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Intersection of argumentation and the use of multiple representations in the context of socioscientific issues

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ABSTRACT

Using multiple representations and argumentation are two fundamental processes in science. With the advancements of information communication technologies, these two processes are blended more so than ever before. However, little is known about how these two processes interact with each other in student learning. Hence, we conducted a design-based study in order to distill the relationship between these two processes. Specifically, we designed a learning unit on nuclear energy and implemented it with a group of preservice middle school teachers. The participants used a web-based knowledge organization platform that incorporated three representational modes: textual, concept map, and pictorial. The participants organized their knowledge on nuclear energy by searching, sorting, clustering information through the use of these representational modes and argued about the nuclear energy issue. We found that the use of multiple representations and argumentation interacted with each other in a complex way. Based on our findings, we argue that the complexity can be unfolded in two aspects: (a) the use of multiple representations mediates argumentation in different forms and for different purposes; (b) the type of argumentation that leads to refinement of the use of multiple representations is often non-mediated and drawn from personal experience.

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Introduction

Current science education reform initiatives call for a shift from solely teaching science as isolated facts about the natural world to engaging students in practices similar to that of scientists, so that the students can develop more coherent understanding of how science progresses (National Research Council, 2012; NGSS Leads States, 2013). Among the eight core practices for students' engagement that has been promoted in the Next Generation of Science Standards (NGSS Leads States, 2013), argumentation has received a significant amount of attention from the science education research community (Lin, Lin, & Tsai, 2014). Empirical research in the field has indicated that argumentation could, for instance, enhance students' conceptual science understanding (e.g. Bell & Linn, 2000; Cross, Taa-soobshirazi, Hendricks, & Hickey, 2008; Zohar & Nemet, 2002), improve their nature

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of science understanding (e.g. Bell & Linn, 2000; Yerrick, 2000), and foster achievement for inquiry goals (e.g. McNeill, Pimentel, & Strauss, 2013). Nonetheless, how to best support students' argumentation remains relatively unexplored (Evagorou & Osborne, 2013).

One way to support argumentation is to use multiple representations. Practicing scientists use various forms of representations to design experiments and communicate their results and ideas (Kozma, 2003; Lemke, 1998). Similarly, research in science education has indicated that when presented with representations, students are able to acquire relevant information from given representations to support their claims and, thus, construct sound arguments (e.g. Hand & Choi, 2010; Pallant & Lee, 2014). However, expert scientists not only use representations to support their arguments but also employ argumentation as a way to enhance existing representations or even create new representations that would enable them to better execute their practices. In the meaning-making process, scientists move freely between their representations and arguments (Kozma, 2003). It seems that using multiple representations and argumentation are two naturally coupled processes.

Despite the importance of the interaction between argumentation and the use of multiple representations, there is no clear framework about how to connect them in a more systematic way. Although they were mentioned together in the new Framework for K-12 Science Education (e.g. 'over the years, students will develop more sophisticated use of scientific talk- which includes making claims and using evidence- and of scientific representations' (NRC, 2012, p. 252)), their intersections were not described. In fact, in the science education research community, they have been typically pursued as two different research agendas. Research related to the use of multiple representations has shown that students are capable of creating their own representations (DiSessa, 2004; Lehrer & Schauble, 2006) to construct and represent their understanding and claims (Hand & Choi, 2010; Kozma & Russell, 2005; Mayer, 1997). Research related to argumentation has typically focused on the elements and structure of arguments (e.g. Kelly & Takao, 2002; Leitão, 2000; Schwarz, Neuman, Gil, & Ilya, 2003) as well as dialogical relationships (e.g. Barth & Krabbe, 1982; van Eemeren, Grootendorst, & Henkemans, 1996; Walton, 2007). However, the mechanisms by which these two practices support each other have received scarce empirical research (Munneke, Amelsvoort, & Andriessen, 2003). As a result, still little is known about how students' use of representations intersects with their argumentation practices. Therefore, in this study, we focused our inquiry on exploring this important relationship and asked the following questions:

(1) How does the use of multiple representations mediate argumentation on a socioscientific issue, and vice versa?
(2) What types of discourse characteristics exist when the use of multiple representations intersects with the use of argumentation on a socioscientific issue?

Theoretical perspectives

The noun *argument* has been defined in many ways by different scholars. Many of these definitions stress the idea of providing evidence or support. For instance, Reike and Sillars

(1993) defined an argument as 'the intersection of a claim and its support' (p. 3). In their definition, claims are the statements that someone makes to convince others. Supports, on the other hand, are all the things that are used to secure coherence and persuade others to accept one's claim. Similarly, Besnard and Hunter (2008) defined an argument as a set of assumptions (support or premises) and its conclusions (claims). They also stated that 'support of an argument provides the reason (justification) for the claim of the argument' (p. 2). Zohar and Nemet (2002) gave a broader definition of an argument. According to them, 'an argument consists of either assertions or conclusions and of their justifications or of reasons or supports.' (p. 38). Toulmin (1958), in his seminal book *The Uses of Argument,* described a comprehensive model of the structure of argument that includes six core components: *Claims* are assertions about facts or people's perceptions or beliefs; *Data* (Grounds) are statements of foundational evidence that supports a claim; *Warrants* are used to show why data are relevant to a claim; *Qualifiers* indicate the strength of warrants to a claim; *Backings* refer to underlying assumptions which strengthen the acceptability of a claim; and *Rebuttals* are statements that rebut and defeat the warranting conclusion.

Toulmin's (1958) structural model of argument has been widely used to both introduce and assess argumentation in K-12 science education settings (e.g. Christodoulou & Osborne, 2014; Erduran, Simon, & Osborne, 2004; Jiménez-Aleixandre, Rodriguez, & Duschl, 2000; Zohar & Nemet, 2002). It has also been used to describe the small-group argumentation patterns in science classrooms (Erduran et al., 2004). Recently, an increasing number of studies use the Claim, Evidence, and Reasoning framework to introduce argumentation, which was built on Toulmin's argumentation model (e.g. Berland & Reiser, 2009; Sampson & Clark, 2009; Sandoval & Reiser, 2004). In this study, we adopted this framework to introduce argumentation. We introduced claim as the initial response or assertion to the question posed, evidence as observations and/or data that support a claim, and reasoning as justification connecting how and why the evidence supports the claim (McNeill & Krajcik, 2007).

The word *argumentation* refers to the process of creating arguments. It is 'aimed at convincing a reasonable critic of the acceptability of a standpoint by putting forward a constellation of proposing, justifying, or refuting the proposition expressed in the stand point' (van Eemeren & Grootendorst, 2004, p. 1). Argumentation can be conceptualized as a three-dimensional construct (Namdar & Shen, 2012). First, it is a *linguistic* process in which people produce verbal or written arguments (Kuhn, 1992); second, it is a *cognitive* process when a person executes reasoning while arguing (Kuhn, 1993); and third, it is a *social* process as arguers discuss things together or an arguer constructs an argument while having an imaginary interlocutor in mind (Leitão, 2000).

The process of generating and evaluating arguments can be defined as reasoning (Voss, Jeffery, Means, Greene, & Ahwesh, 1986). Formal reasoning in science, where the problems are well structured and the premises reached are fixed, often requires reasoners to use mathematics and logic to avoid adding personal ideas and belief when drawing conclusions (Evans & Thompson, 2004). On the contrary, in informal reasoning, both problems and premises tend to change when additional information becomes available (Kuhn, 1991; Means & Voss, 1996). Thus, informal reasoning 'involves reasoning about causes and consequences and about advantages and disadvantages, or pros and cons, of particular propositions or decision alternatives' (Zohar & Nemet, 2002, p. 38). As socio-scientific issues (SSI) are ill-structured problems with multiple possible solutions, arguers often use informal reasoning to reach conclusions about these issues (Sadler, 2004; Sadler & Donnelly, 2006).

In our study, we approached argumentation on SSI from a collaborative argumentation perspective similar to recent argumentation studies in the context of SSI (e.g. Albe, 2008; Evagorou & Osborne, 2013). In these contexts, we consider both the structure of argumentation such as Toulmin's model and the informal reasoning characteristics. During collaborative argumentation, learners share ideas, discuss alternative interpretations, consider additional evidence, question each other, and try to understand inherent complexity of the issues (Acar, Turkmen, & Roychoudhury, 2010; Albe, 2008; Evagorou & Osborne, 2013; Sadler & Donnelly, 2006; Sampson & Clark, 2009). In this process, learners work in small groups (either online or face-to-face) to find workable solutions on a given task instead of solely focusing on defeating the others' ideas (Baker, 2009).

Research in the area of employing argumentation in classrooms has grown exponentially in the last few decades (Bathgate, Crowell, Schunn, Cannady, & Dorph, 2015; Berland & Hammer, 2012; Berland & Reiser, 2011; Erduran et al., 2004; Forbes, Biggers, & Zangori, 2013; Garcia-Mila, Gilabert, Erduran, & Felton, 2013; McNeill & Knight, 2013; Nielsen, 2012; Osborne, Simon, Christodoulou, Howell-Richardson, & Richardson, 2013; Sampson, Enderle, Grooms, & Witte, 2013; Tal, Kali, Magid, & Madhok, 2011; Zohar & Nemet, 2002). In the following, we further elaborate on two aspects: the use of representations to mediate argumentation and the use of argumentation to mediate further use of multiple representations. Next, we define SSI and computer-supported collaborative learning (CSCL) as two instructional contexts that we believe can facilitate the intersection between argumentation and the use of multiple representations.

How does the use of multiple representations mediate argumentation?

Multiple representations '… symbolize an idea or concept in science … and can take the form of analogies, verbal explanations, written texts, diagrams, graphs, and simulations' (Tang, Delgado, & Moje, 2014, p. 306). They emphasize the variety of representations *external* to the mind and, therefore, can be used effectively to improve learning (Wu & Puntambekar, 2012). According to Lemke (1998), it is important to combine multiple representations to do and to communicate science. Therefore, scientists use multiple representations in every aspect of their daily practices in order to effectively organize knowledge, communicate, and justify their ideas and claims to their peers and to the public (Kozma, 2003; Lemke, 1998).

The use of representations has been studied in science education from many aspects including enhancing students' conceptual understanding and engagement (Ainsworth, 1999, 2006; Hubber, Tytler, & Haslam, 2010; Prain, Tytler, & Peterson, 2009; Tsui & Treagust, 2003; van der Meij & de Jong, 2006) and communicating complex ideas (Brooks, 2009; Roth & McGinn, 1998). Recent emphasis in the use of representations has been placed on their role in scientific argumentation (Mendonça & Justi, 2013) as learners select, combine and organize information through different representations to construct explanations (Mayer, 1997; Sandoval & Millwood, 2005). The majority of studies on how multiple representations mediate argumentation have focused on students' practices of constructing arguments using evidence from multiple representations. For instance, in a recent study, Pallant and Lee (2014) found that students incorporate evidence from multiple representations such as models and graphs to develop written arguments about climate change. Hand and Choi (2010) further suggested that students use information embedded in representations as evidence to recite their claims and to reflect on their ideas. Similarly, studies done by Hand and colleagues indicated positive impacts of using multiple representations on writing to learn physics and chemistry (Gunel, Hand, & Gunduz, 2006; Hand & Choi, 2010; Hand, Gunel, & Ulu, 2009).

We conceptualize two types of mediation regarding how representations are used to facilitate argumentation: *implicit mediation* (i.e. implicit use of representations) and *explicit mediation* (i.e. explicit use of representations). During implicitly mediated talks, arguers do not physically point to or look at their representations but express the information embedded in their representations while arguing. Learners may or may not have that particular reference in their mind and they verbalize the information embedded in these representations while talking. During explicitly mediated talks, arguers physically refer to their representations or intently look at them while arguing and verbalizing the information embedded in these representations (Sawyer & Berson, 2004). Very few studies have explicitly investigated the underlying mechanism that explains the argumentation process when mediated by multiple representations. In a case study where they investigated a group of college students' use of external representations to support collaborative conversation, Sawyer and Berson (2004) identified the effects of external representation on students' lecture notes on groups' collaborative conversation. In this study, we extend the existing literature by investigating how different modalities of representations mediate students' argumentation while explicitly or implicitly attending to those representations.

In dialogical argumentation settings, learners may interact with each other in different ways during explicitly and implicitly mediated talks. First, we are content with Sawyer and Berson (2004) in the notion that mediated talk is more authoritative and gives less space for interaction than non-mediated talk (i.e. which occurs when students do not mention information from their representations). One important indicator of social interaction in group conversation is the frequency of verbal back channeling instances, or turns interrupted verbally by another student. These instances demonstrate 'attentiveness, involvement and alignment with the speaker' (Sawyer & Berson, 2004, p. 395). Therefore, we expect that verbal back channeling would occur more frequently during non-mediated talk. Second, pauses taken between turns and overlapping speech instances also signal for turn-taking strategies during a conversation (Pomerantz & Fehr, 1997) and these instances signal for the social interaction in the group setting. Therefore, we consider these three conversational characteristics in our analysis to identify emerging conversational moves during either mediated or non-mediated talk.

How does argumentation mediate the use of multiple representations?

Argumentation feeds into the use of representations. Scientists, for instance, often present their results to disseminate knowledge by using multiple representations. Furthermore, encountering new data and evidence, they constantly revise their arguments to the best of their knowledge through available evidence. As a result, they reorganize knowledge by altering and/or creating representations through argumentation (Kozma, 2003). Similarly, in science classrooms, students revise their (use of) representations in light of argumentation that makes students to consider additional available data and evidence.

Recently, there have been calls for studying science from a modeling perspective (Namdar & Shen, 2015; Shen, Lei, Chang, & Namdar, 2014; Gobert & Buckley, 2000). During modeling, students engage in practices such as constructing, evaluating, using, and revising models (Schwarz et al., 2009). Revising models involves taking into account of new evidence. This new evidence often times arises from discourse and argumentation. For instance, in their study with five pairs of high school students, Hogan and Thomas (2001) investigated students' system modeling in ecology when they used a computer-based modeling tool STELLA®. Model revision occurred as a result of interpreting model outputs, to test new ideas or to make predictions. Although the place of the use of representations has been implicitly studied during argumentation, past studies did not investigate students' discourse patterns when learners engaged in argumentation in such learning settings. Hence, in this study, we extend existing literature by providing empirical evidence on how argumentation influences the use of representations by studying the conversational moves.

Instructional contexts that can facilitate the intersection

We discuss two, among many, instructional contexts that we believe can facilitate the intersection between argumentation and the use of representations: SSI and CSCL. Despite its importance in science learning, argumentation has been found repeatedly absent from science classrooms (Newton, Driver, & Osborne, 1999; Osborne, 2010). To overcome this challenge, many researchers advocated for the incorporation of SSI in science curricula (Tal & Kedmi, 2006; Venville & Dawson, 2010).

As SSI are related to citizens' lives, discourse and policies about these issues have become a part of daily conversations (Sadler & Donnelly, 2006). This demands science education to equip future citizens of democratic societies with well-informed decision-making skills about these local or global issues (Sadler & Zeidler, 2005b). According to Sadler and Zeidler (2005a), decision-making processes about SSI encompass skills for discussing, weighing evidence, and drawing conclusions. Recently, an increasing number of studies in science education have focused on students' decision-making process of SSI (e.g. Liu, Lin, & Tsai, 2011; Patronis, Potari, & Spiliotopoulou, 1999; Sadler & Zeidler, 2005b; Sadler, 2005; Sakschewski, Eggert, Schneider, & Bögeholz, 2014). With respect to different positions and solutions to SSI, it is important to build sound arguments on these issues when reaching a decision (Acar et al., 2010; Sakschewski et al., 2014). High-quality decision-making about SSI can be attributed to the integration of synthesizing pro- and counter- arguments and weighing different arguments (Sakschewski et al., 2014). The latter has been shown a common difficulty that students face when reaching an informed decision (Kolstø, 2006; Seethaler & Linn, 2004).

Another difficulty of arguing about SSI can be attributed to the amount of available information about these issues. With the fast advancement of information communication technologies, SSI are debated through multiple media channels more often than ever before. Today, ocean of raw relevant (and irrelevant) data about these issues typically exists in multiple modalities of representations such as text, tables, graphs, and models. This demands learners to extract the information in a systematic way that makes sense to them so that they can construct sound arguments (Pallant & Lee, 2014; Visintainer & Linn, 2015). In return, argumentation leads learners to further search, sort, and clustering information in multiple formats. On top of that, learners need to make smooth transitions between different representations so that the representations in different formats can complement each other(Ainsworth, 1999, 2006; Kozma & Russell, 2005).

CSCL environments offer solutions to the aforementioned challenges of facilitating the interactions between the use of representations and argumentation for three reasons. First, CSCL helps us to understand how people best learn together with the aid of computers. Representations are fundamental tools in CSCL because they mediate discourse and collaboration in different platforms such as face-to-face or online (Stahl, Ludvigsen, Law, & Cress, 2014). Therefore, CSCL offers unique ways to facilitate the creation and use of representations as a joint activity (Koschmann, 2002). Second, in CSCL, users can create more than one representation in a more interactive way. These learning environments incorporate representations such as dynamic models and graphs in one space (Pallant & Lee, 2014; Visintainer & Linn, 2015). CSCL environments also let users to move between representations easily. Furthermore, users can archive information that can be easily retrieved for later use. Finally, in CSCL environments, users can create arguments and share those interactively with others in the classrooms based on the manipulated representations (Noroozi, Weinberger, Biemans, Mulder, & Chizari, 2012). Therefore, we approach CSCL as an appropriate context to study the intersection between argumentation and the use of representations, as these environments support constructing and sharing multiple representations and arguments. However, our focus will be on the underlying conversational mechanisms that the participants were involved in this study.

Methods

Context and participants

As a part of a larger design study (Cobb, Confrey, Lehrer, & Schauble, 2003), the current qualitative study (i.e. third iteration of the overall design study) took place in a large public research university in the Southeastern United States. The participants of the study were pre-service middle-grade teachers. Although we focus on the learning aspect in the study, the main reason why we recruited pre-service teachers was that they are effective mediums to teach seminal topics that have been identified in the field and, therefore, to influence future students (American Association for the Advancement of Science, 1993; National Research Council, 1996).

We developed a unit on the topic of nuclear energy incorporating a CSCL platform (see the section below) with the overall goal to engage students in collaborative argumentation and knowledge organization (Sadler, 2004; Zeidler & Nichols, 2009; Zohar & Nemet, 2002). We chose the topic of nuclear energy because there was a recent debate on whether to build a nuclear power plant near where this study took place and the Fukushima Daiichi nuclear disaster just happened not too long ago. We asked our students whether the nuclear power plant should be built and how far we should depend on nuclear energy as an alternative energy source. Specifically, the unit was designed to help students: (a) understand the science related to the SSI of nuclear energy, (b) organize knowledge effectively with multiple representations, (c) retrieve and identify relevant information efficiently, (d) co-construct knowledge and learn from each other, and (e) learn the structure of arguments using claim, evidence, reasoning framework (e.g. Sampson & Clark, 2009). Two pilot studies were conducted to test the curriculum unit and refine the CSCL platform before the current study (i.e. results reported elsewhere Namdar & Shen, 2013, 2014).

At the beginning of the study, a total of 23 students who were enrolling in a pair of bundled middle school physical sciences methods and content courses consented to participate in the activities. Only two participants had science as their primary content concentration, while the others were in the areas of mathematics or social studies. This unequal distribution of participants' content concentration prevented us from making judgments about the outcome of the study related to participants' backgrounds on science. Therefore, the participants were randomly assigned to four working groups to complete the tasks. A total of 20 participants (4 male and 16 female) completed all the activities. The content course met three times a week for 115 minutes each time, followed by the methods course that met for 50 minutes right after. To build rapport with the participants, the first author attended several class sessions and participated in class activities prior to this research (Creswell & Miller, 2000). The nuclear energy unit was implemented toward the end of the semester in four sessions for a total of six hours that spread out in three weeks (Table 1). The first author taught these sessions in a computer lab equipped with 28 desktops connected to the Internet. Each participant had one computer to work on.

Technology platform

The students used a web-based hypertext knowledge organization platform, innovative Knowledge Organization System (iKOS: ikos.miami.edu), to organize their knowledge. The technology platform incorporates three distinct external representations: Wiki, Event, and ConceptMap (Figure 1). Wiki is primarily a textual representation mode, similar to Wikipedia in which learners organize their arguments on a science phenomenon or issue. Furthermore, textual representations are more familiar to most learners to generate questions, interpret evidence, and formulate explanations and arguments (Wu & Puntambekar, 2012). Event is primarily a pictorial representation mode in which learners can upload pictures, and tag and annotate the pictures to help illustrate and highlight the important parts of a science event or phenomenon. This kind of representation can be used as visual evidence in argumentation (Latour, 1990). Learners can also create concept maps in the ConceptMap mode and visualize the connections among a set of related science concepts (Novak & Cañas, 2007). Research has shown that the use of concept map can facilitate learners' discourse and argumentation processes (van Boxtel, van der Linden, Roelofs, & Erkens, 2002). What is unique to our technology platform is that it automatically interlinks student-generated knowledge representations through shared keywords and creates a web of knowledge entries (Figure 1). Students can easily navigate in this knowledge web and see and learn from others.

Data collection

Multiple sources of data were used in the study for triangulation and to provide richer description of the interaction between argumentation and knowledge representation

Table 1. Summary of the activities in the nuclear energy unit.

Sessions	Duration (min)	Topic	Description
1 (Methods course)	50	Introduction to argumentation and concept mapping	Students were introduced to argumentation following the claim, evidence, reasoning framework (Sampson & Clark, 2009), place of argumentation in the recent science education policy documents, and creating a good concept map as suggested by Vanides, Yin, Tomita, and Ruiz-Primo (2005).
2 (Methods course)	50	Introduction to technology platform and nuclear energy	Students were introduced to the technology platform and learned how to create entries in Event, ConceptMap, and Wiki, submit them to the teacher to make them open to the class. They talked about the benefits of using these particular modes of representations. Students watched videos about the pros (news coverage on France's nuclear power dependency: https://www.youtube.com/watch?v = i-rKBrs7kYE) and cons of nuclear energy (news coverage on Fukushima power plant melt down: https://www.youtube.com/watch?v = Vn8oGZHCBu8).
Home-work	N/A		Students were given a newspaper article about the proposed power plant construction in the state they live. The article mentions both the economic benefits and environmental risks of nuclear power (http://usatoday30.usatoday.com/news/washington/story/2012-02-09/us-nuclear-reactors-approve/53027204/1). Students were asked to find more information about the nuclear energy topic and organize their knowledge using the technology platform.
3 (Content course & methods course)	165	Collaborative argumentation and knowledge organization	Students used collaboration tools in the given technology to comment, rate, coedit other students' entries in the class. Then, they were engaged in small-group argumentation based on two questions 'how far should we depend on nuclear energy' and 'should we build a nuclear power plant in our state.' They collaboratively organized further knowledge using the platform on a specific scientific aspect of nuclear energy in their small groups.
4 (Methods course)	50	Presentation	Students presented their group's findings and final arguments about nuclear energy dependency/use and power plant construction. They discussed the issue as a whole class. Finally, they briefly discussed how to use the technology platform in their future teaching and the place of socioscientific argumentation in science classrooms.

practices (Lincoln & Guba, 1985). The primary data sources included transcripts of student discussions along with the video data and students' knowledge entries. Video recordings and the verbal transcripts provided key information to investigate how students engaged in the activities (Collins, Hawkins, & Frederiksen, 1993; Powell, Francisco, & Maher, 2003). They were especially helpful to understand how students' argumentation was mediated by their collaborative knowledge representation that occurred during the third session when the students worked in their small groups (Table 1).

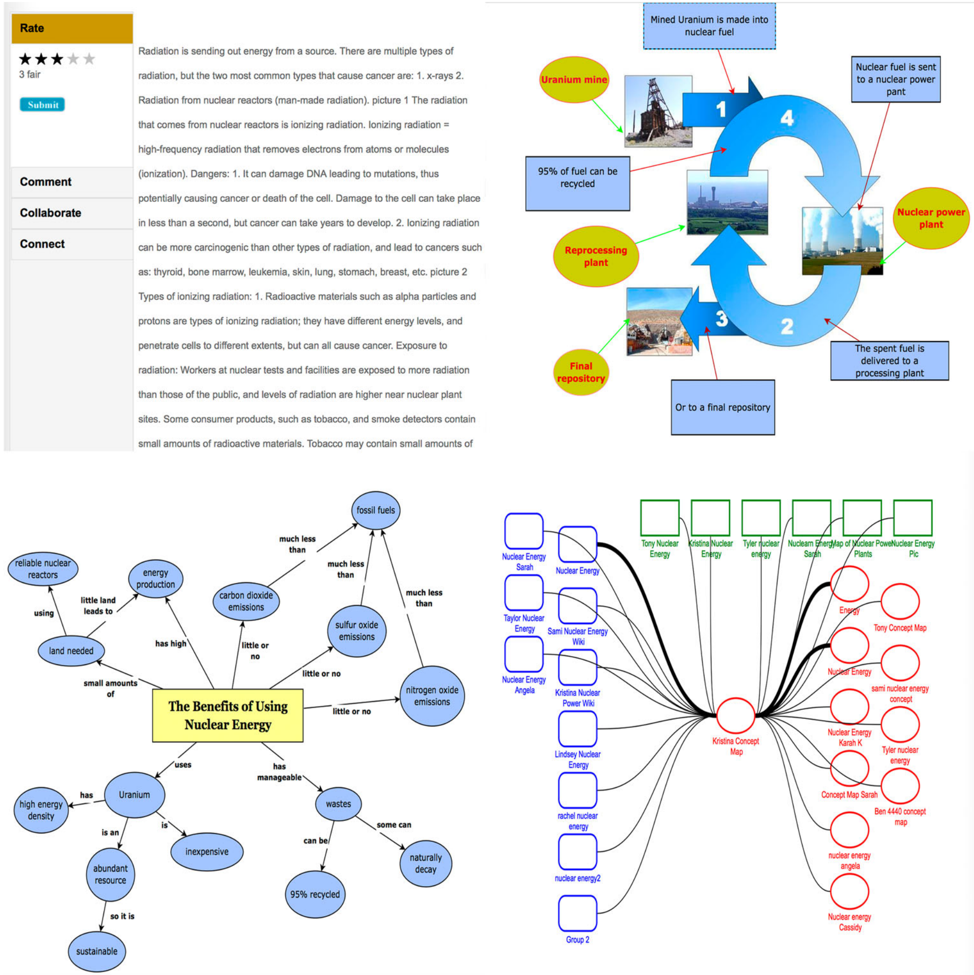

Figure 1. Wiki (top left), Event (top right), Concept Map (bottom left), Knowledge web (bottom right) in the technology platform.

All class activities were video recorded using four sets of video cameras and table microphones. We were aware that video recording might affect students' responses and behavior in the learning environment, so we tried to move the camera as little as possible to keep the distraction at the minimum level to ensure the ecological validity (Erickson, 2006). Two teaching assistants in the classroom helped to set and check the video cameras. The entries students generated were logged in the technology platform. The researchers had access to the entries that the students created and other associated information, such as the students' names. Each entry included the main content (wiki texts, pictures, or a concept map), and the tags and keywords that the students used to annotate their entries.

Data analysis

In this study, we employed conversation analysis (Pomerantz & Fehr, 1997) along with summative content analysis (Hsieh & Shannon, 2005) to understand the intersection between the use of representations and argumentation. During the analyses, codes were compared with the data constantly and they were described in a codebook. Researchers also met regularly to discuss alternative interpretations of the results (Gibbs, 2007).We utilized the following steps in our analysis. Table 2 illustrates our analysis.

Step1 – transcribing

Discourse transcripts and activity summary

All of the video records were transcribed verbatim by the first author. The irrelevant conversations were excluded from the transcripts. Images of video recordings were used to identify student actions during argumentation, especially the key instances of the following: (a) when the students were explicitly and physically referring to their entries during

Table 2. Transcripts and knowledge entry content analysis: an example.

Categories		Data/Coding
Time segment		04:35–04:50 Group A Video 1
Activity summary		Small-group argumentation session. Session 3
Student action		Haley is not looking at the screen. She leans toward her friends while speaking
Discourse transcripts		Haley turn (2): 'the *radiation* kills living cells so that might not affect them right away but it could affect them over ten years if they are exposed to that radiation, and it develops *cancer* (2)'
Entry content		'the potential release of *radiation* from nuclear power plants is a huge *risk*,' (Haley's Wiki Entry)
Content codes	Turn	Radiation and cancer
	Entry	Radiation risk
	Revised code	Risk of radiation release
Analytic notes	Mediation	Wiki-mediated turn
	Discourse characteristics [Verbal back channeling Overlapping Speech Pauses*]	No verbal back channeling No overlapping speech instances *2 seconds of a pause
	Argument component	(a) The number of justifications (1 point), (b) the level of embedding scientific knowledge in the argument (2 points, general); (c) the number of aspects incorporated in the answer (1point) and (d) the extent of synthesizing and rebutting counterclaims (0 point)

group discussion (i.e. by opening their entries on their computer and pointing to the parts of an entry), (b) when the students used their entries during the whole-class level argumentation. The overall activity conducted by the instructor during the small-group argumentation or the whole-class presentation was also recorded.

Step 2 – coding

The first author coded all the data initially, then the two authors went through multiple cycles of peer debriefing and refinement of codes to ensure consistency and coherence (Lincoln & Guba, 1985). Then, the first author recoded all the data. As a result of this iterative process, we generated the following coding categories.

Time segment

To begin our conversation analysis (Pomerantz & Fehr, 1997), first, we selected two sequences of transcripts to be investigated. The first sequence occurred during small group argumentation and lasted for 8 minutes and the second one occurred during the whole-class argumentation and lasted for 10 minutes. We chose these two specific sequences because they included the instances where the participants were asked to explicitly argue about the nuclear energy use. The sequences started when the first participant initiated the argumentation in the group and finished when the participants were no longer responding to the prior action. During both sequences, participants were able to access to their computers.

Student actions

Second, we identified each turn taken by a participant and actions performed in each turn as a part of the conversation analysis. A turn constituted a time frame until a participant finished presenting her/his idea. Here, we asked what the participant was doing during a turn. For instance, the participants' eye gaze to the representations on their computer screen, participants' movements toward the screen, and their physical location in their group were recorded.

Mediation and modalities

Considering our theoretical perspective on interaction between the use of multiple representation and argumentation, we also made the analytic notes regarding the explicitly and implicitly mediated turns based on the modalities of the representations.

Discourse characteristics

Third, as a part of our conversation analysis, we identified the turn-taking strategies employed by the participants to provide an understanding of the discourse characteristics. Here, we examined the following features of the discourse: verbal back channeling (presence/absence of verbal back channeling instances during the turn), pauses (length of pauses taken when switching between the turns), and overlapping speech instances (frequency of instances occurred during mediated and non-mediated turns).

Entry content

We also employed summative content analysis (Hsieh & Shannon, 2005). We first looked into the knowledge entries logged in the technology platform. We generated summarizing words or phrases (initial codes) for the contents of each entry that was created by each student or group. Each entry may have multiple summarizing words or phrases. Then, we identified the turns taken by the participants during small-group discussion and whole-class argumentation based on the video transcripts. A turn constituted a time frame when a participant initiated presenting an idea and finished it. Similarly, we generated summarizing words or phrases (initial codes) for each turn. We compared the initial codes for the conversation turns and those for the entries created by the same participant (either individually or in a group). If the codes matched to a satisfactory level, we identified the turn as an interaction point. Then, revised codes were generated for these interaction points to summarize the overlapping contents.

Argument structure and content

Although conversation analysis and content analysis identify the patterns of intersection between the use of representation and argumentation, it did not signal how these conversational patterns affected learning. Therefore, in our analysis, we also coded the students' arguments using the following criteria: (a) the number of justifications (0–3 points), (b) the level of embedding scientific knowledge in the argument (0–3 points, superficial-specific), (c) the number of aspects incorporated in the answer (1–4 points), and (d) the extent of synthesizing and rebutting counterclaims (Tal & Kedmi, 2006).

Step 3 – quantitizing.

In order to recognize patterns and also to depict a condensed view of the results, we *quantitized* (Sandelowski, Voils, & Knafl, 2009) the data by counting the number of utterances occurred for implicitly and explicitly mediated turns based on the representation modes, non-mediated turns, and indicators related to discourse features.

Findings

Among the four groups, we decided to analyze and report in detail only two of them: Group A with Ashley, Daphne, Haley, Melissa, and Raina, and Group B with Brandon, Elizabeth, Katie, Sami, Tim (pseudonyms are used in the paper). We chose these groups for two reasons. First, the data from these two groups were more complete. We excluded one group from the study due to low sound quality and the other one due to two absent students in the third session. Second, these two groups had interesting contrasting characteristics. In Group A, Haley took the leadership role, dominated group discussion, and led her teammates when they collaboratively organized knowledge. In contrast, in Group B, students participated in the activities in a more equal way. These two groups also held opposing views regarding nuclear energy: Group A was against the construction of the nuclear power plant and Group B was supporting it. In the following, we report the findings in three aspects that emerged from our analysis.

How does the use of multiple representations mediate argumentation?

In our theoretical perspective, we categorized the mediation as either implicit or explicit. During implicitly mediated turns, arguers do not physically point to or look at their representations but express the information embedded in their representations while arguing. Learners may or may not have that particular reference in their mind and they verbalize the information embedded in these representations while talking. During explicitly mediated turns, arguers physically refer to their representations or intently look at them while arguing and verbalizing the information embedded in these representations.

Table 3 shows the number of instances students' argumentation was mediated, implicitly or explicitly, by the information embedded in the students' entries during small-group discussion; it also reports the number of non-mediated turns. Non-mediated turns included the instances where students' turns did not include any information from their entries. Table 4 shows the numbers during the whole-class presentation.

Implicit use of multiple representations

During the small-group discussion, mediated turns only occurred implicitly (Table 3). In the majority of these instances, the students drew information from their Wiki entries (10 out of 16 turns). For instance, when the students came to the classroom during Session 3, they were asked to argue on the following two questions in their small groups: (a) Should we build nuclear power plants in our state? (b) For how long should we depend on nuclear energy as an alternative energy source? In Group B, Brandon initiated the group argumentation and Elizabeth followed him, as shown in Excerpt 1.

[1][Excerpt 1. Transcripts 09/04/2013: Video Group B: 02:48-03.21. Italicized texts indicate where Elizabeth and Brandon were drawing information from the Wiki entries they created prior to class]

(1) Brandon: I don't think necessarily nuclear; I think there is plenty (*2*) of *alternatives* to go with, *solar, wind, and geothermal=*
(2) Elizabeth: =I think that it is a good '*alternative' energy source*. It *shouldn't be our only one*, but I think we'll do the best *using a variety of sources* because you should not become too dependent on one thing (*3*) We can't depend on one thing
[Brandon: Yeah-]
(3) Elizabeth: some coal, some hydro, some wind, some thermal-

Table 3. Number of mediated and non-mediated turns in small-group discussion.

Group & active students in discussion		Small-group discussion						
		Implicitly mediated			Explicitly mediated			
		Wiki	Concept Map	Event	Wiki	Concept Map	Event	Non-mediated
A	Haley	7	4	0	0	0	0	8
	Melissa	0	0	0	0	0	0	1
	Ashley	0	0	0	0	0	0	2
	Daphne	0	0	0	0	0	0	1
	Raina	0	0	0	0	0	0	0
B	Elizabeth	1	0	0	0	0	0	5
	Brandon	2	1	0	0	0	0	6
	Tim	0	1	0	0	0	0	1
	Katie	0	0	0	0	0	0	0
	Sami	0	0	0	0	0	0	0
Total		10	6	0	0	0	0	24

Table 4. Number of mediated and non-mediated turns in whole-class presentation.

		Whole-class presentation						
		Implicitly mediated			Explicitly mediated			
Group and presenting students		Wiki	Concept map	Event	Wiki	Concept Map	Event	Non-mediated
A	Haley & Raina	0	0	0	1	2	4	4
B	Elizabeth	1	0	0	2	2	2	4
Total		1	0	0	3	4	6	8

Excerpt 1 indicates that Brandon's (Turn 1) and Elizabeth's (Turn 2) turns were implicitly mediated by their individual knowledge entries. Brandon included the ideas of alternative energy sources of solar, wind, and geothermal in his Wiki entry and started the group discussion with the same argument. Elizabeth, on the other hand, brought two ideas that she included in her Wiki: (a) nuclear energy being one good alternative energy source and (b) having a variety of energy sources for making energy use sustainable.

The students also drew information from their ConceptMap entries (6 out of 16 turns). Haley, for instance, was able to retrieve some information from her concept map (Figure 2), as shown in Excerpt 2.

[Excerpt 2. Transcripts 09/01/2013 Video Group A: 12:26-13:14; Italicized texts indicate where Haley was drawing information from her *ConceptMap* entry she created prior to class]

(7) Haley: If we continue to use the nuclear power, more people will be … are going to think that it is ok and are going to develop the ways to
[Melissa: Destroy us]=

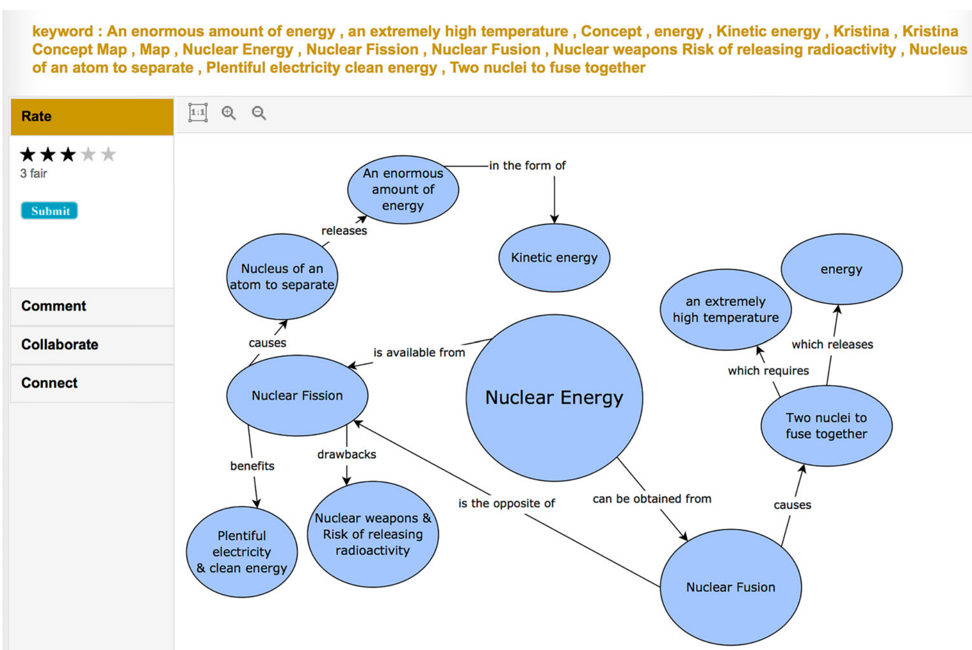

Figure 2. Haley's concept map entry prior to group argumentation.

(8) Haley: =Yeah, obviously *atomic bomb* is created from the process of *nuclear fission* so if that's going to end in the wrong people's hands you never know what could happen.
Researcher: Can you guys think of any positive things about nuclear energy?
(9) Haley: More electricity, it's efficient but
[Researcher: Is it cheap?]
(9) Haley: and it is *not burning fossil fuels,* so it *reduces* all the *green gas emission* and ((*3*)) but they said France has the cleanest air out of all the industrialized countries because there are so many power plants.

In her ConceptMap, she included 'plentiful electricity' and 'clean energy' as the benefits of harvesting energy from nuclear fission. In the group discussion, she was able to draw that information into the group argumentation by mentioning nuclear power plants not burning fossil fuels and reduction of green gas emission (Turn 9). She also mentioned about nuclear fission as the process leading to creation of atomic bomb (Turn 8). This matched her ideas in the concept map about nuclear weapons.

Overall, as shown in Table 3, implicitly mediated turns only occurred in Haley's turns in Group A as she was the dominant speaker during small-group discussion. Her argumentation included seven Wiki-mediated and four ConceptMap-mediated turns. There were also eight non-mediated turns from Haley. In Group B, on the other hand, Elizabeth's argumentation included 1 Wiki-mediated and five non-mediated turns; Brandon's included two Wiki-mediated, one ConceptMap-mediated, and six non-mediated turns; Tim's included one ConceptMap-mediated and one non-mediated turns. None of the implicitly mediated turns during small-group discussion drew information from the Event entries.

Explicit use of multiple representations

These instances only occurred during groups' final presentation in the whole class (Table 4). In these occasions, Event was the main mode for the mediation for Group A and equally frequent for Group B. For instance, Raina from Group A started to present her groups' arguments by stating how ionizing radiation damages DNA and causes cancer with their Event entry shown on the class screen (Figure 3).

[Excerpt 3. Transcripts 09/04/2013, Video Group A Presentation 33:24- 34:11, Italicized texts indicate where Raina was pointing to information from her groups' Event entry explicitly]

(1) Raina: So what we have here is the *double helix model of DNA* so *UV radiation is hitting DNA and over here is DNA's mutated* [standing in front of the screen and pointing to the picture on top left](2). Over here is [moving toward the screen and pointing to the picture on top right], essentially is the same thing [moving towards to right and pointing to the picture on below right] and *here cells are hit by a form of radiation is being emitted and the cell turns cancerous* (2). And that is the same thing (2) down here so that *the growth turns into a tumor*. And this is just the *sign of radiation* [pointing to the danger sign] pointing out to the danger.

Overall, both groups' final presentations were explicitly mediated by the information embedded in all three modes. Furthermore, there was only one implicitly mediated turn that was taken by Elizabeth, where she stated her claim about nuclear energy being an alternative energy source, as she did in her Wiki. During these instances, the students argued for the underlying reasons for their positions on nuclear energy.

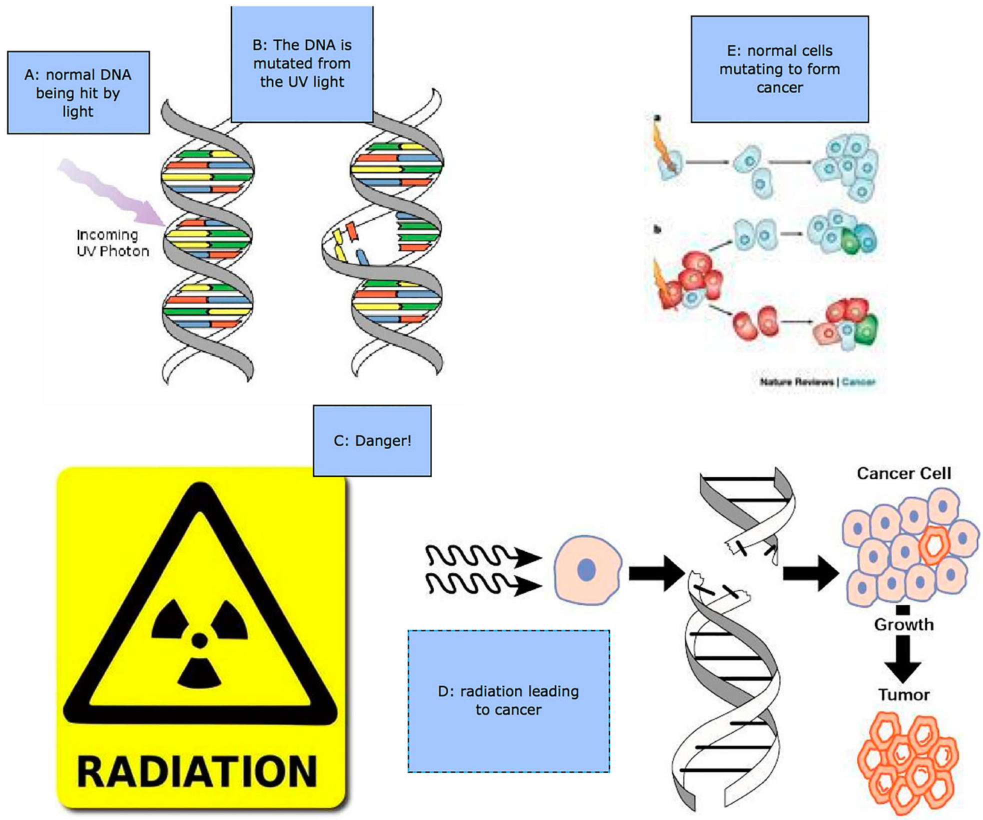

Figure 3. Event entry created by Group A after their small-group argumentation.

Emergent group pattern: the purposes for which mediated turns support argumentation

Our analysis also showed an emergent group phenomenon which was identified through studying the overall interaction instead of paying specific attention to a particular individual's conversational acts. Although our analysis showed that the turns included implicit and explicit use of multiple representations, these two different types of mediation served different purposes during argumentation.

It appears that the students' implicitly mediated turns were used to recite individual claims and justifications. These justifications often times included the students' reasoning based on their values, experiences, and common sense. For instance, in her Wiki entry, Haley wrote her claim about the nuclear power plant construction as 'no we should not build nuclear power plants in X state.' In their small-group conversation, she also brought the same claim 'I do not think we should [build a new nuclear power plant].' She continued to support this claim by providing a justification from her Wiki entry again. In her Wiki, she stated one of her justifications as 'the fact that this power plant will be located 26 miles from Skycity makes it a potential hazard to a large population of people.' Similarly, she mentioned the same justification in her argument, 'because one in the article is talking about building it within 25 miles, or something like that from Skycity.' She continued her argument with her reasoning that 'So if anything were to go wrong. That would affect, it's very close to a high population of people.' She concluded her arguments stating that radiation kills living cells, and therefore, it would affect a lot of people directly (Transcripts 09/01/2013: Group A Video: 04:35-05:32). Similarly, Elizabeth, in Group B, made the same claim in her Wiki entry that nuclear power is a good 'alternative energy source' and it should not be our only source of power: 'I think that it is a good "alternative" energy source. It shouldn't be our only one, but I think we'll do the best using variety of source.' Brandon, for instance, mentioned his justification that there are multiple alternatives to go with such as solar, wind and geothermal energy (Transcripts 09/04/2013 Video Group B: 00:48-01:21). Similarly, Tim mentioned his justification that he included in his wiki and concept map entries about nuclear energy being safe and clean (Transcripts 09/04/2013 Video Group B: 04:45-04:55). However, none of the students in Group B were able to elaborate on their justifications and none of the group members in both groups presented or elaborated on scientific principles and theories to support their claims.

In contrast, during explicitly mediated turns, the students were providing specific scientific theories and principles as evidence to support their group's position on nuclear power plant construction. For instance, Group A started their presentation with providing scientific explanation on how radiation affects DNA, cells, and causes tumors in turns 1 (see Excerpt 4). Similarly, Group B elaborated on the mechanism of nuclear fission. Elizabeth was showing her group's Event entry to the class.

[Excerpt 4. Transcripts 09/04/2013: Video Group B Presentation: 00:14–00:45 Italicized texts indicate where Elizabeth was drawing information from her groups Event entry]

(1) Elizabeth: *You start off with uranium 235* and then *you add a neutron and then it becomes uranium 236* which is unstable and then it *splits into krypton and barium* and also releases particles from there and that's where the energy comes from.

She finally stated that based on the nuclear fission process, they were supporting nuclear power plant construction because of the fact that it is a clean burning energy source.

Overall, the results indicated that the use of scientific content during argumentation in two different collaborative contexts were different for both groups. Although the students in both groups mentioned their claims and supported those claims with justifications, none of them included scientific theories and principles to support those claims during small-group discussion (coded as superficial 1 point). However, after students were prompted to organize knowledge on a specific scientific aspect of the nuclear energy issue, both presenters from Group A and B provided specific scientific explanations to support their overall position on the nuclear energy issue (coded as specific 3 points). Both groups also increased the number of justifications that they used during explicitly mediated turns (coded as 3).

How argumentation drives further use of multiple representations

The nature of non-mediated turns

First, as we have illustrated above, mediated turns, explicitly or implicitly, indicate direct interaction between the use of representations and argumentation. Non-mediated turns also have important functions in the interaction. Indeed, we found that students' non-mediated turns drove the students to organize knowledge on a specific subject. Often times, these non-mediated turns were drawn on the students' personal experience. For instance, Haley gave an example of a movie that she saw in which a lawyer was trying to save a community that lived near a nuclear power plant. The plant contaminated the ground water and caused cancer in the community. After giving this example, Haley led the group's conversation in a direction where they started to talk about cancer and radiation (Excerpt 5).

[Excerpt 5. Transcripts 09/01/2013: Video Group A: 15:30-15:41]

(32) Haley: It [nuclear power plant] contaminates *(2)* even if there isn't an accident they are still spreading nuclear radiation into the ground.
[Raina: They cause cancer.]
(33) Haley: Yeah, it caused cancer and they did not know where it was coming from and they just thought, you know, cancer, you really never know where it comes from.

After about 10 minutes into their small-group discussion, the students were asked to choose one scientific aspect associated with nuclear energy topic and create entries to organize their knowledge on this specific aspect. Haley's group decided to focus on the topic of radiation exposure and its connection to cancer (see Excerpt 6).

[Excerpt 6. Transcripts 09/01/2013: Video Group A: 17:35- 18:05]

(36) Ashley: Why do not we do radiation and cancer, so we do not want it=
Raina: = ((3))
(37) Ashley: We are done. We are gonna do radiation and cancer
(38) Haley: [How radiation kills cells?]
[Ashley: Yeah]
(38) Haley: Radiation exposure and cancer.

Following their small-group argumentation, they created three entries, one in each mode, on radiation and cancer. These entries had nuanced content differences: In Event, they used a picture they found online to visualize the process in which radiation alters DNA and causes tumors; In Wiki, they talked about dangers of exposure to radiation as well as cancer types caused by ionizing radiation; In Concept Map, they summarized the types of radiation and tied those to the cause of cancer.

A similar instance happened in Group B, where the students talked about a TV show and their conversation moved toward nuclear fission topic. After about 10 min into their small-group argumentation, Group B decided to focus on the topic of fission and how energy is created by this process. Interestingly, even though the students in both groups did not include these personal real-life stories in their individual representations, these non-mediated turns oriented them to further organize knowledge on these topics by using multiple representations.

Features of non-mediated discourse

Verbal back channeling

Verbal back channeling indicates social interaction during argumentation. It may occur for different purposes. It often signals an audience's attentiveness. In mediated turns in our study, verbal back channeling was often used to simply show agreement with the speaker without any substantive contribution to conversation. This is illustrated in

Excerpt 7, where the mediated turn of Elizabeth received back channeling when Brandon agreed with her claim.

[Excerpt 7. Transcripts 09/04/2013: Video Group B: 02:13- 02:34]

(2) Elizabeth: I think that it is a good 'alternative' *energy source*. It shouldn't be our only one, but I think we'll do the best *using variety of sources* because you should not become too dependent on one thing *((2))* we can't depend on one thing
Brandon: [Yeah]
Elizabeth: some coal, some hydro, some wind, some thermal

In contrast, non-mediated turns received more back channeling instances and these instances often showed more substantive involvement from the audience. For example, Elizabeth mentioned a TV show and talked about radiation in Chernobyl. Back channeling occurred four times during her eight non-mediated turns. In the back channeling instance shown in Excerpt 5, Brandon added an example in a joking tone to Elizabeth's discussion about mutated species after Chernobyl disaster.

[Excerpt 8. Transcripts 09/04/2013: Video Group B: 08:00- 08:20]

(23) Elizabeth: He [the person in the TV show] goes on fishing and he went to Chernobyl to go fish. And it was wild, then because they were like 'oh he is going to find a giant mutated fish.' No he is not. I mean granted, there are mutations but they are not mutated into a monster.
[Brandon: Yeah, there are probably fish with more than two eyes [says indistinctively]]

The students also used verbal back channeling instances to take a turn from a speaker. Excerpt 9 indicates that right before Brandon could finish his turn (3), Tim interrupted and continued stating his ideas.

[Excerpt 9. Transcripts 09/01/2013: Video Group B: 03:35- 03:55]

(3) Brandon: We got the video of France. It showed that it was … France is running pretty well on nuclear energy. However, France is smaller than Texas. I don't think that the US can operate on that large of a scale
[Tim: Yeah]
Brandon: I …
(4) Tim: I think different regions of the United States should take advantage of what they have if they have a lot of sun they should go solar, if they have a lot of wind they should go wind either than nuclear.

Similar to Elizabeth, Haley's non-mediated turns also received more back channeling than her mediated turn. Overall, she received 6 back channeling instances during mediated and 11 back channeling instances during non-mediated turns. These instances occurred 10 times when Haley mentioned the movie related to nuclear energy.

Table 5 reports the overall number of back channeling instances occurred during mediated turns (disaggregated into representation modalities) and non-mediated turns for the group discussion and the final presentation. The results indicated that there was less verbal back channeling during mediated turns than non-mediated turns in both groups. This is because during a whole-class presentation, the turns were not interrupted as frequently as in small-group discussion. In terms of meditational modes, no verbal back channeling instances occurred during Event-mediated turns, as all of these turns occurred during whole-class presentations.

Table 5. Number of back channeling instances during mediated and non-mediated turns.

	Group A				Group B			
	Mediated				Mediated			
Context	Wiki	Concept map	Event	Non-mediated	Wiki	Concept map	Event	Non-mediated
Group discussion	4	2	0	12	1	0	0	7
Final presentation	0	1	0	0	1	0	0	0
Total	4	3	0	12	2	0	0	7

Pauses

Our results also indicated that the argumentation in small groups started with mediated turns where students referenced knowledge from their multiple representations either explicitly or implicitly. However, conversation analysis results showed that students left longer pauses following their mediated turns and then they switched to non-mediated turns. The number of pauses between mediated and non-mediated turns was counted as 20, whereas the number of pauses between similar turns (from mediated to mediated or from non-mediated to non-mediated) was 13 in total. Duration for an average pause between similar turns was 1.3 seconds, whereas it was 2.4 seconds during the instances where the participants switched from meditated to non-mediated turns. The longest pause during mediated turn was 3 seconds while the longest pause was 5 seconds during a non-mediated turn.

[Excerpt 10. Transcripts 09/01/2013 Video Group A: 06:12-07:52, italicized text indicates where Haley explicitly refers to a textual representation]

(13) Haley: France citizens trust it [nuclear power]. They call it controlled power plant. Whereas Americans are more skeptical, I guess *(4)*
(14) Ashley: I mean it's just scary, I think=
(15) Haley: =This says *they need more nuclear powerplant than us and they fear less*
[Ashley: They need more than us?]
Haley: Because (8) [she continues reading]
(16) Ashley: They got to light Eiffel Tower. It is expensive to light up
(17) Haley: If they are doing it for 30 years they can't like, be hard to go back (5)
Ashley: [Yeah]
(18) Melissa: That's really scary though. When I watch Chernobyl dairies, it scares me. Have you seen that?
(19) Haley: I recently watched this movie

Excerpt 10 illustrates that the students left longer pauses when switching from mediated turns to non-mediated turns. Overall pauses were more frequent between turns, especially when the students shifted from mediated turns to non-mediated turns, channeling students' use of representation to a certain direction. Note that students, for instance in Group A, decided to focus on the topic radiation and cancer, and consequently created representations on this topic to organize their knowledge using multiple representations. Furthermore, there was no existing pattern of pause lengths during mediated turns.

Overlapping speech instances

In another contrast, we found that more overlapping speech occurred during non-mediated turns (10 times for Group A and six times for Group B) than mediated turns (Four times for Group A and two times for Group B). Note that these instances only

Table 6. Number of overlapping speech instances during mediated and non-mediated turns.

	Group A				Group B			
	Mediated				Mediated			
Context	Wiki	Concept map	Event	Non-mediated	Wiki	Concept map	Event	Non-mediated
Group discussion	1	1	0	8	0	2	0	6
Final presentation	0	2	0	0	1	0	0	0
Total	1	3	0	10	1	2	0	6

occurred during argumentation. Overall, these instances indicated speakers' agreement toward a shared goal of creating representations on a specific subject. For instance, in excerpt 6, overlapping speech exists in non-mediated turns (Turns 36–38). During these instances, Haley and Ashley agree on the topic that their group is going to create representations to organize their knowledge on radiation and cancer topic. Here, overlapping speech signals for collaborative discourse and consensus instead of a disagreement or an interruption of a turn. This overlapping speech finalizes group's decision of the topic preference (Table 6).

Discussion

In this study, participating students used a web-based CSCL platform to organize scientific knowledge using three representational modes in an SSI unit on nuclear energy. We investigated the interaction between their use of multiple representations and argumentation on nuclear energy. Our findings illustrated that the use of representations and argumentation intersect with each other bi-directionally in a complicated way. The complexity can be unfolded in two aspects: (a) multiple representations mediate argumentation in different forms and for different purposes; (b) argumentation, especially non-mediated turns, leads to refinement of using multiple representations. In the next sections, we further elaborate on these aspects. To help the reader see the complex connections among different aspects, we provide a graphic organizer as shown in Figure 4.

Multiple representations mediate argumentation in different forms and for different purposes

Researchers argue that the use of SSI can enhance students' understanding of science content knowledge (Zeidler, Walker, Ackett, & Simmons, 2002). Several empirical studies have also suggested a link between science content knowledge and SSI-based instruction (e.g. Zohar & Nemet, 2002). Still, it has been criticized that the use of SSI in classroom may sacrifice the integrity of science content (DeBoer, 1991). Furthermore, there is little empirical evidence showing effective scaffolds for students' content knowledge integration in SSI-based curricula. Our findings indicate that students' argumentation on SSI may involve scientific knowledge organized in different representational modes in different ways. Depending on the context, many times, the references to science knowledge can be made implicitly. During these implicitly mediated turns, the students may re-voice the knowledge that they previously organized by stating their claims or justifications about a phenomenon of interest. This finding is consistent with the literature

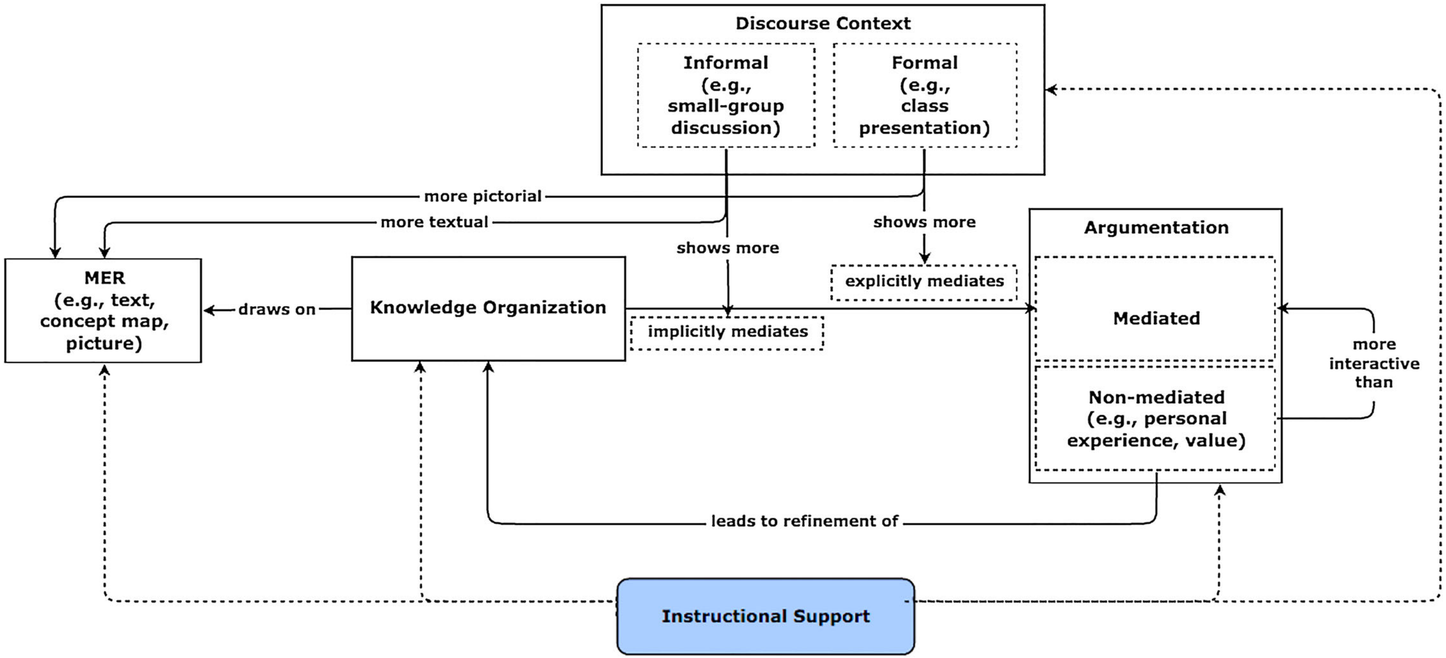

Figure 4. Intersection between the use of multiple representations and argumentation.

reporting how representations are used to support argumentation in science education settings (e.g. Hand & Choi, 2010; Pallant & Lee, 2014).

Our study further shows that explicitly mediated turns may differ from implicitly mediated turns by providing students with opportunities to elaborate on scientific principles and theories to support their arguments. Making this distinction between implicitly and explicitly mediated turns is important as it affects the students' choices of representational modalities in an SSI-based argumentation setting. This makes sense because explicitly mediated turns tend to use more pictorial representations (i.e. Event entries in this study). In this way, more abstract concepts and theories such as the underlying mechanism of nuclear reaction can be illustrated.

One important factor that may affect the complex bi-directional relationship between the use of multiple representations and argumentation is discourse context. This study involved two contexts: a relatively formal context where the students presented their results and a relatively informal context in which the students shared their ideas and arguments within their small groups. First, we observed that the students' argumentation was mostly implicitly mediated in an informal context and more explicitly mediated in a formal context. Our interpretation is that in formal presentation settings, explicitly mediated turns allow presenters to invoke an authoritative voice, hence, leading to less back channeling than implicitly mediated turns.

Our findings further illustrate that representational modes, through which argumentation is mediated by knowledge organization, may be different in different contexts. In our study, the students were acquiring information mostly from their Wiki and then ConceptMap entries during small-group argumentation. The finding is, therefore, aligned with previous research indicating that learners usually attend to textual representations and mostly tend to ignore visual ones (Barnea & Dori, 1999; Corradi, Elen, & Clarebout, 2012). One possible reason for this result is that, these two representational modes might have provided the students with a space to reference relevant information, as textual information is more proximate to verbal communication. This might be partially the case in our study, when the students were not looking at/showing their representations while arguing in their small groups.

However, during the final presentation, Event entries were referenced as well as ConceptMaps and Wiki entries. Indeed, the findings suggested an increasing degree of visual mediation in the final presentation (i.e. Tables 3 and 4 show that in small-group discussion, the total number of mediated turns decreases with increased visualization, whereas in whole-class presentation, it is reversed). The reason for this might be because compared with Wiki, during a presentation pictorial representations (i.e. Event in this study) can be more appealing to the audience (Cook, 2006). The data must be interpreted with caution because the presentation took place in a formal format where the students stood in front of their peers and presented the content of their entries in a lecture style.

Argumentation refines the use of multiple representations through different mechanisms

Our findings further indicate that students' argumentation may lead to refinement of knowledge organization through the use of multiple representations. There are two underlying mechanisms that we identified in the study for how argumentation feeds into the use of multiple representations. First, the students in the two groups started their small-group argumentation with implicitly mediated turns and switched to non-mediated turns. The switch was driven by real-life examples and personal experience. These non-mediated turns drove the groups' conversation to a certain point where they redirected their use of multiple representations in a specific direction. We also found that students left more pauses when switching to non-mediated turns and they channeled the conversations to real-life experiences. One possible interpretation of this finding might be related to the value-laden nature of SSI. This might require arguers to make moral considerations while constructing socioscientific arguments (Sadler & Donnelly, 2006). During this process, it is natural that learners refer to some issues that they encounter in their daily life to exemplify their moral considerations. This was the case when the students started to give examples from their daily life in their small-group argumentation. Additionally, our result further suggests that the students' value-laden authentic discourse can further direct their interest on specific subjects for the use of multiple representations.

Second, we found that the non-mediated turns received more verbal back channeling than mediated turns. As these back channeling instances occurred mostly before collaborative knowledge organization, they may have led the groups to choose the science topic on which they wanted to focus. Similarly, the conversation analysis indicated that overlapping speech occurred more during these non-mediated turns. During these turns, students' conversation moved toward personal experiences rather than mediated turns. These turns created opportunities for both groups to channel their interest on organizing their knowledge by using multiple representations on a certain topic. This result complies with the existing literature indicating that overlapping speech instances allows learners to reach a consensus in collaborative learning settings (Sawyer & Berson, 2004). Finally, our data indicated that the participants took longer pauses when transitioning between mediated to non-mediated turns, which involved more casual speech. This contradicts with some of the previous findings in the literature indicating that learners might take more frequent and longer pauses during mediated turns (Sawyer & Berson, 2004). This was not the case in our study, as the use of representations occurred more implicitly in which leaners did not need the time to process the information embedded in their representation, as they were not looking at them. These instances are important, as the students' experiences are a start of students' further knowledge organization by using multiple representations and take ownership during their own learning.

Implication in instruction and future research directions

The study aims to advance our understanding about the interaction between students' use of multiple representations and their argumentation. In the following, we argue for a few instructional implications based on the findings. Given the exploratory nature and small scale of the study, our findings are far from being conclusive. Therefore, the reader should take these implications with caution.

First of all, our study echoes with established research with multiple representations, suggesting that teachers need to provide representational opportunities and make the role of representation in learning science explicit (Hubber et al., 2010). With appropriate scaffolding, students can use multiple representations in their argumentation in different forms and for different purposes. But their knowledge and skills of using different representations may vary significantly. Therefore, teachers should provide students with training on specific knowledge representations that would serve for specific purposes. Wu and Puntambekar (2012), for instance, argued that using multiple representations can be brought to the science classrooms and different representations can be tied to different scientific processes based on their pedagogical affordances. Verbal–textual representations, for example, are fundamental entities in asking questions, evaluating information, formulating hypothesis, and constructing explanation. Visual and graphical representations such as simulations can be used to plan and carry out investigations.

Our study focused on the intersection between the use of representations and argumentation. However, our investigation was limited by the three representational modes we incorporated in our design. Future instructional practices and research studies will need to explore additional representational modes. Also, a student's effective use of multiple representations to support his/her learning depends on his/her (prior) knowledge and skill of the specific representation. Although we considered this factor by providing students with tutorial sessions on concept mapping and using the technology platform in our lesson design, we did not consider formally assessing their ability of how effectively they used these representational modes. Hence, we suggest that future research should consider developing effective assessments of students' knowledge and skill of using different representations in supporting their knowledge organization and argumentation practices.

Teachers should understand that non-mediated turns can play a significant role in both argumentation and knowledge organization and oftentimes, these turns are drawn from everyday experience. Therefore, ample opportunities should be created for students to bring up everyday experience in classroom activities and link them to academic knowledge. This is not a new insight (Linn, 2006). However, what is still unclear is how instructional scaffolds can be provided so that students' non-mediated turns can allow them to channel their curiosity and reasoning arose from everyday experience toward scientific issues and as a result, lead to better knowledge organization. One challenge in an SSI-based curriculum is that when students are involved in argumentation about SSI, they often tend to ignore scientific evidence and rather rely on values, common sense, and personal experiences (Aikenhead, 2006). Another challenge is that these non-mediated turns or non-academic discourse may function differently in different contexts (e.g. they do not appear in students' knowledge entries). Therefore, there should be appropriate scaffolds in different contexts for students to employ both scientific evidence and everyday experience in their argumentation and knowledge organization. In our study, we asked the students to organize knowledge individually using different representational modes on the same topic, and asked them to focus on a specific scientific aspect of nuclear energy in their collective knowledge organization after their small-group discussion. Future research needs to explore context sensitivity of these scaffolds.

Our study shows that the representational modes students use in argumentation are closely tied to discourse contexts: a specific context may promote the use of a specific representational mode. Based on this observation, one instructional support that teachers can provide to students is to engage them in argumentation in different instructional contexts such as small group, whole-class argumentation, and other contexts we did not include in our study. These contextual influences on the relationship between knowledge organization and argumentation should be empirically tested in future studies.

Teachers should give more explicit instruction on how to use multiple representations in a way to create a knowledge web that is more accurately and coherently linked, and also use the knowledge web as an instructional means to advance both individual and collective knowledge organization and argumentation. In our study, the platform provided the knowledge web, but we did not provide specific instructional support based on it. We anticipate that more accurately linked knowledge web might allow students to access more relevant information. Then, the knowledge web could lead them to use that information in their discourse as the sources of arguments and counterarguments. One way to create more accurately and coherently linked knowledge base is to provide instructional support for students to learn and practice how to better use knowledge organization tactics (i.e. tagging and keyword generating). Another way is to employ the Semantic Web technologies (e.g. Berners-Lee, Hendler, & Lassila, 2001) so that the machine can understand the content of the knowledge web and provide targeted feedback.

In this study, we focused our inquiry in the intersection of learners' use of multiple representations and argumentation without focusing on the peer influences on this process. Recent studies show different mechanisms when learners are engaged in collaborative argumentation in the context of SSI without elaborating on the use of multiple representations (Albe, 2008; Evagorou & Osborne, 2013). Hence, future studies should determine the possible peer influence on argumentation when learners use multiple representations.

Note

1. [] overlapping speech
   ((x)) unintelligible speech of x seconds
   (x) a pause of x seconds
   = two turns were spoken without any pause
   , a pause of less than one second
   - a flat pitch

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