insulators.

Victor and Lily observed other groups' uses of materials in the lunchbox to explore reasons for the success of their invention. Victor first claimed that his project was moderately successful based on the difference in temperature measurements, then provided reasons based on his observations and investigation. He observed other groups' experiments and investigated to find a common feature: three of four top-performing lunch boxes were covered by white paper. With this in mind, he argued that the white paper contributed to the success of his invention. Lily also observed other groups' use of materials to investigate the possible reasons for greater and smaller differences between water-bottle temperatures. After the scientific observation and investigation, she concluded that aluminum foil may cause greater temperature differences; thus, she concluded that aluminum foil is not an efficient insulator. Victor's and Lily's writing demonstrated their advanced science thinking skills. Their writing showed their deep engagement in scientific observation and investigation. They observed other groups' experimental results and investigated materials to form their own explanations and conclusions.

Unlike Victor and Lily, Elia's writing lacked logical reasoning; instead, her writing only demonstrated her understanding of the experiment and scientific understanding of phenomena. She wrote:

To prevent convection we use paper, styrofoam, tape, packing peanuts, rubber bands, aluminum foil, and wax paper. These materials were effective in preventing convection because the materials blocked most of the hot air from reaching the cold water in the bottle.

Although Elia presented her understanding of convection as heat transfer through air, her writing was not successful in explaining why she chose the materials; she only indicated that the materials were placed to block heat transfer into the lunchbox and did not explain how each material prevented heat transfer. Her writing indicated that her scientific-thinking skills were less advanced than those of Victor and Lily.

#### *Science as a way of extending knowledge: Connection to real-life*

Some of the L2 learners illustrated their extension of scientific knowledge and applications of scientific concepts to real-life experiences:

**Lily:** Conduction is the transfer of heat through a solid. When this project was in its process phase, conduction occurs when the top of the box was heated and that heat transferred through all the materials outside the box. ... This process is related to ... when people wear cooking mittens to prevent heat from transferring from a hot

pan to a person's hand, the cooking mittens slow down the transfer of heat so the hand won't heat up, and have a burning feeling.

In writing, Lily demonstrated her understanding of conduction ("conduction is the transfer of heat through a solid") and how it occurred in the invention experiment ("conduction occurs when the top of the box was heated and that heat transferred through all the materials"), then how this scientific concept relates to people's daily experiences. Elia also demonstrated her understanding of convection and the application of convection in the invention experiment. However, she was unable to connect the concept of convection in the experiment to everyday life phenomena.

Elia: Convection is the transfer of heat through a liquid or a gas. And throughout this project convection occurs when the air outside the water in the bottle heats up, the air that is heating up due to the heat lamp, transfers to the cold water causing the water to heat up ... heat can transfer from boiling water to cause steam and to stop this transfer of heat simply remove heat to lower the temperature.

She was correct that transferring water to steam is a process of convection, but this process does not relate to the lunchbox experiment. As she explained above, convection occurred when the lamp heated up the air surrounding the water bottle; however, this does not relate to her example of heat transfer from boiling water to steam. This shows how Elia was able to understand the concept of convection in the experimental setting but was not able to extend the knowledge further.

## Discussion and implication

This case study showed how three L2 learners developed science literacy and scientific understanding through reflective activities in the IBL project. The findings demonstrate L2 learners' ability to conceptualize, apply, and reconstruct scientific knowledge through the IBL project as well as their linguistic and conceptual development through writing.

### *Before and after writing instruction*

Evaluation of L2 learners' expression before and after writing suggests that the development of language skills relates to the development of thinking. As Halliday (1993) noted, "language is the essential condition of learning, the process by which experience becomes knowledge" (p. 94). The L2 learners' revisions demonstrated their development of linguistic and scientific comprehension. Students' revisions showed that, by adding or changing language, voice, referent, evaluative language, and construction of noun groups, students were able to better express their point to readers and strengthen their writing and thinking. Fang (2005) argues that

Learning science means learning to control the unique linguistic forms and structures that construct and communicate scientific principles, knowledge, and beliefs. Thus, developing literacy in science is fundamentally a semiotic process involving systematic remodeling of everyday grammar and concomitant reconstrual of everyday ordinary life experiences (Wells, 1994, p. 337)

Likewise, as L2 learners learned to use accurate language in appropriate context, their understanding of scientific phenomena developed, showing that writing can be important to the process of learning science. As Magnifico (2010) claimed, "the language becomes part of how [they] understand the situation" (p. 173). As a result, with the growth of understanding of language, writing solidified L2 learners' understanding of science concepts and provided opportunities to rethink, reflect, and reconstruct what they learned (Bakhtin, 1994; Calkin, 2018; Flower and Hayes, 1981; Magnifico, 2010).

### *Advancing Knowledge Transfer (KT) to Knowledge Reconstruction (KR) through writing*

Our findings described how three L2 learners extended the knowledge-transfer mechanism (Engle, 2006; Engle et al., 2012; Hayes & Flower, 1980; O'Connor & Michaels, 1993; Perkins & Salomon, 2012; Scardamalia & Bereiter, 1987) to knowledge reconstruction in IBL. Previous studies have described knowledge transfer as an application of knowledge from one context to another (Bransford, Brown, & Cocking, 1999). The three L2 learners in our study learned, applied, and extended science concepts. Furthermore, they reconstructed their knowledge to apply it to the real world.

During the IBL process, students reconstructed their scientific knowledge. For example, to create an effective lunchbox, students had to investigate and reflect on learned scientific concepts at each stage of the invention process, from selecting materials to building low heat transferring lunchboxes. The process of transferring scientific knowledge to the lunchbox provided students the opportunity to experience how intangible ideas come alive. During the lunchbox experiment, students saw how the scientific concepts of conduction and radiation affected the water-bottle temperature inside their lunchbox. This knowledge reconstruction took place through a process of internalizing and demonstrating their understanding through writing. The students engaged in the process of knowledge reconstruction, extending the transferred knowledge to the invention experience and their own lives. Because writing requires in-depth reflection, problem-solving, investigating, critical thinking, and scientific-reasoning skills, it challenges students to rethink and connect their knowledge and experience. The process of writing provided time and space for students to reflect, extend, and reconstruct the knowledge to their invention and to phenomena outside the school setting (Engle et al., 2012; Fang, 2005; Fang et al., 2010; Hand & Prain 2006; Jiménez-Aleixandre et al., 2000).

Furthermore, being a writer about one's invention creates a sense of expertise, responsibility, and authorship that enhances the transfer of knowledge into a new context (Engle, 2006; Jacoby & Gonzales, 1991; Strom, Kemeny, Lehrer, & Forman, 2001). Engle (2006) claims:

[Thus] being framed as an author prepares a learner to both generatively use the specific content he or she has authored so far and regularly engage in authoring ideas of all kinds, both of which would make transfer more likely. These mechanisms crucially make use of the fact that the one form of intercontextuality that always exists between learning and transfer contexts is the presence of the same learner. (p. 457)

L2 learners' application of knowledge to their daily activities is evidence of transferring and reconstructing knowledge in a new context. For instance, Lily's explanations of the purpose of cooking mittens and the use of sunscreen show how she extended her thinking by connecting curricular knowledge to real-life settings. However, the application of knowledge to daily activity is an advanced learning step that requires deep thinking and understanding of scientific phenomena. Thus, providing sufficient opportunity to engage in deeper thinking and constant feedback will be essential to achieve this stage of learning.

### *Implications of writing in science*

Implications of writing science include: (a) the benefits of a hands-on IBL program, (b) explicit writing instruction in science class, and (c) sufficient instruction and scaffolding. First, it is clear that the combination of a hands-on IBL program and writing enhanced students' science literacy and extended their understanding beyond traditional classroom learning. Creating an innovative and comprehensive program provides a better opportunity for students to engage in science learning, making it more enjoyable and more connected to real-life learning.

Second, through explicit instruction, students' access to science learning becomes more effective. Writing in science was challenging,

but students described the importance of writing. For instance, Victor expressed his anxiety toward writing, whereas Lily and Elia reported their struggles to effectively use appropriate words in writing. All three students described writing as an essential skill to learn in science; they claimed that their writing experience facilitated their understanding of scientific concepts and experiments. Derewianka and Jones (2016) argue that educators should “make the language demands of the curriculum explicit so that all students have access to linguistic resources needed for success in school and to the powerful ways of using language in [the] culture” (p. 3). This describes how, to use writing as a tool for learning, it is essential for students to learn how to write in the context of science (Carrasquillo et al., 2004; Fang et al., 2010; Martin & Rose, 2005).

Third, incorporating explicit writing instruction enables students to use writing as a learning tool to facilitate their understanding in science (Carrasquillo et al., 2004; de Oliveira & Lan, 2014). Having appropriate explicit writing instructions and guidance is critical. We created explicit writing instructions for this project (see Appendix A). The improvement of writing helped students to accurately express their knowledge in writing and as the writing become definite and precise, students’ understanding expanded further. L2 learners in this study have fluent levels of English proficiency and writing tasks did not reflect their home culture or home language. However, they continued to improve their academic writing skills. Writing to learn can be an abstract and seemingly unachievable goal. To adequately support and guide students, explicit instructions and guided practices are essential (Daniello, 2012; Derewianka and Jones, 2010; Derewianka & Jones, 2016). In addition, writing support will assist students in overcoming their challenges and anxiety toward writing in science and eventually build confidence in writing.

**Conclusion**

This case study explored the effectiveness of writing among the three proficient L2 learners in an IBL environment in a science classroom. The findings demonstrated how, as students used scientific concepts to create

an invention, they experienced intangible ideas coming alive. Students observed the effects of abstract concepts and internalized and transferred knowledge by creating an invention. Then, through writing, students reconstructed the knowledge to deepen their understanding of scientific concepts and extend the knowledge to their daily lives (Florence & Yore, 2004; Rivard & Straw, 2000). These results suggest that writing and IBL together can help L2 learners develop their science literacy and understanding. In addition, student interviews suggested that, to maximize student learning, more explicit writing instruction is necessary to address the high language demands in the science classroom.

This research provides insights into the three L2 learners’ experiences of learning and writing in an IBL program. However, because IBL is a new emerging approach to teaching, more research is necessary. Future studies can address diverse applications of IBL and writing processes with teachers’ experiences and perceptions of the new curriculum. Such future work can describe more specifically how teachers might adopt IBL and writing processes in their curricula.

**Declaration of Competing Interest**

There are no conflicts of interest to disclose.

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**Appendix A. Explicit writing instructions**

Language Features checklist  (#8)

Topic	Explanation and direction	Checkbox
1. Voice	<p>A scientific report is completed in the third person, present/past tense. This allows readers to focus on the topic, rather than the author’s point of view.</p> <p>Using a pink highlighter on your rough draft, highlight every time you say “I” and/or “We” in your essay. Revise the highlighted part on your final draft.</p> <p>* Example: “I believe the metric system can be applied in the United States” should be highlighted and later changed to “<b>According to evidence provided by other countries</b>, the metric system can be applied in the United States.”</p> <p>*Example: “In this project we looked at the traditional heating system in South Korea” should be changed to “<b>This project examined</b> the traditional heating system in South Korea”</p> <p>Using a green highlighter, highlight verbs both in past and present tense.</p> <p>Check if it is used appropriately:</p> <p>Use present tense for scientific concepts and theories (general truth/facts)</p> <p>Use past tense for all the procedures used in experiments</p> <p>Revise the highlighted part on your final draft.</p> <p>*Example: “During this project, radiation <b>occurs</b> when the heat lamp ...” should be changed to “During this project, radiation <b>occurred</b> when the heat lamp...”</p>	<p>Inventor’s signature: _____</p> <p>Teacher’s approval: _____</p> <p>Inventor’s signature: _____</p> <p>Teacher’s approval: _____</p>
Generic vs. Semantically related adjectives	<p>A general adjective, like “nice” and “great” does NOT describe the noun in relation to the topic. Semantically related adjectives aim to describe the meaning of the noun more accurately.</p> <p>Using a yellow highlighter, highlight any adjectives that you have used in your essay. If needed, revise the highlighted parts of your final draft.</p> <p>*Example: if someone was writing about a pyramid, they might use adjectives like “<b>traditional</b>”, “<b>historic</b>”, and “<b>ancient</b>” instead of “big” or “old”.</p>	<p>Inventor’s signature: _____</p> <p>Teacher’s approval: _____</p>
Conjunctions and connectives	<p>We use conjunctions and connectives in scientific writing to combine ideas and create relationships within a sentence.</p> <p>Using a blue highlighter, find two sentences in each paragraph that might be better as one sentence. Highlight these two sentences. Try combining them into one sentence in your final draft</p> <p>*Example: “He lost his money. He could not go to the restaurant” should be combined as, “<b>Since he lost his money, he could not go to the restaurant</b>”</p>	<p>Inventor’s signature: _____</p> <p>Teacher’s approval: _____</p>

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