

# Knowledge Organization with Multiple External Representations in an Argumentation Based Computer Supported Collaborative Learning Environment

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**Abstract:** Collaboration is one of the core practices in science education (NRC, 1996; NRC, 2012) that has been built into many technology-enhanced learning environments to promote deep understanding (Manlove, Lazonder, & De Jong, 2009). Typically, these environments provide multiple external representations (MERs) for students to understand and communicate scientific knowledge. However, little is known about how students organize knowledge in MERs when they engage in collaborative argumentation. In this study, we designed an argumentation based science unit in a computer supported collaborative learning environment. We investigated how this learning environment affected students' knowledge organization and argumentation on the socio-scientific issue of nuclear energy. We found that the students used all the available representational modes in the environment to make sound arguments and it appeared that the textual representation knowledge entries were the most linked nodes in the knowledge web the students produced as a group.

## Introduction

Students nowadays access information in the forms of multiple external representations (MERs) such as computer models, dynamic and static pictures, and texts through information communication technologies (ICT). Research suggests that students benefit from MERs when learning complex scientific phenomena and processes (Ainsworth, 2006; Kozma, 2003). MERs can be used in the classrooms as pedagogical tools to promote scientific argumentation. The quality of MERs "becomes the focal point of the discussion in the classroom as students evaluate and critique methods, explanations, evidence, and reasoning" (Sampson & Clark, 2009, p.450). However, it is still unclear how students organize MERs to make coherent scientific arguments (Erduran, 2012).

In this study, we designed and implemented an argumentation based computer supported collaborative learning (CSCL) unit on socio-scientific issues (SSI) in order to study the connection between students' knowledge organization through MERs and their scientific argumentation processes. Through the study, we addressed the following research questions:

1. How does an argumentation-based CSCL environment affect learners' collaborative knowledge organization with MERs?
2. How does students' collaborative knowledge organization with MERs affect their argumentation on a given socio-scientific issue in a CSCL environment?
  - a) What is the most prominent type of MERs students mostly rely on when they collaboratively organize their knowledge on a given SSI in an argumentation based CSCL environment?
  - b) What is the process of using MERs when they argue on a given SSI in an argumentation based CSCL environment?

## Theoretical Framework

### Knowledge Organization

In today's technology mediated society, information is easily generated, distributed and accessed through ICT. Since there is almost no limit on accessing information, education should help students develop competencies in searching for, archiving, using, and generating relevant information and organizing it in ways that make sense for current or future use. Our conceptualization of knowledge organization stems from the literature in learning sciences including MERs, knowledge integration (Linn, 2006) and knowledge building (Scardamalia & Bereiter, 2006).

People understand, communicate, and organize information in a variety of modalities including actions, verbal explanations, written texts, physical experiments, computer models, and static and motion pictures and diagrams. The use of MERs can help capture learners' interest (Ainsworth, 1999), and enhance their understanding of science concepts (e.g., Chandrasegaran, Treagust, & Mocerino, 2011; Waldrup, Prain, & Carolan, 2010).

Linn and colleagues developed the knowledge integration framework that emphasizes students' abilities in establishing connections among scientific ideas (Linn & Eylon, 2011; Linn, 2006). The framework

promotes coherent understanding by encouraging students to elicit, add, distinguish, and sort out ideas. The framework has been used to develop a rich library of technology enhanced curricula supporting student learning in science (Linn, Lee, Tinker, Husic, & Chiu, 2006; Liu, Lee, Hofstetter, & Linn, 2008; Slotta & Linn, 2009).

Knowledge building advocates for creating communities of learners who build knowledge together (Scardamalia & Bereiter, 2006). Members of a knowledge community use epistemic artifacts (Sterelny, 2005) such as abstract or concrete models to reflect their understanding. Since these epistemic artifacts are fundamental components of the knowledge building process, organizing them in a coherent way is the key to developing scientific understanding for both individual and groups of learners.

We define knowledge organization as the individual or collaborative processes of searching, sorting out, archiving, and externalize knowledge in a systematic way to achieve a better understanding of the world and to prepare for future learning. It differs from knowledge integration (Linn, 2006) in the sense that it focuses on tagging and organizing knowledge that is externally represented, but not necessarily conceptually integrated in the mind of the learner at the moment. Knowledge organization can be personnel; therefore, the organization structure may not be aimed for public use, which is essential in knowledge building (Scardamalia & Bereiter, 1994). A knowledge organization process of an individual or a group could be intertwined with and complement to knowledge integration and knowledge building.

## Collaboration

Collaboration has been advocated as one of the core practices of science education in national science education policy documents over the past two decades (NRC, 1996; NRC, 2012). Collaboration is also a core component of inquiry activities (Simons & Clark, 2005) as it engages students to knowledge construction and delve into their own understanding of scientific phenomena (Komis, Ergazaki, & Zogza, 2007). Additionally, when students involve in collaborative learning, they encounter vast amount of distinct ideas and views, which urges them to organize and integrate those ideas (Linn, 2006). Research indicates that students achieve higher learning goals when they collaborate comparing to individual learning (see, for example, Cohen & Scardamalia, 1998; Lou, Abrami, & D'Apollonia, 2001).

Collaboration has been built into many technology-enhanced learning environments to promote deep understanding (Manlove et al., 2009). As a rising field, computer supported collaborative learning (CSCL) studies how people learn together with the help of computers (Stahl, Koschmann, & Suthers, 2006). It is different from traditional types of learning as it is "concerned with collaborative meaning making processes that go beyond information sharing among multiple people" and "highlights the potential impact of social community through computers as vehicles for transforming activity procedures" (Yoon & Brice, 2011, p.251).

## Scientific Argumentation

There are several reasons for practicing argumentation in science classrooms, especially on SSI related topics (e.g., Sadler & Donnelly, 2006; Zohar & Nemet, 2002). As Duschl and Osborne (2002) argued "situating argumentation as a critical element in the design of science learning environments both engages learner with the conceptual and epistemic goals and, for the purposes of the practice of formative assessment by teachers, can help make science thinking visible" (p. 44). Practicing argumentation allows students to use available data and evidence to construct knowledge, clarify meanings, and reflect on their own thinking (Duschl & Osborne, 2002). In addition to making thinking visible, Jimenez-Aleixandre and Erduran (2007) propose five advantages of using argumentation in science classrooms: (1) the access to students' cognitive and metacognitive processes, (2) the development of discourse practices and thus critical thinking, (3) increased scientific literacy, (4) enculturation into scientific culture and the development of epistemic criteria, and (5) developing reasoning and rational criteria. CSCL may incorporate scientific argumentation. Noroozi, Weinberger, Biemans, Mulder, and Chizari (2012) did an extensive review of literature on argumentation based CSCL and found that these environments foster in-depth discussions (Andriessen, Baker & Suthers, 2003), and help learners achieve deeper understanding and productive arguments (Buckingham-Shum, 2003). SSIs are particularly useful for promoting interest in learning science (Sadler & Zeidler 2004; Zeidler, Walker, Ackett, & Simmons, 2002). Research indicates that facilitating argumentation through the use of SSI can increase students' use of scientific knowledge in constructing arguments (Zohar & Nemet, 2002).

In sum, in an active and collaborative learning environment, individual learners work with each other to learn and co-construct scientific knowledge. Their understanding will evolve through processes including re-organization of information, representation of knowledge in MERs, and cogeneration of argumentative discourse. So will the knowledge artifacts produced by the group of learners. With this vision in mind, we build and test a new learning environment, the innovative knowledge organization system (iKOS), which will be described in the following.

## Methods

We developed a science unit on nuclear energy using the iKOS system and implemented it with a group of college students. We examined the nature of the knowledge web the students created and the argumentative discourse they generated, in order to make sense of the interaction between their knowledge organization and scientific argumentation.

### The innovative Knowledge Organization System (iKOS)

iKOS is a web-based knowledge organization platform that incorporates three distinct MERs: *Event*, *Wiki*, and *Concept Map*. In the event mode students can insert static pictures and can tag them in order to have a holistic understanding of complex scientific phenomena and systems. Students write textual entries in the wiki mode similar to popular Wikipedia pages. Students can also create concept maps (Novak & Cañas, 2008) in the system and visualize the connections among a set of related science concepts. iKOS automatically interlinks students' knowledge entries through keywords and forms a web of knowledge entries. The system has also social functions such as co-editing, commenting and rating blocks to foster students' collaborative learning practices. The system also reports basic descriptive statistics of group learning and social networking (see Figure 1).



Figure 1. iKOS snapshots: (left) an event entry and (right) a statistics screen.

### Design of an Argumentation-based Science Unit on Nuclear Energy

We designed an argumentation-based science unit using the iKOS system with the following goals in mind: 1) to help students understand the complex nature of a phenomena or SSI through the interlinked knowledge web, 2) to help students organize knowledge effectively, 3) to help students efficiently retrieve information and identify information, 4) to help students co-construct knowledge entries and learn from each other. We chose the topic of nuclear energy based on notions associated with SSI, which can engage students in argumentation and drive them to think critically (Zeidler & Nichols, 2009; Zohar & Nemet, 2002). Nuclear energy is a prominent, controversial, and open-ended real life phenomenon (Sadler, 2004) with the historical crisis including the recent meltdown of the nuclear reactor in Fukushima, Japan. The unit included the following major steps:

- Introduction to the iKOS system. Students get familiar with the learning environment (e.g., create accounts, create iKOS entries in different modes).
- Introduction to the topic of nuclear energy. Students read news regarding a new nuclear reactor to be built in the state they are living in. They also watch videos focusing on the pros and cons of using nuclear energy. They brainstorm initial ideas related to nuclear energy.
- Creating iKOS entries individually. Students create entries in different modes individually. They then submit these entries as open for the whole class.
- Creating iKOS entries collaboratively. The students work in small groups to create iKOS entries and form arguments about either supporting or objecting the construction of the power plant. They also need to argue: 1) should we build nuclear power plants? 2) How far should we rely on nuclear energy as an energy source? During this small group activity, the students were also encouraged to investigate one specific scientific aspect of Nuclear Energy (e.g., radiation).
- Peer critique and revision. Students may co-edit or critique peers' entries and revise their own based on peers' feedback.
- Final presentation and argumentation. At the end of the unit, students present their findings and argue for their stance on the issue of building nuclear power plants.

### Participants and Implementation

This study was implemented with a class of student who were enrolled in a course Technology for Science Teaching in a large public southeastern university in the United States. The second author taught the course. There were 21 students enrolled in the course and 19 students (2 undergraduate students, 17 graduate students)

consented to participate in the study. We only collected data from the students who consented. The class met once a week (2.5hrs/wk), and the unit was carried out in three consecutive weeks (only the second week was entirely devoted to this unit). In week one, it took the class about 45 minutes to go through the iKOS system. They were then assigned as homework to create individual entries, one per mode. In week two, the students were divided into four small groups (2 with four students each and 2 with five students each) and carried out the bulk of the activity (~150min). Also, two groups were able to present their work during week two. In week three, the two remaining groups presented their findings and we carried out a whole class discussion (~35min).

### Data Collection and Analysis

Our data collection included participant observation (Suzuki, Ahluwalia, Arora, & Mattis, 2007), video recording, and iKOS entries and descriptive statistics generated through the iKOS system. We were conscious that video recording might affect the students' responses and behavior in the learning environment so we tried to move the camera as little as possible to keep the distraction at a minimum level.

To investigate our first research question, we focused on examining the patterns of the iKOS entry networks created by the students. We considered each individual iKOS entry as a node, and the links between the nodes were categorized into two types: direct links and indirect links. A direct link is defined as a connection between two entries when the title of one entry is a keyword of the other; an indirect link is defined when two entries share one or more keywords.

Applying the social network analysis techniques, we calculated the degree centrality for each iKOS entry which measures the extent to which one node is connected with the rest of the knowledge web (Knoke & Yang, 2007). In the iKOS system, we summed all the links associated with one entry; to get the normalized degree centrality, we divided this number by the possible number of links this entry has in the knowledge web. We then calculated the mean normalized degree centralities associated with the particular representational modes and the whole knowledge web.

In order to investigate our second research question, we transcribed the videos verbatim and analyzed students' final presentations. Our unit of analysis was a coherent statement made by a student that delivers a stand-alone meaning. We coded each relevant statement in terms of its direct relevance to the type of iKOS entry for each group and we summed up these numbers and reported the percentages. In addition to the quantified results, we also reported a representative case in order to provide a more vivid scenario for the reader to make sense of the learning processes (Creswell, Hanson, Clark Plano, & Morales, 2007).

## Results

### Network of Students' iKOS Entries

The students created 20 event 19 wiki and 24 concept map entries for the homework assignment and created additional 4 event, 4 wiki, and 4 concept map entries during the class activity in the second week. Table 1 shows the total number of links for the entries in each of the three iKOS modes. Apparently, indirect links are much more pervasive than direct links between entries. In terms of total links, the wiki mode has the highest number.

Table 1: Degree Centralities of iKOS Entry Modes

Types of Links	Event	Wiki	Concept Map
Direct	11	20	29
Indirect	402	467	389
Total	413	487	418

Table 2 shows the mean normalized degree centrality for the iKOS knowledge web, in which the entries were linked either directly or indirectly. Our results indicated that the wiki mode had the highest mean degree centrality, for both the directly and indirectly linked knowledge webs. This suggests that the most "centralized" entry mode was the wiki mode in this learning unit. This was not expected because students had to manually type in keywords for the wiki mode, while in other modes the computer will automatically register the keywords. This result suggests that the students were mindful of and good at generating their wiki entry keywords.

Table 2: Mean Normalized Degree Centrality (NDC) for iKOS Entries in terms of Direct and Indirect Links

Types of Links	Mode	Mean NDC	SD
Direct	Event	0.009	0.015
	Wiki	0.013	0.031

Indirect	Concept Map	0.010	0.030
	Overall	0.009	0.015
	Event	0.245	0.218
	Wiki	0.291	0.179
	Concept Map	0.261	0.201
	Overall	0.265	0.199

### Knowledge Organization and Argumentation

We analyzed students' arguments on the final presentation sessions. Table 3 shows the percentages of each groups' argumentation relevant to their MERs. Apparently, different groups relied on different types of representations in their arguments. Overall, there was a significant relationship for groups and representational modes, meaning that categorical variables were not independent and groups relied on to certain modes more on their arguments (Chi square test for independence,  $\chi^2 = 27.6$ ,  $df=6$ ,  $p<0.001$ ).

Table 3: Distribution of Knowledge Organization Entries in Collaborative Argumentation

Representation Mode	Relevance of Statements to Representation Types			
	Group 1	Group 2	Group 3	Group 4
Wiki	37%	<b>42%</b>	30%	11%
Event	<b>55%</b>	21%	13%	28%
Concept Map	8%	37%	<b>57%</b>	<b>61%</b>

Although the groups referred to the representation modes quite differently in their argumentation, through the analysis of group discussions and presentations, we found that students incorporated MERs in a holistic manner to present a sound argument on the given SSL. In the following we present a case to illustrate this point.

Group 1 focused on the environmental impact of the nuclear energy in general and the group was against the construction of the nuclear power plant and relying on nuclear energy as an energy source. A total of 55% of their statements were based on the event entry they created. However, they initiated their argument based on the wiki entry they created. In their wiki entry they stated that they will focus on the "environmental impacts associated with the disposal of effluent wastewater produced by a secure and functioning nuclear power facility" and described the effluent water waste in the process of cooling nuclear rods (Group1, Wiki Entry). They initiated the discourse based on their definitions and knowledge organization about the effluent water waste:

Derrick: We are looking actually at the water which is most of the time not retaining and injected right back into environment. Ok? This water typically starts as sewage. They take sewage water, remove contaminants, cool the nuclear rods, and then ship it right back at ocean, river or lakes. So what are the impacts associated with that? Number one we super-heated the water. And so... we also have environmental impact there as far as changing ecosystems.

These statements made by Derrick also reflected his group's collaborative knowledge organization in the Concept map mode. Because in their concept map, they illustrated that nuclear waste flows to water and the water temperature rises. Ray, on the other hand, changes the direction of the conversation using the event entry they created.

Ray: This [shows their event entry to the class] is just a representation that you [Derrick] are talking about how the water is either evaporated and this contaminants get into the atmosphere or they are directly injected into the water system. And the end result is it affects humans directly and the atmosphere and plant life animal life affected negatively as well.

Derrick: It also represented in the bio magnification. Because when you start to impact what we eat that is magnified to us tenfold twentyfold. So there is a lot of contamination out there that we are not looking at when we just think about nuclear power.

Here Ray showed the part of their pictorial representation where contaminants from the water go through the irrigation process to grass and then to the cows and then humans. This argument was also reflected in their concept map, which showed that nuclear waste can leak to underwater repository and directly harms people's or animals' lives.

The discourse above illustrates that although this group relied mostly on the event mode, they also incorporated all the other representation modes in order to drive their argument to the point that they stated possibilities of how effluent water waste can impact the environment. Derrick was a representative when they were presenting their argument. Based on their knowledge organization practices with using MERs Derrick concluded that:

We don't think there are enough standards or safe guards in place based on what just happened in Japan, which is supposed to be the technology leaders. As far as natural disasters protecting yourself against natural disaster we do not feel there is enough safeguards in place yet put one in our own backyard.

This case shows how students' knowledge organization process affects their discourse and arguments. In this case, although the students' argumentation benefited from one particular type of representational mode, further analysis of their argumentation indicated that the students used all the three representational modes in the proper places of the discourse to arrive at their conclusion and make sound arguments with the help of data they put in MERs.

## Discussion and Conclusion

Recently, science education field has been witnessed the growing body of research advocating for using those representations to capture learners' interest (Ainsworth, 1999), and capture and enhance students' understanding of science concepts (e.g., Chandrasegaran, Treagust, & Mocerino, 2011; Waldrup et al., 2010). Based on the positive effects of using MERs in science learning, we were interested in students' collaborative knowledge organization practices with MERs on socio scientific issues. Our results indicated that degree centrality of students collaborative knowledge entries were highest in their wiki entries. We were hypothesizing that the concept maps would be most prominent representations in terms of degree centralities for indirect links since the computer automatically generates key words and links the entries. However, our results showed that students made their knowledge organization process more interconnected in the wiki mode, because students generated better key words to connect their entries with other entries. Also, our interpretation is that even though students can represent their knowledge in the forms of concept maps and pictorial representations, they may still feel the need for verbally explaining their findings to make their knowledge organization and understanding visible for their audience.

We were also interested in seeing how students' knowledge organization relied on the use of MERs when students argue on a given SSI. Our results indicated that students used different modes of representations in their arguments. We want to point out that even though this result might be interpreted as students with different learning abilities use different representation in their arguments, our analysis of students' discourse illustrated that the students used all three representational modes in their arguments to produce a sound argument based on their collaborative knowledge organization with MERs. Therefore, we conclude that students can create MERs in our system when they organize their knowledge and make their arguments based on multiple data sources they put in those MERs.

Although our learning unit is promising from several aspects, it also has several limitations. First, our intervention is short for making general judgments on students' collective learning using iKOS. Secondly, we did not analyze the student-generated arguments in terms of their structural, content, and justification qualities. In the future we will analyze students' collaborative arguments with a larger sample size to make judgments about the effect of our learning unit. It is our hope that teachers and students will be able to use this tool in order to make quality arguments, enhance deep understanding of the scientific concepts, and organize scientific knowledge in a more coherent way to learn complex scientific phenomena in a more holistic manner, and collaborate and assess their peers' entries in the system.

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## Acknowledgements

This material is based upon work supported by the Office of STEM Education at The University of Georgia. Any opinions, findings and conclusions expressed in this poster are those of the authors and do not necessarily reflect the views of the Office.