Knowledge Organization with Multiple External Representations for Socioscientific Argumentation: A Case on Nuclear Energy

Bahadir Namdar, The University of Georgia, Athens, GA, USA, baha@uga.edu
Ji Shen, University of Miami, Coral Gables, FL, USA, j.shen@miami.edu

Abstract: Given the vast amount of information readily available through the Internet in different forms of representation, learners need to organize their knowledge strategically in order to make a sound argument, especially on a complex topic such as socioscientific issues. In this study, we designed a science unit on nuclear energy using a newly developed online knowledge and learning management system that offers three types of representations: pictorial, textual, and concept maps. We investigated how learners organized their knowledge with multiple external representations and how their knowledge organization practices interacted with their argumentation. Our results indicated that concept maps and wiki entries were more connected than the pictorial modes in the network of knowledge entries created by the learners. Moreover, we found evidence showing that students' knowledge organization enabled them to draw information while arguing and that their argumentation guided them to advance their knowledge organization practices.

Introduction

Socioscientific issues (SSI) are useful pedagogical tools in science classrooms. They are often relevant to learners' lives and therefore, can promote interest in learning science (Kolstø, 2006; Sadler & Zeidler, 2005). They can engage diverse learners in participating in scientific discourse and argumentation (Zeidler & Nichols, 2009). Producing sound arguments on SSI requires learners to synthesize complex information and use evidence-based reasoning (Zeidler & Nichols, 2009). It is important to create opportunities for learners to discover mutual influence of science and society, which can empower learners' science learning as well as their decision making in their lives(Simonneaux, 2008). Zeidler & Nichols (2009) submitted that arguing and debating about SSI in classroom could engage students in scientific thinking and reasoning, and provide students with firsthand experience of the advancement of scientific knowledge in daily life.

With the rapid development of information and communication technology (ICT), relevant (and irrelevant) information and data pertinent to particular SSI are distributed across a vast network of resources. Such information and data are often presented in multiple external representations (MER), such as tables, graphs, texts, models, and pictures (Ainsworth, 2006; Chandrasegaran, Treagust, & Mocerino, 2011). When arguing about a given SSI, students need to organize relevant information in an effective way and construct and represent their arguments accordingly, especially in computer supported collaborative learning (CSCL) environments. Therefore, learners must know how to search, sort, cluster, tag information in the forms of representations that reflect their understanding. We call this process *knowledge organization* (Namdar & Shen, 2013).

Although SSI, MER, and argumentation have been widely studied in science education, the process of knowledge organization with MER and the interaction between knowledge organization and argumentation on SSI remains relatively unexplored. Hence, to address this gap in the literature, we designed a learning unit on a SSI and asked learners to organize their knowledge using MER and argue about the issue using a CSCL platform. Our inquiry has focused on the following two research questions: (In an argumentation-based CSCL environment)

1. How do learners organize knowledge effectively with MERs?
2. How does learners' knowledge organization with MER interact with their argumentation practices?

Theoretical Framework

This study is built on both cognitive and social constructivist perspectives toward learning science. First, from a social constructivism standpoint, we hold the assumption that learning occurs within a community of learners and that learners construct their understanding within this socially interactive context (Lemke, 2001; Vygotskiĭ, 1986). Therefore, in our research we created a collaborative learning environment for learners to construct their knowledge using a CSCL tool in small groups and also at the class level. Second, based on the assumption of cognitive constructivism, learners use tools to construct their individual understanding (Piaget, 1970). In this study students used different representations to coordinate and construct meanings of a SSI.

Researchers have reported many benefits of using MERs in science instruction, such as capturing learners' interest (Ainsworth, 1999) and enhancing students' understanding of scientific concepts (Chandrasegaran et al., 2011; Waldrip, Prain, & Carolan, 2010). According to Ainsworth (1999), one goal of utilizing MER is to enable learners to take advantage of the benefits that are associated with each representation, and help individuals with varying learning abilities. It has been noted that naturally many students have meta-representational competency (diSessa, 2004), which might lead to improved learning gains (Grossen & Carnine, 1990).

Ainsworth (2004, 2006) argued that learners have difficulties with integrating information from multiple data sources as they see individual representations in MERs in isolation. Therefore, learners need to make meaningful links between those representations. We define knowledge organization as "the process of searching, sorting, clustering, archiving, and externalizing knowledge in a systematic way to achieve a better understanding of the world" (Namdar & Shen, 2013, p. 345). This process will enable learners to have more systematically organized and externalized information which will help them to retrieve information from multiple sources.

Our conceptualization of knowledge organization also stems from knowledge integration and knowledge building theories. We adopt the premises of helping learners make connections about their ideas and conceptually integrate those ideas from knowledge integration (Linn, 2006). We also believe in the needs of creating a knowledge building community and representing knowledge as in the forms of epistemic artifacts (Sterelny, 2005) from the knowledge building perspective (Scardamalia & Bereiter, 2006). Knowledge organization therefore embraces two distinct attributes. First, knowledge organization requires learners to actively create, manipulate, and connect MERs, especially with the aid of technological tools. Second, knowledge organization demands the creation of interrelated knowledge webs at different social levels.

Learning Platform and Unit Design

Innovative Knowledge Organization System (iKOS)

iKOS is a web-based knowledge organization platform that helps learners to organize knowledge both individually and collectively (ikos.miami.edu). It follows three core design principles: providing learners with means to externalize knowledge in multiple forms and facilitate the transformation among them; engaging learners' knowledge organization and construction at both the private and the public spaces and ease the flow between them; nurture learners' independent, critical thinking as well as collaborative mind set and catalyze the transition between them. In iKOS, learners can create knowledge entries in three distinct representation modes: *Event, Wiki,* and *Concept Map*. In Event, learners search the web, find, and upload pictures of a complex scientific phenomenon. Learners tag and annotate those pictures to understand the phenomenon of interest. Wiki is similar to the Wikipedia interface in which learners can write text. Learners can also create Concept Maps in the system and visualize the connections among a set of related science concepts (Novak & Cañas, 2008). iKOS automatically links and visualizes learners' knowledge entries based on similar keywords.

Context and Lesson Sequence

This study took place in a large southeastern public US university. The sample included a class of 23 pre-service teachers who were taking a middle school methods class for science teaching. The study was conducted in 4 sections in total of six hours. The first, second, and last sections took one hour, while the third section took three hours. We assigned students in four groups and each group had five students except one group with four students.

Although we focus on the learning aspect in the study, there are two main reasons to recruit pre-service teachers. First, we concur with Zeidler, et al.(2002) in that "[pre-service teachers] are in a position for effecting change with the future learners they teach concerning the topics that have been identified as seminal issues for science education" (p.346). Therefore, introducing an innovative learning approach to pre-service teachers may be more transformative for the future of science education. Second, introducing a new learning approach, especially in its early phase, may be risky for existing teachers as they face the pressure of high-stakes testing. Pre-service teachers are more accessible in this regard.

The lesson sequence was implemented as the following: (1) introduction to argumentation and concept mapping; (2) Introduction to the topic of nuclear energy by reading an article and watching videos that focused on pros and cons of nuclear energy; (3) Creating iKOS entries individually; (4) Creating iKOS entries collaboratively in small groups on a particular scientific aspect of nuclear energy and engaging in argumentation; (5) Peer critique and revision of MERs, 6) Final presentation and argumentation. At the end of the unit, students presented their findings and argued for their stance on the issue of building nuclear power plants. First author taught the class sessions for this study.

Data Collection and Analysis

We employed a *concurrent nested* mixed methods study design (Creswell, Plano Clark, Gutmann, & Hanson, 2003) to *better understand* the knowledge organization and argumentation practices (Greene, 2007). We collected multiple sources of data for the purposes of complementarity as the different data were used to tap into different facets of the learning process (Greene, Caracelli, & Graham, 1989). The data collection included participant observation of class interventions (Suzuki, Ahluwalia, Arora, & Mattis, 2007), learners' artifacts (MERs created on iKOS), log file created by iKOS, and video recordings of classes. Quantitative methods that focused on understanding the students' knowledge organization through the use of MERs and qualitative methods aimed at understanding the interaction between knowledge organization and argumentation practices (Greene et al., 1989; Greene, 2007). Both qualitative and quantitative data were collected concurrently.

The first research question was answered by analyzing the log file that was generated by iKOS. As the iKOS system automatically interlinks MERs that were created by the students, this file reports the number of links, the number of entries created, and the number of team members if the entry is co-created. We considered each individual iKOS entry as a node (or actor) in a graph to enact social network analysis (Knoke & Yang, 2007). We calculated the mean normalized degree centrality by adding all the links that were associated with one entry and divided this number by the possible number of links that this entry could possess in connection to the knowledge web (Knoke & Yang, 2007). Then, we added all the individual mean normalized degree centralities that were associated with one mode of MER and normalized this number by dividing it by the possible number of links that entries of particular mode have in the network.

To have a better understanding of the actors in the network, we ran key actor analysis using the *R* statistical package. We calculated betweenness centrality and eigenvector centrality measures for each actor in the network. Betweenness centrality measured the number of shortest paths that an actor is on, which makes this actor important in controlling the flow of the information in the network (Knoke & Yang, 2007). Eigenvector centrality measured how central an actor is and how central the ties of this actor are in the network (Bonacich, 2007). These two measures indicate how well connected an actor is in the network.

To answer our second research question, based on the results of key actor analysis, we examined the argumentation that involved those students who created the highest ranked key actors. We analyzed the videos by adopting the analytical model suggested by Powell et al. (2003). First, we watched the videotapes several times to become familiar with the content of the video without intentionally imposing critical and theoretical lenses toward the data. Second, based on 5-minute intervals, we described data without including interpretations or inferences. After becoming familiar with the content of the videos, we carefully identified the significant instances, or critical events (Powell et al. 2003). Critical events in this research refer to the instances in which learners argue collaboratively and take actions in their knowledge organization (revising, editing entries, creating new ones) or use their knowledge organization entries in their arguments. Next, we transcribed relevant argumentation sessions. In the coding stage, we specifically examined students' statements and their relationship to the specific entries that the students created or how the students' arguments led them to create a certain entry type. For instance, when a student wrote in her wiki "The fact that this power plant will be located 26 miles from SkyCity makes it a potential hazard to a large population of people" (Haley, Wiki entry) and employed a similar idea in her argumentation in the class, we coded her verbal argument as "a reference to a wiki."

Results

Network of Students' iKOS Entries

The students created 17 events, 23 wikis, and 20 concept map entries (see Table1). Our results indicated that the wiki mode had the highest mean degree group centrality. This result suggests that in this sample the most centralized/prominent entry mode was the wiki mode. These results also show that the event mode was the least centralized. Moreover, normalized degree centrality for the concept map mode was close to that of the wiki mode.

Table 1. Mean Normalized Degree Centralities for iKOS Modes

Entry Mode	Total Number of Entries	Normalized Degree Centrality	*SD*
Event	17	0.38	0.28
Wiki	23	0.51	0.21
Concept Map	20	0.49	0.22

Figure 1 shows the results of our key actor analysis weighted by eigenvector and betweenness centralities. Each numbered actor in the figure represents an iKOS entry. The diameter of each actor is proportional to the product of eigenvector and betweenness centralities. We closely examined the top five key actors in the network (#A149, A145, A130, A121, A157; see figure 1). Our results indicated that three out of five actors were concept maps and the remaining two actors were wiki entries.

Additionally, the network density was 0.55which means that 55% of the possible links were present. In other words, this knowledge network was a very dense network.

Interpretation

Overall, the knowledge web that was generated as a result of this intervention was highly connected (see Figure 1), which suggests a good knowledge organization practice by the students. The high density of the network also suggests that the students were mindful when organizing their knowledge; that is, they carefully connected concepts in their concept map entries and generated keywords for their wiki entries as the tags and keywords are the sources for links in iKOS.

Both concept maps and wiki entries were more central than the event entries, as expected. Since the function of a concept map is to connect big ideas (Novak & Cañas, 2008), it makes sense for them to be central, relatively speaking, in a knowledge web. Also, students created more wiki entries. This was natural as textual representations are more approximate to verbal arguments. This result is consistent with our SSI unit that had an argumentation-based design. On the other hand, the event entries were not as connected in the knowledge web (Table 1). An event entry was relatively harder to create compared to the wiki and concept map entries in the system. Also, the function of an event entry is to encourage students to reflect their understanding of scientific processes and concepts.

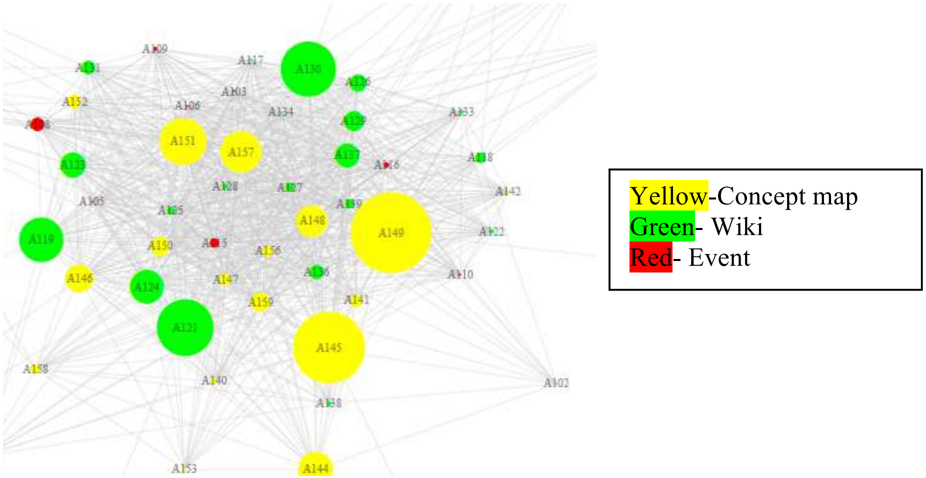

Figure 1. Key Actor Analysis for iKOS Entries Weighted by Betweenness and Eigenvector Centralities

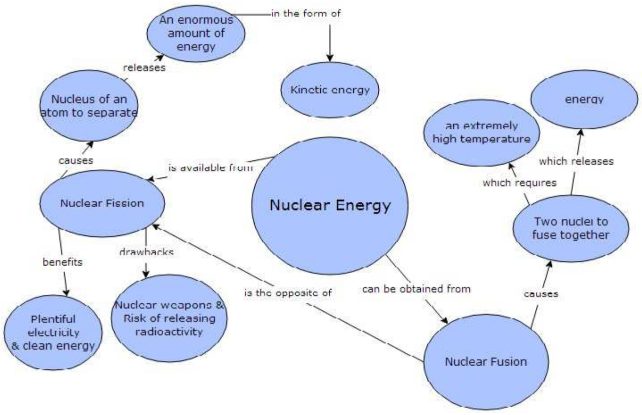

Figure 2. Haley's Concept Map Entry

Interaction between Knowledge Organization and Argumentation: The Case of Haley

To address our research question 2, we further examined the top ranked key actors. The concept map entry created by Katie was the top ranked entry overall. However, Katie needed to leave the class after the first group discussion. Therefore, we decided to focus on the case of Haley, who created the second highest ranked key actor, which was a concept map (see Figure 2).

In her homework Haley generated an entry in each mode (step (3) in lesson sequence). In her event entry, Haley inserted a picture of a nuclear power plant and focused on how this nuclear fission power plant worked. In her concept map, she looked at different types of nuclear energy creation processes: nuclear fission and fusion (See Figure 2). In her long wiki entry she listed the benefits, drawbacks of nuclear energy, and wrote her claim to the question of 'should we build nuclear power plant in our state?" She summarized her *claim* as:

“no, we should not build nuclear power plants in our state.” and listed six pieces of *evidence* : “(1) Costs billions of dollars, (2) Benefits do not outweigh the risks, (3) Power companies don't pay if accident happens, families pay by losing their loved ones (sometimes years later due to cancer), (4) Exposure to radiation kills living cells, (5) People around power plant are displaced (property value goes down since no one wants to live near a power plant), (6) Located 26 miles northeast of a city - too close to a densely populated area.” Finally, she wrote her justification:

> While nuclear energy is a relatively clean source of energy, the potential release of radiation from nuclear power plants is a huge risk. Accidents can happen, and they have happened. The fact that this power plant will be located 26 miles from SkyCity makes it a potential hazard to a large population of people. We do not have the technology yet to make sure harmful radiation is not released. Why should we build a nuclear power plant when the proper safety measures are not in place? [Haley, wiki entry, 04/17/2013]

We compared Haley’s individual entries with those created by her teammates’ (her group had 5 students). Two students did not create any entries prior to the class. None of the other two students created a concept map. Haley was the only student in her group who created all three types of external representations. When we look at the event entries, we saw that all three students (Haley, Rachel, and Melissa) inserted a picture of a nuclear power plant. Melissa only inserted a picture and did not use any tags, a poor knowledge organization practice. Rachel on the other hand, used seven tags in her event. But instead of using central scientific concepts such as radioactive elements, heat, and energy as Haley did, she used specific terms such as coolant and cooled liquid to refer to concrete objects.

Key actor analysis indicated that Haley’s event entry was more central compared to the other two students’ event entries. For wiki entries, Melissa’s wiki entry was one of the key actors (A130). In her entry she wrote:

> Nuclear energy comes from a process called fission. This generates heat which produces steam, which then generates electricity. There is another type of reaction called fusion (Melissa, Wiki Entry, 04/17/2013).

Rachel, on the other hand, wrote several things about nuclear energy (e.g., the percentage of energy and electricity generated from nuclear power, some benefits such as reducing carbon emissions and some drawbacks such as radiation threats to environment).

When coming to the class, students were asked to argue on the following two questions in their small groups (step (4) in lesson sequence): Should we build nuclear power plants in our state? For how long should we depend on nuclear energy as an alternative energy source? Haley immediately initiated the discussion:

[Excerpt 1. Transcripts 09/01/2013: 04:35-05:32]

Haley:	I do not think we should, because in the article it is talking about building it like within twenty-five miles, or something like that from SkyCity. So if anything were to go wrong. That would affect… it’s like very close to a high population of people.
Ashley:	Yeah.
Haley:	That would affect a lot of people.
Researcher:	What would be the effect?
Haley:	Well, the radiation kills living cells so like that might not affect them right away but it could affect them like over ten years if they are exposed to that radiation, and it develops cancer and then ten years down the line, power plants are not gonna be the ones that wait for that. They are not gonna come and say “oh you know we gave you cancer” and we are not gonna be able to fix it so people are gonna lose their lives.

This excerpt indicates that Haley was able to draw information from the wiki entry she created in which she mentioned the “lethal amounts of radiation, “the potential release of radiation from nuclear power plants is a huge risk,” and “The fact that this power plant will be located 26 miles from SkyCity makes it a potential hazard to a large population of people.”

As Haley initiated the discussion, she actually dominated it. She drew information seven times from her wiki, four times from her concept map, and one time from her event entry. Following their group argumentation session 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. It contaminated the ground water and caused cancer in the community. After giving this example Haley drew the group's conversation to a certain point that they started to talk about cancer and radiation.

[Excerpt 2. 09/01/2013: 15:30-15: 41]
Haley: It [nuclear power plant] contaminates…even if there isn't an accident they are still spreading nuclear radiation into the ground.
Rachel: They cause cancer.
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 ten minutes into their small group discussion, students were asked to choose one scientific aspect associated with nuclear energy and create iKOS entries to explain it. Haley's group decided to focus on the topic of radiation exposure and its connection to cancer (see excerpt 3 below).

[Excerpt 3. 09/01/2013: 17:35- 18:05]
Ashley: Why do not we do radiation and cancer, so we do not want it.
Rachel: [Inaudible]
Ashley: We are done. We are gonna do radiation and cancer
Haley: How radiation kills cells?
Ashley: Yeah.
Haley: Radiation exposure and cancer.

As a result, Haley's group created one entry on each mode and all entries focused on the connection between radiation and cancer. However, there was a slight difference in terms of the information represented in three modes. In the wiki, they stated that **"**The radiation that comes from nuclear reactors is ionizing radiation," and listed two dangers:

(1) It can damage DNA leading to mutations, thus potentially causing cancer or death of the cell. Damage to the cell can take place in less than a second, but cancer can take years to develop, and
(2) Ionizing radiation can be more carcinogenic than other types of radiation, and lead to cancers such as: thyroid, bone marrow, leukemia, skin, lung, stomach, breast, etc.

They also wrote about the dangers of exposure to radiation and the testing of nuclear reactors in their wiki. In the event entry, they inserted several pictures that showed different information: about how UV photon mutates the DNA, how normal cells mutate to cancer cells, and how cancer cells leads to a tumor. In the concept map, they summarized the types of radiation and tied those to the cause of cancer.

Interpretation

Our analysis showed that Haley was able to draw information from different representations as she argued on the nuclear energy topic within her group. She mostly used text-based entries (wiki-7 times; concept maps-4 times) as the source of information for her argument. This is natural as she was asked to verbally argue on the same topic, and she referred to her statements in the wiki mode. She only referred once to her event entry. Acquiring information from a pictorial representation during a verbal argumentation might be more challenging, as it requires students to explain and elaborate on the nuances that the picture includes. Through looking into Haley's case, we extracted two characteristics of the type of knowledge organization practices that contribute to argumentation.

The first characteristic of a better knowledge organization might be the number of different types of representations that were created. Compared to her group members Haley was the only student who created all three representations. The creation of more representations might have allowed her to acquire different pieces of information as she used MERs to represent slightly different units of information on a given topic.

The second characteristic of better knowledge organization that fostered argumentation speaks to the quality of the entries that were created. For instance, although Melissa's wiki was a key actor in the knowledge network, we see that she did not elaborate on the fission concept. The reason for Melissa's wiki entry to be key actor is that it connects with key actors in the knowledge network (e.g., #A148, A149, A157, A159; see figure 1); as Melissa used the key concepts as her keywords (i.e., nuclear, energy, nuclear energy, and fission). Therefore, her entry was highly connected with other entries in the class. However, in the argumentation, she was not actively involved, and she did not acquire any information from her event entry during argumentation. Rachel, on the other hand, only listed facts about nuclear energy in her wiki entry without further elaboration. However, the structure of Haley's wiki entry was very organized. She wrote her claim and justification about nuclear energy. As we also analyzed the group discussion, we saw that Haley was drawing information easily from her wiki entries for her arguments. Therefore, good knowledge organization might have fostered argumentation in the classroom. Similarly, as knowledge organization fostered students' argumentation, their argumentation also encouraged them to find and organize new information before they presented their findings to the class. However, specific types of interactions need further research Individually Haley's representations focused on different aspects of nuclear energy, but in their group knowledge organization, they created representations in three modes that focused on the connection between radiation and cancer. Additionally, as Haley used key concepts such as fission, fusion, and energy as central concepts in her concept map, her concept map was highly connected to other entries.

Ainsworth (2006) listed three functions of MERs: complementary roles, constrain interpretation, and construction of deeper understanding. As we see from Haley's individual entries, they were clearly complementary to each other. In that regard, MERs served to expand the scope of her understanding. Her group's entries, on the contrary, included more or less similar information. This was partially because in our lesson design we asked students to focus on one topic and present their findings to the class so that they might chose to create similar entries. On the other hand, Haley's group created their entries on the similar topic to emphasize their shared points. Therefore, to a certain degree, these similar entries in different modes served as constrains to each other, and helped the group develop a more in-depth understanding.

Conclusion and Discussion

Linn (2000) argued that "the internet provides a rich, confusing, chaotic, informative, persuasive set of scientific information" (p. 785). This is more so for SSI topics. Therefore, it is crucial to help learners use tools to organize and coordinate pieces of information that they use to make sound arguments. We designed a science unit on nuclear energy using an online knowledge and learning management system (iKOS) that offers three types of representations: pictorial, textual, and concept maps. Our results suggest that the interaction between knowledge organization and argumentation is bidirectional (i.e., students' knowledge organization enables them to draw information while arguing and that their argumentation guides them to advance their knowledge organization practices. On the other hand, we need more sophisticated methods to be able to capture relevant learning process both on an individual and a collaborative level.

According to Erduran and Evagorou (2012), educators should make the best use of visual representations as these are fundamental objects of enhancement of scientific knowledge and students' lives. Along these lines, we found that use of visual representations, MER in our case, enabled learners to organize their knowledge on SSI and helped them in argumentation. More specifically, our results indicated that when organizing knowledge with MERs, learners mostly created wiki and concept map entries. Additionally, when our system automatically created a knowledge-web based on the MERs that were created by the students, wiki and concept map entries were highly connected representation types. On the other hand, when we looked at the key representation across the whole network and the student (Haley) who created it, we also found that Haley was acquiring information from her wiki and concept map entries while she was arguing on the topic. Also, students' argumentation encouraged them to (re)organize knowledge.

References

Ainsworth, S. (1999). The functions of multiple representations. *Computers & Education*, *33*(2-3), 131–152.

Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction*, *16*(3), 183–198. doi:10.1016/j.learninstruc.2006.03.001

Bonacich, P. (2007). Some unique properties of eigenvector centrality. *Social Networks*, *29*(4), 555–564. doi:10.1016/j.socnet.2007.04.002

Chandrasegaran, B. A. L., Treagust, D. F., & Mocerino, M. (2011). Facilitating high school students ' use of multiple representations to describe and explain simple chemical reactions. *Teaching Science*, *57*(4), 13–21.

Creswell, J. W., Plano Clark, V. L., Gutmann, M. L., & Hanson, W. . (2003). Advanced mixed methods research designs. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of mixed methods in social and behavioral research* (pp. 209–240). Thousand Oaks, CA: Sage.

Erduran, S., & Evagorou, M. (2012). Visualising evidence and scientific methods : Implications for science education. In *National Association of Research in Science Teaching, Indianapolis, IN* (pp. 1–15).

Greene, J. C. (2007). *Mixed methods in social inquiry* (p. 216). San Francisco: John Wiley & Sons.

Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). Toward a Conceptual Framework for Mixed-Method Evaluation Designs. *Educational Evaluation and Policy Analysis*, *11*(3), 255–274.

Grossen, B., & Carnine, D. (1990). Diagramming a logic strategy e Effects on difficult problem types and transfer. *Learning Disability Quarterly*, *13*(3), 168–182.

Knoke, D., & Yang, S. (2007). *Social network analysis (Quantitative applications in the social sciences)*. (T. Liao, Ed.) (p. 133). Sage Publications, Inc.

Kolstø, S. D. (2006). Patterns in students' argumentation confronted with a risk focused socio-scientific issue. *International Journal of Science Education*, *28*(14), 1689–1716. doi:10.1080/09500690600560878

Lemke, J. L. (2001). Articulating communities: Sociocultural perspectives on science education. *Journal of Research in Science Teaching*, *38*(3), 296–316. doi:10.1002/1098-2736(200103)38:3<296::AID-TEA1007>3.3.CO;2-I

Linn, M. C. (2000). Designing the knowledge integration environment. *International Journal of Science Education*, *22*(8), 781–796.

Linn, M. C. (2006). The knowledge integration perspective on learning and instruction. In R. Sawyer, Keith (Ed.), *The Cambridge handbook of the learning sciences* (pp. 243–264). New York, NY: Cambridge University Press.

Linn, M. C., & Hsi, S. (2000). *Computers,teachers, peers: Science learning partners.* Mahwah,NJ: Lawrence Erlbaum Associates.

Novak, J. D., & Cañas, A. J. (2008). *The theory underlying concept maps and how to construct and use them*. (IHMC CmapTools Report). Retrived from: http://cmap.ihmc.us/Publications/ResearchPapers/TheoryCmaps/TheoryUnderlyingConceptMaps.htm

Namdar, B**.** & Shen, J. (2013). Knowledge organization with multiple external representations in an argumentation based computer supported collaborative learning environment. In Rummel, N., Kapur, M., Nathan, M., & Puntambekar, S. (Eds.). *To See the World and a Grain of Sand: Learning across Levels of Space, Time, and Scale: CSCL 2013 Conference Proceedings Volume 1 — Full Papers & Symposia*. International Society of the Learning Sciences. *pp*, 344-351.

Piaget, J. (1970). *Genetic epistemology*. New York: Columbia University Press.

Powell, A. B., Francisco, J. M., & Maher, C. a. (2003). An analytical model for studying the development of learners' mathematical ideas and reasoning using videotape data. *The Journal of Mathematical Behavior*, *22*(4), 405–435. doi:10.1016/j.jmathb.2003.09.002

Sadler, T. D., & Zeidler, D. L. (2005). Patterns of informal reasoning in the context of socioscientific decision making. *Journal of Research in Science Teaching*, *42*(1), 112–138. doi:10.1002/tea.20042

Scardamalia, M., & Bereiter, C. (2006). Knowledge building : Theory , pedagogy , and technology. In K. Sawyer, R. (Ed.), *The Cambridge handbook of the learning sciences* (pp. 97–115). New York, NY.

Simonneaux, L. (2008). Argumentation in socio-scientific contexts. In S. Erduran & M. P. Jimenez-Aleixandre (Eds.), *Argumentation in science education: An overview* (pp. 179–199). Springer Netherlands.

Sterelny, K. (2005). Externalism, epistemic artefacts and the extended mind. In R. Schantz (Ed.), *The Externalist Challenge: New Studies on Cognition and Intentionality*. Berlin: de Gruyter.

Suzuki, L. A., Ahluwalia, M. K., Arora, A. K., & Mattis, J. S. (2007). The pond you fish in setermines the fish you catch: Exploring strategies for qualitative data collection. *The Counseling Psychologist*, *35*(2), 295–327.

Vygotskiĭ, L. (1986). *Thought and language*. (A. Kozulin, Ed.). Ipswich, MA: MIT Press.

Waldrip, B., Prain, V., & Carolan, J. (2010). Using Multi-Modal Representations to Improve Learning in Junior Secondary Science. *Research in Science Education*, *40*(1), 65–80. doi:10.1007/s11165-009-9157-6

Zeidler, D. L., & Nichols, B. H. (2009). Socioscientific issues: Theory and practice. *Journal of Elementary Science Education*, *21*(2), 49–58. doi:10.1007/BF03173684

Zeidler, D. L., Walker, K. A., Ackett, W. A., & Simmons, M. L. (2002). Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education*, *86*(3), 343–367.