KNOWLEDGE ORGANIZATION WITH MULTIPLE EXTERNAL REPRESENTATIONS IN A COMPUTER-SUPPORTED COLLABORATIVE LEARNING ENVIRONMENT FOR ARGUING ON A SOCIO-SCIENTIFIC ISSUE

by

BAHADIR NAMDAR

(Under the Direction of Ji Shen)

ABSTRACT

The purpose of this research was to examine learners' knowledge organization with multiple external representations (MER) in an argumentation-based computer-supported collaborative learning environment. For this purpose, an argumentation-based socioscientific unit on nuclear energy has been developed and implemented with a group of preservice science teachers (n=20), who enrolled in a Physical Sciences for Middle School Teachers Content and Methods courses at a Southeastern public research university in the USA.

During the unit, the participants used a new hypertext platform that incorporated three external representational formats. This technology enables knowledge organization, collaboration, and classroom management tools. In the unit, the students were asked to use the platform individually and learn about nuclear energy. Later in the unit, the students engaged in argumentation about the issue in their small groups and were asked to organize knowledge on a specific scientific aspect of the nuclear energy. Finally, the students presented their findings and final arguments about nuclear energy use and power plant construction to the whole class.

This study documented the students' knowledge organization with MER, their argumentation qualities, and the interaction between students' knowledge organization and argumentation practices. The findings of the study showed that students mostly relied on their Wiki and ConceptMaps in the unit. These representation types were more centralized and had higher knowledge organization quality scores than pictorial representations created by the students. Also, two focus students' argumentation practices indicated that when they were asked to present their group's argumentation based on their collaborative knowledge organization, the student with the low knowledge organization and individual argumentation score incorporated more justifications, aspects, and a counterargument in the collaborative argument she presented. The student with a high knowledge organization and argumentation score, on the other hand, used specific scientific knowledge to support her argument and maintained the high quality of argument. Finally, interaction analysis indicated that the focus groups' knowledge organization practices interacted bi-directionally in this settings and students' use of representations differed in small group argumentation and the class presentation. Implications for curriculum designers, science teachers, and feature research directions were discussed.

INDEX WORDS: Knowledge organization, Multiple external representations, Argumentation, Socio-scientific issues, Social network analysis, Mixed methods study

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DEDICATION

To my amazing parents Mrs. Esen and Mr. Ercan Namdar for their unconditional love and support, and to my beautiful country Turkiye…

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CHAPTER 1

INTRODUCTION

Background of the Problem

The rapid advancements in information communication technologies have altered the ways people work, live, and communicate. Technologically advanced nations have started to shift their economies from agrarian to information-based ones, which demand their citizens to be more digitally-literate and well-equipped with information skills (Griffin, Care, & McGaw, 2012). In this ever changing cyber world, education has placed strong emphasis on fostering skills such as critically evaluating information and generating new knowledge about complex socioscientific issues; and arguing, communicating and collaborating with others using new digital media. These new practices in education have urged the constant use of technology in classrooms. A recent survey showed that in the United States 99% of public school teachers had a computer, the ratio of students in the classroom to computers was 1.7, and classroom computers with Internet access was 95% in 2009 (Gray, Thomas, &Lewis, 2010).

Socioscientific Issues (SSI)

Technology has both shaped the scientific advancements and become a source of various challenges and debates that societies face today**.** Social dilemmas related to science and technology have been defined as socioscientific issues (SSI) (Sadler, 2011). These issues stem from rapid technological and scientific developments such as biotechnology and environmental challenges resulting from these advancements. As the issues are directly related to citizens' lives, discourse and policies about these issues have become a part of daily conversations (Sadler &

Donnelly, 2006). Hence, one of the major responsibilities of individuals in a democratic society is to make well-informed decisions about today's SSI (Sadler & Zeidler, 2005; Zeidler, Walker, Ackett, & Simmons, 2002)

Incorporating SSI in science curricula has been suggested as a way for achieving scientific literacy (Sadler, 2004). Sadler and Zeidler (2009) argued that scientific literacy should be a goal for all students regardless of their future occupation trajectories.(Sadler and Donnelly (2006) noted that "scientific literacy, at least in part entails the ability to discuss, interpret relevant evidence, and draw conclusions in response to socioscientific issues" (p. 113). Therefore, any science teacher who takes scientific literacy as a major goal for all students needs to find a way to bring SSI into his/her class.

Argumentation

Science advances through a set of practices utilized by scientists to refine, evaluate, and extend scientific knowledge (NRC, 2012). Recent science education policy documents call for engaging students in practices similar to those of scientists (NGSS Leads State, 2013; NRC, 2012). Dawson and Venville (2010) argued that "the ability of young people to reason, think critically, understand and present arguments in a logical and coherent way both orally and in writing allows them to fully participate in society and is a desirable outcome of education in a democratic society" (p. 134). Therefore, engaging students in argumentation from evidence becomes particularly relevant when students argue about SSI, which requires evidence-based reasoning to reach well-informed decisions. Through this engagement students are expected to develop in-depth understanding about these issues, including the underlying scientific mechanisms at the appropriate level. Specifically, argumentation about SSI can provide a space for students to a) demonstrate their scientific understanding, b) increase conceptual understanding through discourse (Klosterman & Sadler, 2010; Zohar & Nemet, 2002), and c) make evidence-based decisions. These issues are relevant to students' lives and therefore, they can promote their interests in learning science. Hence, using SSI has been promoted as a powerful tool for argumentation in science education (Kolstø, 2006; Sadler & Zeidler, 2005).

More recently collaborative argumentation practices for knowledge construction have been incorporated for learning school science (e.g., Osborne, Erduran, & Simon, 2004; Sampson & Clark, 2009). The use of collaborative practices can expose students to diverse perspectives on SSI (Zeidler & Nichols, 2009). When students with different beliefs and ideas about SSI come to a collaborative learning environment, they need to understand, communicate, and evaluate the reasons why their beliefs and ideas are more or less credible than others. With the ill-structured and interdisciplinary nature of SSI, argumentation on these issues requires learners to collaboratively build an understanding while considering the complexity of these issues. Therefore, engaging students in collaborative argumentation enables learners to consider the quality of claims, warrants, evidence, and assumptions from multiple perspectives (Zeidler, Sadler, Simmons, & Howes, 2005).

There has been much effort on developing and using online environments to foster students' argumentation skills. As computers have become important mediators of learning and collaboration a common practice, computer-supported collaborative learning (CSCL) has gained popularity by challenging the premises of learning software that approaches individuals as isolated learners (Stahl, Koschmann, & Suthers, 2006). CSCL offers new ways for students to collaboratively argue in and across classroom settings as well as in informal learning environments. CSCL environments can support the construction, sharing, and representation of arguments (Noroozi, Weinberger, Biemans, Mulder, & Chizari, 2012). These environments, also known as argumentation-based computer supported collaborative learning (ABCSCL), are aimed at scaffolding student argumentation, and fostering in-depth discussions (Andriessen, Baker, & Suthers, 2003 as cited in Noroozi et al., 2012).

Multiple External Representations (MER)

Historically, representations have constituted a fundamental place in the advancement of science (diSessa, 2004**.** During knowledge construction processes, scientists engage in scientific discourse practices in which they check, review, and criticize others' knowledge claims in the field (Newton, Driver, & Osborne, 1999). They use mathematical, verbal, textual and visual modes in coordinated ways to represent their claims of scientific discourse (Waldrip, Prain, & Carolan, 2010). The recent call for engaging school students in scientific practices demands science educators to incorporate appropriate representation practices in science learning.

Bringing representations into the classroom settings is not a new idea. Science teachers have been actively using various kinds of representations to make abstract concepts more concrete (Ainsworth, 2008). In science educational research, there has been a major focus on the roles of representations in learning science for the past five decades (Prain & Tytler, 2012). For instance, research has shown that using expert created representations improved students' conceptual understanding and motivation (e.g.,Tsui & Treagust, 2003; van der Meij & de Jong, 2006). Recent research has acknowledged students' capabilities of inventing and evaluating their own representations (diSessa, 2004; Lehrer & Schauble, 2004). diSessa (2004) argued that "it is always tempting to believe only brilliant scientists create really new things so it may not seem sensible to bring representational invention into schools but students are productively capable of designing their own representations" (p. 296). In fact, there has been an increasing interest in student generated representation in science education research (Prain & Tytler, 2012).

Lately, research on learning with representations shifted its focus on using more than one representation (e.g., Corradi, Elen, & Clarebout, 2012; Hsu, 2006; Kozma, 2003; Wong, Poo, Hock, & Kang, 2011). Researchers have argued that students benefit from multiple external representations (MER) when learning complex scientific phenomena and processes (Ainsworth, 2006; Kozma, 2003). Moreover, the use of MER can help capture learners' interest (Ainsworth, 1999) and enhance their understanding of science concepts (e.g., Chandrasegaran, Treagust, & Mocerino, 2011; Waldrip et al., 2010).

Modern technology not only offers affordances for creating more varied and interactive representations but also allows new ways of sharing MER (diSessa, 2004). Computer mediated representations used for science education include computer simulations, computer animations, virtual labs, computer games, and concept visualization tools, and sharing mechanisms include Wiki sites (e.g., Wikipedia), media sharing sites (e.g., YouTube), and social networking media (e.g., Twitter).

Advancement in modern technology also allows learners to use MER to support learning. For instance, Norrozi et al. (2012) argued that "to support learners in focusing on specific content, argumentation must be framed, scaffolded, and guided by external representations (p. 82)". To achieve this aim, ABCSCL environments allow users to create MER during their learning instead of learning from texts (Yoon & Brice, 2011). More importantly, it enables learners to collaboratively find information and create MER to reflect on their understanding similar to what scientists do in their daily practice. Hence, it is important to incorporate argumentation on SSI in a highly collaborative, technology rich environment such as ABCSCL that incorporates MER.

Knowledge Organization and Statement of the Problem

The science education practices and research in SSI, argumentation, and MER as reviewed above all point to the importance of knowledge organization, defined here as the processes and strategies in searching, sorting, clustering, tagging, and achieving information in the forms of representations that reflect their understanding (Namdar & Shen, 2013). This is even more pressing given the fast development of information technology. Learning and arguing about SSI become more challenging because of the increased accessibility of information through the Internet. Relevant or irrelevant information pertinent to particular SSI and scientific data or nonscientific anecdotes are distributed and coexisting across a vast network of resources in MER (Namdar & Shen, 2014). Therefore, when arguing about a given SSI, students need to find and organize relevant information in an effective way and construct and represent their arguments accordingly.

Despite the proliferation of research in using SSI in scientific argumentation (e.g., Evagorou & Osborne, 2013; Tal & Kedmi, 2006) and on understanding students' learning with MER (Ainsworth, 2008; diSessa, 2004; Waldrip, Prain, & Carolan, 2006), the process of knowledge organization with MER and the interaction between knowledge organization and argumentation on SSI remain relatively unexplored. To address this gap in the literature, I designed a learning unit in which learners need to organize their knowledge and argue about a SSI using MER, and evaluated the impact of the unit on student learning using a CSCL platform.

Purpose and Research Questions

The purpose of this study is, therefore, to understand students' knowledge organization with MER and the interplay between their knowledge organization and argumentation practices in a CSCL environment. The inquiry in this study has focused on three research questions. In an ABCSCL environment;

1. How do learners organize knowledge effectively with MER?

    a. What is the most prominent representation type learners create?

    b. What are the key actors in the knowledge network?

    c. What is the quality of representations created by the students on a given SSI topic?

2. What is the quality of student generated arguments on a given SSI topic?

3. How does learners' knowledge organization with MER interact with their argumentation practices?

It is anticipated that the findings will suggest a distinct approach to foster students' argumentation practices by incorporating MER in a CSCL environment. The findings may also provide practical insights for curriculum developers and science educators who incorporate MER to facilitate students' knowledge organization.

Overview of the Chapters

This dissertation is organized in five chapters. In this chapter, I introduce the background of the problem, the statement of the problem, purpose and research questions, and the definitions of relevant terms. In chapter 2, I present the theoretical framework that is organized in three subsections: Argumentation and SSI, knowledge organization with MER, and computer supported learning. In chapter 3, I briefly introduce the first two iterations of this larger design study. I also introduce the technology that was used in the study and the revised learning unit. Next, I describe the mixed methods design of the current study. In chapter 4, I report the findings and interpretation with respect to each research question as well as the culmination of all relevant information in a final subsection. In chapter 5, I provide a brief summary of the study by discussing the findings and report implications and suggest further research directions.

Definition of Terms

To make the terms used clearer to the reader, I will briefly define the key terms in this section.

- Computer-Supported Collaborative Learning (CSCL): A branch of the learning sciences that studies how people learn together with the help of computers (Stahl et al., 2006).
- iKOS: innovative Knowledge Organization System: An online learning system that incorporates three types of external representations, designed to provide a space for students to archive, sort cluster information in multiple external representational formats, as well as to collaborate with each other (Namdar & Shen, 2014). Specific terms related to iKOS are also defined below:
    - Entry: Each external representation created by a learner on the computer.
    - Link: When two entries have one or more keyword in common.
    - Mode: Each representation type (i.e., Event, Wiki, and ConceptMap) that is available on the knowledge organization system (iKOS).
- Knowledge organization: The process in which a learner searches, sorts out, tags and clusters information with MER to reflect their understanding on a given subject (Namdar & Shen, 2013).
- Multiple external representations (MER) are representations that are explicitly created by a person or a group. There are many representation types in the literature as it is suggested by Tsui and Treagust (2013, p.3). However, in this study, MER will only refer to the concept maps, annotated pictures, and text. These are the representational modes

available in the technology-enhanced learning platform that students use in the study iKOS.

- Socioscientific issues: In this study socioscientfic issues (SSI) refer to the open-ended, ill-structured problems which are typically subject to multiple perspectives and solutions (Sadler & Donnelly, 2006; Zeidler et al., 2002); that require moral, ethical evidence-based reasoning in their solutions (Zeidler et al., 2005).

CHAPTER 2

THEORETICAL PERSPECTIVE AND LITERATURE REVIEW

In this chapter, I provide a brief overview of the theoretical perspectives that guide this research: sociocultural and cognitive constructivism. The literature review following the theoretical perspectives will be presented in three subsections: argumentation, knowledge organization with multiple external representations (MER), and computer supported learning. Each subsection will be concluded with implications for the current research.

Sociocultural and Cognitive Constructivism

Constructivism has been used as an overarching epistemology in science education research with various applications and orientations (Rodriguez, 1998). Constructivism includes cognitive constructivism and sociocultural constructivism. The French philosopher Jean Piaget (Piaget, 1970) is considered as one of the founding fathers of cognitive constructivism. He viewed learning as a process in which children personally and actively construct knowledge through their interaction with the world (Matthews, 1994) “in an increasingly objective and differentiated way” (Marchand, 2012, p.169). According to Rodriguez (1998) this notion challenged the teacher-centered approach in traditional classroom settings and therefore, transformed the ways in which learning is taking place. On the contrary to the belief that learners are passive receivers of knowledge, Piaget (1970) suggested that there is a bidirectional relationship between a learner and the knowledge to be learned; and learners construct their knowledge through their actions on and activities in the world (Rodriguez, 1998).

Although cognitive constructivism offered unique ways in learning and teaching (e.g., taking students' prior knowledge into account), it is still somewhat constrained by the boundaries of the mental processes of individuals without fully considering the social context. In contrast, framing learning as a sociocultural process, sociocultural constructivism focuses on all the forms of language (e.g., text, documents, visuals) (Gregen, 1995) and the activities humans engage as cultural tools during the knowledge construction process.

According to Lemke (2001) sociocultural perspective on science education views "science, science education, and research on science education as human social activities conducted within institutional and cultural frameworks" (p. 296). In this perspective, the central piece of learning and doing science is the interpersonal/social interactions (i.e., dialogue, argumentation, collaboration). Lemke further argued that cooperative activities are only plausible because our lives situate around social organizations. Lemke (2001) noted that:

> Our lives within these institutions and their associated communities give us tools for making sense of and to those around us: languages, pictorial conventions, belief systems, value systems, and specialized discourse and practices. Collectively such tools for living-our social semiotic resource systems and our socially meaningful ways of using them constitute the culture of a community (p.296).

Hence, sociocultural constructivists approach science learning as an interpersonal process that learners engage in by using the available tools in a learning environment (Vygotskiĭ, 1986).

The present study has been influenced by both cognitive and sociocultural perspectives toward learning. For instance, MER is used as both cognitive and social tools. First, from a cognitive constructivism's stance on learning science, I designed the learning unit on nuclear energy so that individual students can actively construct their personal knowledge and understanding with the aid of MER based on their personal preference and prior knowledge. Second, from a sociocultural perspective, I asked students to collaboratively argue about the issue and generate shared artifacts using MER. The web-based learning environment also incorporates collaboration features that enable learners to comment, rate, and coedit each other's' representations. Furthermore, the technology automatically interlinks students' representations in the learning environment and creates a collective knowledge network. Using this network, students can better learn from each other.

Incorporating both cognitive and sociocultural constructivist views on learning, the review of the literature relevant to the current study will be centered on three specific areas: argumentation, knowledge organization with MER, and computer supported learning in the context of science education. Table 1 presents each area's relationship to cognitive and sociocultural constructivist orientations.

Table 1.

Cognitive and Sociocultural Constructivist Accounts in Each Subsection for the Current Study

	Argumentation	Knowledge Organization with MER	Computer Supported Learning
Cognitive Constructivism	Rhetorical argumentation	Personal knowledge integration	Personalized learning
Sociocultural Constructivism	Collaborative argumentation	Knowledge building	Computer-supported collaborative learning
Integrated	Dialogical argumentation	Knowledge organization	Making thinking visible Making science accessible

Argumentation

> *"... the use of language for the purposes of reasoning or argumentation plays a major part in our lives, and it is natural and proper that we should set about trying to understand this particular use of language- and so become self- aware also about the arts of speaking and writing, communicating and expressing ourselves, presenting "claims" and supporting them with "arguments*."" (Toulmin, Reike, & Janik, 1979, p. 18).

In this study, argumentation on SSI was approached from both cognitive and sociocultural constructivist theories. First, from a sociocultural constructivist standpoint argumentation takes place in a social environment, in which students engage in interpersonal social interactions to construct their collaborative arguments. More specifically, the students were asked to collaboratively argue about a given SSI by capitalizing on the sociocultural tools in the settings (i.e., MER in this study). Second, from a cognitive standpoint the students acquired information and wrote their individual arguments before and after collaborating with their peers to construct their individual understanding.

Definition and Theoretical Underpinnings

The term argument has been defined by many scholars. For instance, Reike and Sillars, (1993) defined an argument as "the intersection of a claim and its support" (p. 3). From their perspective claims are the statements that are made when someone tries to convince others to accept these claims. Supports on the other hand, are all the things that are used to secure coherence and persuade others to act upon your 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).

Argumentation on the other hand is the cognitive and social process of creating arguments. It is linguistic, social, and cognitive activity "aimed at convincing a reasonable critic of the acceptability of a stand point by putting forward a constellation of proposing, justifying, or refuting the proposition expressed in the stand point" (van Eemeren & Grootendorst, 2004, p. 1). Namdar & Shen (2012) further proposed that there are three dimensions of argumentation (Figure 1). Firstly, it is a *linguistic* process in which people produce verbal or written arguments (Kuhn, 1992); secondly, it is a *cognitive* process when a person executes reasoning while arguing (Kuhn, 1993); and thirdly 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).

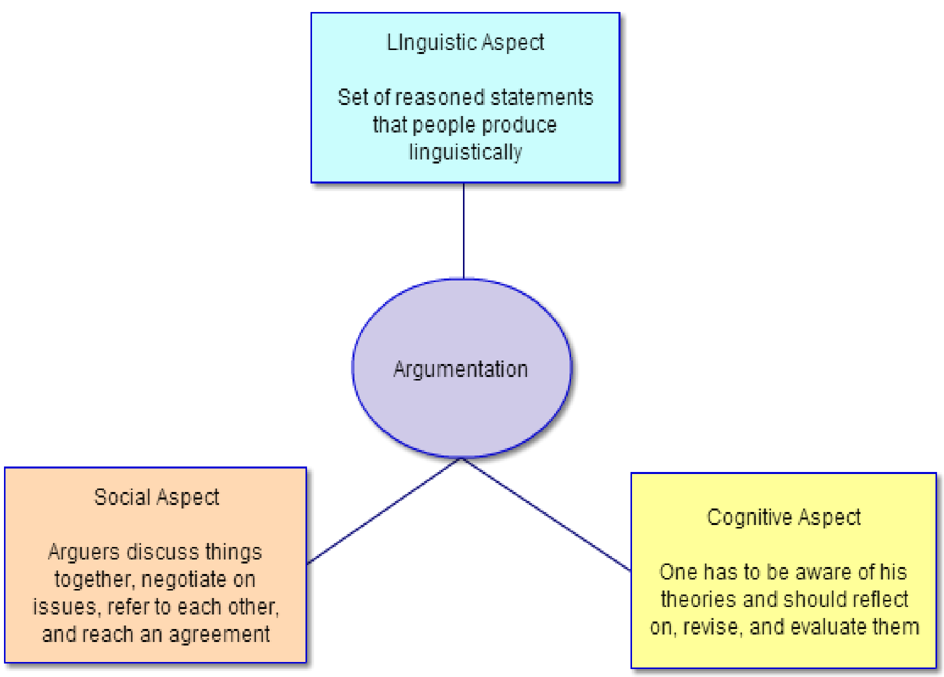


Figure 1. Three dimensions of argumentation

Rhetorical, Dialogical, and Collaborative Argumentation

In the educational literature argumentation has been defined in two forms: rhetorical and dialogical (Duschl & Osborne, 2002). Rhetorical argumentation includes the linguistic aspect of argumentation when creating arguments. Philosopher Stephan Toulmin made a breakthrough contribution to our understanding of rhetorical arguments. In his seminal book *The Uses of Argument* (Toulmin, 1958), he described a comprehensive model of the complex 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. Rhetorical arguments are one-sided premises which aim to convince the audience. Additionally, rhetorical argumentation can be framed from a cognitive constructivist account as it considers the individual acquisition and use of knowledge for the argumentation purposes.

Complementary to Toulmin's model, argumentation has also been approached as a social, dialogical practice (Andriessen, 2006). In dialogical perspective the opponent takes an important place in developing multiple perspectives and constructing an understanding for the arguer himself or herself in the argumentation process (Andriessen, 2006; Jonassen & Kim, 2009). Dialogical argumentation, therefore, can be framed naturally from a sociocultural constructivist account as the dialog influences the development of argumentation in a social context.

Argument analyses are also based on the frameworks of scholars who see argumentation as a dialogue in learning sciences (Noroozi et al., 2012). For instance, sequential dialectics describes argumentation as an interactive and social activity where it follows the sequence of argument, counterargument, and replies. Pragma dialectics (van Eemeren, Grootendorst, & Henkemans, 1996) approaches argumentation as an opportunity to provide a space for resolving difference of opinions. Formal dialectics (Barth & Krabbe, 1982), on the other hand, sees argumentation as a dialog between a proponent and an opponent around certain topic by following certain rules. In dialog theory (Walton, 2007) argumentation is considered as a process where two parties attempt to reason together. All of these theories give the same importance to the counterarguments as well as arguments in the conversation (Noroozi et al., 2012). In the following, I will briefly describe each of these dialogical argumentation frameworks.

Sequential dialectics. Leitão (2000) approached argumentation as a social activity and stressed the importance of dialectical nature of argumentation. Hence, this approach incorporates both cognitive and social aspect of argumentation. Leitao (2000) asserted that an arguer will always presuppose a virtual or a natural audience in mind while arguing. Overall, she pointed out that arguments are developed in order to justify a person's position to convince others, where at the same time parties examine their claims in the light of others' claims. Therefore, she saw counterarguments as tools for "calling a speaker's point into question and give people grounds for examining their own views" (p. 336). In this process arguers engage in a dynamic social interaction where they think jointly and reconstruct their perspectives. She noted that argumentation should be approached as "justification of viewpoints and recognition of opposing arguments" (p. 338).

Hence, in this perspective argumentation takes a sequential cycle where an arguer constructs an *argument* first, and then the opponent (i.e., the second person or the speaker her/himself) poses a *counterargument* and the arguer finally creates a *reply* that captures her/her responses to the counterargument. Leitão concluded that argumentation, following this sequence, has a potential for knowledge building (from Clark, Sampson, Weinberger, & Erkens, 2007).

Pragma dialectics. Pragma dialectics describes argumentation as a communicative discourse aimed at providing space for exchanging verbal moves to solve differences of opinion (van Eemeren & Grootendorst, 1992, 1999, 2004; van Eemeren & Houtlosser, 1999). Although an arguer aims to resolve the difference using dialogic dimensions, at the same time the arguer also aims at reaching this resolution in their own favor by using rhetorical devices.

Pragma dialectical analysis includes four stages. (1) *Confrontation stage* when differences of ideas are defined, (2) *opening stage* when the speakers state their initial thoughts and provide a starting point for the discourse, (3) *argumentation stage* when speakers state their arguments, and (4) *concluding stage*: when the final remarks about the issue are made.

Formal dialectics. Barth & Krabbe's (1982) formal dialectics stems from the idea of conflict resolution. Formal dialectics formulates rules to conduct a discussion for resolving conflicts on avowed opinions. In their definition, avowed opinions are the arguments put forward by the proponent (P) and the opponent (O) of the issue. P asserts a thesis and O attacks the thesis with statements. These statements constitute O's concessions (cons): "statements for which the opponent is prepared to take responsibility and which are to be defended if they come under attack" (van Eemeren, 1995, p.150). Argumentation is the attack by the O to the P's statement and the defense of the P against O's attack. O demonstrates that in light of the concessions, P's thesis is not plausible, whereas P tries to prove that it is necessary to accept T. P wins the discussion if O accepts the facts brought by P, and P makes and appropriate *Ipse dixisti! (You said so yourself!)* remark. One can also lose a chain, if the other party already blocks all possible attack or defense channels and does not leave any space for the opponent to discuss.

Dialogue theory. Dialogue theory was introduced by Grice (1975) to provide grounds for improving critical thinking and research skills. Grice's theory approached argumentation as a collaborative conversation between two parties. In this theory, the simplest example of a dialog involves two parties in a conversation where one party asks a question and the other replies. In other words "a dialog is a verbal exchange between two parties, according to some kind of rules, conventions or expectations" (Walton, 2007, p. 20). The arguments evaluated in terms of whether they serve the purposes and move the conversation towards the goals of the dialogue. Walton argued that the Gracian framework does not capture the types of conversational exchanges as well as their rules and goals. Therefore, in his book *The New Dialectic* (Walton, 1998) he proposed six basic types of the dialogues: 1) persuasion: where two parties try to persuade each other for resolve the conflict of opinions, 2) inquiry: it occurs between two parties who collaboratively collect and organize relevant evidence on a particular issue, 3) negotiation: it occurs when the parties have any kind of conflict of interest with the goal of getting the best deal, 4) information seeking: The goal in this type of dialogue is to acquire information regarding the task in hand, 5) deliberation: Parties reason together to discuss and find a solution to the problem, and 6) eristic: the goal of each party is to "hit out" verbally at the other party (Walton, 1998, p. 179) to defeat the other in an adversarial contest.

Dialogical argumentation considers the social dimensions included in an argument but it differs from *collaborative argumentation*. Collaborative argumentation is defined as a "dialogic argumentation that takes place in groups of students when they are asked to work together on the common task of constructing and presenting an argument" (Evagorou & Osborne, 2013, p. 212). Although dialogic argumentation can take place in an individual's mind with a hypothetical interlocutor or between multiple people (Leitão, 2000), collaborative argumentation can only occur with a group of people (Evagorou & Osborne, 2013). Hence, collaborative argumentation theoretically falls under sociocultural constructivist orientations as it is a highly interpersonal activity and the knowledge is constructed within that collaborative setting.

Significance of Practicing Argumentation in School Science

The construction of scientific knowledge occurs within a community of practicing scientists who constantly review, criticize, refine, and extend each other's claims (Newton, Driver, & Osborne, 1999; NRC, 2012). Scientists use argumentation practices as a way to propose, justify, evaluate, legitimize, and communicate with others' claims to construct scientific theories (Driver, Newton, & Osborne, 2000; Kelly, 2008). Argumentation is also used during the experimentation itself to find best workable ways to answer desired questions (NRC, 2012).

Despite the importance of practicing argumentation in science, it is often absent from science classrooms (Newton et al., 1999; Osborne, 2010). As argumentation is at the heart of doing and learning science (Duschl & Osborne, 2002), students need to practice argumentation in school. The new Framework for K12 Science Education and the Next Generation Science Standards (NGSS Leads State, 2013) promote "engaging students in argument from evidence" as one of the core practices of science education. It is stated in the framework (NRC, 2012) that by grade 12 students should be able to

> 1) Construct a scientific argument showing how data support a claim. 2) Identify possible weaknesses in scientific arguments, appropriate to the students' level of knowledge, and discuss them using reasoning and evidence. 3) Identify flaws in their own arguments and modify and improve them in response to criticism, Recognize that the major features of scientific arguments are claims, data, and reasons and distinguish these elements in examples, Explain the nature of the controversy in the development of a given scientific

idea, describe the debate that surrounded its inception, and indicate why one particular theory succeeded. 4) Explain how claims to knowledge are judged by the scientific community today and articulate the merits and limitations of peer review and the need for independent replication of critical investigations (pp. 72-73).

Jiménez-aleixandre and Erduran (2007) argued that introducing argumentation in science classrooms will support five important areas of student learning: 1) Having access to students' cognitive and metacognitive processes as the use of language makes cognitive processes of both students and teachers public. They also pointed out that argumentation, specifically in the school context, may support the higher order thinking skills as it makes reasoning process public and students are expected to justify their claims with evidence and evaluate the alternative options. 2) Developing discourse practices and thus critical thinking: using language and engaging in communicative practices will enable students to reflect on their beliefs and themselves. During this reflection students will seek evidence for their beliefs. Then, they will develop rational criteria to assess it and thus develop critical thinking skills. 3) Increasing scientific literacy: engaging in argumentation will empower students to use the language of science and rhetorical dimensions of science such as persuasion. 4) Embracing scientific culture and developing epistemic criteria: engaging students in argumentation will allow them to practice the ways scientists build the scientific theories. 5) Developing reasoning and rational criteria: Argumentation enhances students' ability to develop and apply rational criteria to choose among theories or positions, and thus developing reasoning skills.

Argumentation on Socioscientific Issues (SSI)

One way to engage students in argumentation practices is to incorporate SSI in the curricula. Since the beginning of the 1980s the proponents of the Science-Technology-Society

(STS) movement have advocated for making scientific, technological, and societal issues integral parts of science education curricula (Tal, Kali, Magid, & Madhok, 2011; Tal & Kedmi, 2006). Although STS movement offered unique ways to incorporate these issues in the curricula, researchers argued that it did not consider the psychological and epistemological growth of children. Instead, they advocated for introducing SSI in school curricula to empower students to consider science based issues based on the available scientific data and principles as well as their moral and ethical values (Zeidler, Sadler, Simmons, & Howes, 2005), and to enhance students' "critical analysis of information, problem solving, argumentation, reflective thinking, and value judgment" (Tal & Kedmi, 2006, p. 621).

SSI includes open-ended, ill-structured problems which are typically subject to multiple perspectives and solutions (Sadler & Donnelly, 2006; Sadler & Zeidler, 2005; Zeidler et al., 2002). These are social issues with ties to the science and technology (Sadler & Donnelly, 2006) and are mutually influenced by science and society (Abd-El-Khalick, Bell, & Lederman, 1998). As technological advancements shape today's society, SSI often revolves around critical and controversial subjects such as cloning, genetically modified organisms, climate change, land use decisions, stem cell research and alternative energy sources and so on. With the fast development of information communication technologies (ICT), SSIs are debated more than ever in terms of number of participants and diverse perspectives in numerous web-based discussion platforms. Students have difficulties while building their arguments because their discourses are influenced by media and public debate (Simmoneaux, 2007). In the new framework for K12 Science Education (NRC, 2012) it is stated that students need to "read media reports of science or technology in a critical manner so as to identify their strengths and weaknesses." (p. 73).

It is important to create opportunities for students to discover mutual influence of science and society. In this process science education should empower students' science learning as well as their decision making in their lives (Simmonneaux, 2008). Zeidler and Nichols (2009) argued that through argumentation and debate, SSI can be implemented in the classroom discourse which leads to engagement of thinking and reasoning processes. In this way, students will have a firsthand experience of the advancement of scientific knowledge in daily life (Zeidler & Nichols, 2009). Although the place of argumentation in school science calls for attention in science education, the question is in what ways we can engage students in argumentation in science classrooms still remains as a challenge. Researchers argue that SSI can be used as pedagogical tools in science classrooms as these issues are relevant to students' lives and promote interest in learning science (Kolstø, 2006; Sadler & Zeidler, 2005; Zeidler et al., 2002). A sound argument on SSI requires students to use evidence-based reasoning (Sadler, 2004; Zeidler, Osborne, Erduran, Simon, & Monk, 2006; Zeidler & Nichols, 2009). Therefore, as these issues have ties to science and technology, SSI becomes an important mediator for promoting argumentation in science classrooms.

Empirical Support of Practicing Argumentation in School Science

Many studies have also reported empirical evidence on the positive effects of incorporating argumentation in learning school science. For instance, in their study with 46 tenth grade students, Dawson and Venville (2010) investigated the impacts of argumentation based pedagogy on students' conceptual genetics understanding. Their results illustrated that experimental group performed significantly higher than control group students' conceptual genetics understanding.

Besides conceptual understanding, other studies have reported positive impact of argumentation on students' reasoning and use of evidence. Walker, Sampson, Grooms, Anderson, and Zimmerman (2012), for example, investigated the impacts of argumentation driven inquiry with a group of college chemistry students. They found that although experimental group did not significantly performed better in the conceptual understanding test, experimental group performed better at reasoning and use of evidence.

Much research focusing on students' argumentation in the context of SSI also reported positive effects. Zohar and Nemet (2002) investigated the learning outcomes of the teaching argumentation skills in the context of current dilemmas associated with human genetics in a ninth grade classroom in Israel. Pre-test results indicated that only 16.2% of the students correctly considered the specific biological content knowledge related to dilemmas in genetics. After the instruction results indicated that 53.2% of the students in the experimental group considered the correct specific biological content knowledge and the frequency of students who formulated arguments, counter arguments and rebuttals were increased.

In his study with twenty-two students in Norway, Kolstø (2006) investigated the patterns in students' argumentation about the local construction of power lines and the possible increase in childhood leukemia. Based on the semi structured interviews Kolstø (2006) found that students used both scientific and non-scientific knowledge to make five different types of arguments the relative risk argument, the precautionary argument, the uncertainty argument, the small risk argument, and the pros and cons argument based on use of knowledge and values in arguments made on an ethical/political question. Case studies showed that students used scientific information in their evaluation and decision making processes without using the scientific theories and content knowledge learned in school. Although students used other types of information, those were not influential in their decision making processes. Overall, this study suggested that students' decisions were limited to research based information.

In their research, Evagorou and Osborne (2013) selected two dyads from a larger group (n=28) and compared the characteristics of students' collaborative argumentation practices and the process of co-construction of written arguments. Five day learning unit (i.e., 50 minute lessons each day) was designed using WISE (Web-based Inquiry Science Environment) and students worked in pairs to argue about whether the government should kill gray squirrels to save the indigenous red in UK. Students both written and verbal arguments were analyzed using a framework suggested by Erduran, Simon, and Osborne (2004). Based on students' verbal arguments, less and more successful dyads were identified. Results indicated that successful pair employed exploratory talk and negotiated a shared understanding while the less successful pair engaged in a cumulative talk and rarely asked questions to each other. Evagorou and Osborne (2013) also argued that the difference between pairs' argumentation quality in terms of asking questions to clarify evidence or understand ideas was also reflected in their written arguments. It is also found that the successful dyad discussed their arguments' structure. Finally, less successful dyad constructed less claims during the unit.

In Tal and Kedmi's (2006) study, the researchers investigated an authentic SSI based unit in Israel, which was developed with the intend to increase scientific literacy. In this study, students were requested to analyze socioscientific case studies under a sub unit of "Treasures in the Sea Use and Abuse." The unit was conducted in total of six, tenth and eleventh grade classrooms (n=20 approximately in each class) and researchers examined the higher order thinking skills of students: argumentation and value judgment. Argument qualities based on student performance in the class was analyzed based on number of justifications, level of incorporating scientific knowledge, the number of different aspects incorporated, and the extent of synthesizing and rebutting counterclaims (see Tal & Kedmi, 2006, p. 634). Results indicated that groups increased the number of justifications provided, incorporated more specific scientific knowledge for their arguments, supported their claims by referring to and rejecting counterarguments about the given SSI.

Tal and Hochberg's study (2003) investigated the effect of participating technology enhanced SSI unit on students' thinking skills such as argumentation, problem solving, and reflective thinking. 159 ninth-grade students from three different schools participated in the study. Lessons were designed in WISE and students asked the reasons for children suffering from malaria. Students were asked for their opinion about use of DDT, vaccine, and bed-nets. Based on the students' reflection sheets and interviews, in terms of argumentation, researchers found that in the post test both the number of structure and number of justifications improved. Researchers further found that student were able to transfer their argumentation skills to a similar case. 96 % of students' portfolios in the four WISE argumentation activities included counterarguments and rebuttals. Moreover, number of responses that included incorrect consideration of scientific knowledge was only 4% of the responses.

Implications: Socioscientific argumentation

The implications of the argumentation literature for the current study are two-fold. First, argumentation is at the heart of doing science and I believe in the importance of engaging students in scientific practices similar to those of scientists. Collaboration is also a fundamental practice that scientist employ, especially when they argue. Research also shows benefits of using SSI as a way to engage students in argumentation practice. Therefore, in this study, I asked students to collaboratively argue about the given SSI and hoped this would promote their collaborative reasoning from a sociocultural standpoint (Tal & Kedmi, 2006). I also share the same notion as Tal and Kedmi (2006) that when students engage in discourse:

> …they are more vocal, and feel freer to express ideas while they have the opportunity to interrelate values with complex conceptual issues. In this way, they learn to build qualified arguments. The discussions are more varied, generative and exploratory, even when the task is demanding (p. 622).

Second, researchers pointed out that the difficulties faced by students while constructing either scientific or socioscientific argumentation can be potentially addressed by creating more affective learning environments (Evagorou & Osborne, 2013). Therefore, in this study I designed a technology enhanced learning unit that provided students a web-based knowledge organization system. The knowledge organization system allows students to create three distinct types of external representations to organize their knowledge about the given SSI From a cognitive constructivist standpoint, providing students with such technology, I believe, would allow them to construct individual understanding and produce better arguments. On the other hand, from a sociocultural constructivist stand point, they collaboratively argue about the issue and also learn from others' knowledge representations to reflect their understanding of the issue and promote students' collaborative reasoning (Tal & Kedmi, 2006). Therefore, in the next subsection, I will introduce the importance of MER in science learning.

Knowledge Organization with MER

Science Learning and Teaching with MER

Theoretically, research on learning with MER has been framed in both cognitive and sociocultural constructivist accounts (Prain & Tytler, 2012). Cognitive constructivist accounts focus on learner's mental and individual strategies while using MER (Piaget, 1970).

Sociocultural accounts, on the other hand, approach MER as cultural resources that learners can use in meaning making processes (Vygotskiĭ, 1986). In this section, I introduce the place and taxonomy of representations in science and science education, expert created versus student created representations, and using MER to organize knowledge. I conclude the subsection with implications for using MER to organize knowledge when arguing on SSI.

Representations refer to a "range of transformations that conceptualize, visualize, or materialize an entity into another format or mode" (Wu & Puntambekar, 2012, p. 755). Scientists use representations (e.g., tables, graphs, models, simulations, formulas) in their inquiry in daily bases to construct their individual understanding and advance science. Congruent with the cognitive constructivist accounts, they benefit from these representations to reflect their own understanding about the world by making connections among those. From a sociocultural perspective, scientists share their representations, many of which are conventions, with others to communicate their understanding through these cultural tools to advance science. However, in educational research there is no consensus on how to classify representations (Ainsworth, 2006). Johnstone (1982, 1991, 1993) elaborated on a three-level classification of representation in chemistry education (Wu & Puntambekar, 2012). This taxonomy includes 1) *Macro representations:* representations that reflect the phenomena as experienced by human senses, 2) *Submicro representations:* qualitative explanations of the scientific phenomena, and 3) *Symbolic representations:* quantitative explanations of the scientific phenomena that incorporates symbols, formulas, drawings, and models Wu and Puntambekar (2012), on the other hand, argued that Johnstone's levels of representations are specific to chemistry education and suggested a new taxonomy based on the works of Lemke (1998) in physics education, and Tsui (2003) in biology education. These categories are *verbal-textual representations* such as metaphors, oral propositions, written text; *symbolic-mathematical representations* such as equations, formulas, structures; *visual-graphical representations* such as animations, diagrams, graphs, tables; and *actional-operational representations* such as demonstrations, gesture, manipulatives, and physical models. Although some scholars include mental models in their classification (Greca & Moreira, 1997), in this study representations will refer to the external representations, unless otherwise stated, that students create, manipulate, and use in a given technology-enhanced learning environment. MER (Ainsworth, 1999, 2006, 2008), on the other hand, will refer to more than one external representation manipulated or created by individuals or groups.

Why should we care about using MER in science classrooms? Over the past three decades representations have been widely used in teaching and learning. This is especially the case for MER, as researchers claim that learners are likely to benefit from using more than one representation (Mayer, 2003). Based on the existing literature, Ainsworth (1999, 2006) outlined the functional taxonomy of MER and proposed that MER can serve for three distinct purposes in teaching and learning. (1) *Complementary functions*: MER can complement each other by either the type of information they each include or the process they support. Therefore, it is hoped that learners will benefit from different affordances of each representation type. (2) *Constraining functions*: Learners can benefit from a use of a representation in the process of understanding an unfamiliar representation. (3) *Constructing functions*: Learners are expected to construct deeper understanding when using more than one representation to achieve broader insights about the phenomena being studied. Ainsworth (2006) further argued that construction might be in three ways. *Abstraction* is the ability to extract subset of information, *extension* is a way of extending knowledge represented from one representation to a novel one, and finally *relational understanding* is the process of associating more than one representation.

As it was mentioned earlier in this chapter, in recent science education policy documents engaging students in practices similar to scientists' have been widely advocated (NRC, 2012; NGSS Leads States, 2013). Wu and Puntambekar (2012), for instance, argued that using MER that are used by scientists can be brought to the science classrooms and these representations can be tied to various scientific processes based on their pedagogical affordances. Drawing from the literature and science education policy documents, these researchers focused on five scientific processes: asking questions, planning and carrying out investigations, analyzing and interpreting data, constructing explanations, and evaluating information. Each representation type was linked to several scientific processes that they support. Building on the existing literature on learning with representations, they claimed that verbal-textual representations, for example, are fundamental entities in asking questions, evaluating information, formulating hypothesis and constructing explanation. Visual and graphical representations such simulations can be used to plan and carry out investigations. Graphs and tables as parts of visual and graphical representations, for instance, can be used to analyze and interpret data in science classrooms (for more examples see Wu & Puntambekar, 2012).

In addition to conceptual affordances claimed by the researchers, there has been also recent interest in using expert created representations in science classrooms, especially in computer supported learning environments. Tsui and Treagust (2003), for example, investigated a class of students' genetics reasoning that involved activities in a dynamic computer program. They reported a case study of tenth grade students (n=24) using *Biologica*, a computer based modeling environment, in an Australian science classroom. In Biologica students looked at the visuals of chromosomes of given dragon figures and observed the behavioral trait following a mutation or monohybrid crosses. Researchers asserted that students constructed deeper understanding of genetics because MER in Biologica constrained students' interpretations of genetics and motivated them in their learning. Based on the pre-post test results, they found that using MER improved students' genetic reasoning in six areas of genetics: cause to effect within generation, effect to cause within generation, effect to cause between generations, process on reasoning on ploidy of gametes and zygotes, process reasoning on meiosis/gamete formation, and process reasoning on identical twins.

van der Meij and de Jong (2006) investigated the effect of integrating/linking dynamic MER on students' learning outcomes. They designed a simulation-based learning environment called 'Moments' in SimQuest. 'Moments' interface included five representations 1) diagrammatic representation, 2) concrete representation, 3) numerical representation, and 4, 5) two graphs (moment-force and moment-arm or moment-force and moment-height). In this learning environment learners studied the physics topic 'moments' by manipulating the open-end spanner tightening a bold and of a crane hoisting a load. Researchers compared a learning environment with separate, non-linked representations (S-NL condition), a learning environment with separate, dynamically linked representations (S-DL condition), and a learning environment with integrated, dynamically linked representations (I-DL condition). They found that, overall, the participating students (n=72, 16-18 year-olds) improved conceptual understanding of the physical concept of Moment'. However, dynamic linking condition alone (S-DL) did not lead to a better learning gains, but they reported better gains in I-DL condition.

In addition to expert created MER, there have been recent interests in the value of *student-generated MER* in science learning as well (Prain & Tytler, 2012). Wu and Krajcik (2006), for instance, characterized the inscriptional practices demonstrated by seventh grade students in two classrooms (n=27), and investigated the students' data tables and graph interpretations. The students in the study explored the nine-month long Water Quality unit designed by the researchers. The unit was built upon a driving question about the water quality of the stream behind the school. The students created and used ten types of representations (data tables, graphs, chemical representations, tables, pH scale maps, models, digital pictures, stream drawings, and web pages during this inquiry based learning. Data tables and graphs were the most created and used representation types. In this study, constructing practices observed during prediction making, designing investigations, presenting findings, analyzing data, and carrying out investigations. Interpreting practices on the other hand were observed during data analysis and data presentation. Results indicated that designing and constructing MER (i.e., data tables and graphs in this study) had positive impact on students' scientific inquiry understanding as, for example, data illustrated that students engaged in discourse about the experimental procedures. Results also showed that when students created their representations, they had more opportunities to discuss, review, and clarify the questions about the investigations. Furthermore, experience with constructing those representations guided students to create more representations. Interpreting practices, on the other hand, allowed students to integrate ideas from different sources during presentation.

Although there has been empirically tested benefits of MER in learning, Ainsworth (2008) claimed that students often do not take the advantages of multiple representations and sometimes inappropriate combination of representations can hinder meaningful learning. Corradi, Elen, and Clarebout (2012), for instance, conducted a study with 67 first year undergraduate educational sciences students to investigate whether using MER helped learners with low prior knowledge in chemistry. In their pre-post randomized experimental design, they had 4 groups. Group 1 only received text, Group 2 received symbolic representations and text, Group 3 received submicroscopic representations and text, and Group 4 received symbolic, submicroscopic, and textual representations. In the intervention students were asked to read five texts. Then on the same page of the textual representation learners could see submicroscopic and symbolic representations. After using the program for 2- minutes, students filled a word search puzzle. The results indicated that the MER helped the students to verbalize their understanding of general concepts. However, results also showed that some students in the condition of the three representations had negative learning gains. The researchers argued that this result might also be caused by low interest in the subject.

Knowledge Organization

As being described, SSI are controversial, arguable issues that are usually subject to multiple perspectives and scientific claims. Furthermore, the vast amount of information about these issues is distributed in many channels and presented in MER. Students need good knowledge organization strategies to effectively argue about SSI and represent them in MER. Knowledge organization, in this dissertation, refers to creating representations to cluster, tag, annotate, sort out information in science classrooms (Namdar & Shen, 2013).

The idea of knowledge organization stems from the premises of knowledge building (Scardamalia & Bereiter, 2006) and knowledge integration (Linn, 2006) theories. The knowledge integration framework is founded on the premises of two general findings of a series of empirical studies (Linn, Clark, & Slotta, 2003; Linn & Hsi, 2000; Linn, Lee, Tinker, Husic, & Chiu, 2006; Linn & Eylon, 2011; Mcelhaney, Matuk, Miller, & Linn, 2012). First, the results indicated that students struggle when learning complex and conflicting science concepts and phenomena. Second, in the process of learning these concepts and phenomena students generate a repertoire of ideas (Linn, 2006). As students come to classroom with diverse and confused ideas about science, the knowledge integration framework promotes four processes that jointly serve for deeper understanding of scientific concepts. 1) Eliciting students' repertoire of ideas: Students develop repertoire of ideas based on their interactions with the word around them (Linn & Hsi 2000). "They formulate these ideas as they use aspects of scientific reasoning such as observation, experimentation, and abstraction" (Gerard, Spitulnik, & Linn, 2010, p.1038). They benefit from considering all of their ideas instead of isolated ones. When students consider the ideas of their community they often recall more of their views and make more connections of ideas (Clark & Linn, 2003). Therefore, knowledge integration instruction helps students to articulate this repertoire of ideas (Linn et al., 2006). 2) Adding new ideas to the repertoire: Knowledge integration instruction gives opportunities for students to add new ideas about science phenomena by interacting with visualizations, for instance. 3) Distinguishing among their new and existing ideas: Knowledge integration instruction help students to develop criteria for evaluating ideas about scientific concepts and promote deep understanding. As students get their ideas from multiple sources such as authorities, internet, peers, it is important to evaluate these massive ideas and distinguish among ideas to build coherent understanding. 4) Sorting out ideas (Linn, 2006; Linn & Hsi, 2000): Knowledge integration framework promotes an instruction that help students to sort out their ideas to make those set of ideas more coherent by building strong connections among them (Linn, 2006).

Although the knowledge integration framework draws ideas from both cognitive and sociocultural perspectives (Linn & Eylon, 2011), it places the social factors as contextualizing factors that promote individual learning (e.g., a common knowledge integration curriculum approach is to pair up students to help them learn from each other). Most knowledge integration studies reported individual students' learning gains (in terms of their knowledge integration abilities). In contrast, the knowledge building perspective (Scardamalia & Berieter, 2006) comes from a different philosophical orientation.

Recent emphasis on collaborative learning rather than individual inquiry and place of argumentation gave birth to the notion of 'knowledge of knowledge' (Scardamalia & Bereiter, 2006). Based on this emphasis, Scardamalia & Bereiter's (2006) conception of contemporary education focused on the idea of knowledge-creating civilization. In their understanding, education should find ways to engage youth and place them in this knowledge creating civilization. Theoretically, from a sociocultural perspective knowledge building encourages students to engage in a knowledge building community through social channels. Therefore, as an overarching theoretical perspective, they suggested the knowledge building theory "to refashion education in a fundamental way, so that it becomes a coherent effort to initiate students into a knowledge creating culture" (p. 97). In short, this theory stems from the idea that a community of learners should jointly create knowledge (Scardamalia & Bereiter, 1994). It assumes that, individual learning and understanding scientific concepts are by products of this knowledge building activity (Moskaliuk, Kimmerle, & Cress, 2009) and the Internet becomes a mediating tool between classroom and the civilization-wide knowledge building community in this process (Scardamalia & Bereiter, 2006). Overall, knowledge building can be defined as "…the production and continual improvement of ideas of value to a community, through means that increase the likelihood that what the community accomplishes will be greater than the sum of individual contributions and part of broader cultural efforts" (Scardamalia & Bereiter, 2003, p. 1370).

Knowledge building approaches advancement of knowledge as a collective community practice and achievement rather than individual achievement. Within a community, the members create some sort of work that advances the state of knowledge (Scardamalia & Bereiter, 2006). The knowledge building work can take place in classroom communities or be situated in larger communities. Knowledge building theory also sees knowledge advancement as idea improvement, instead of progress toward the truth. Scardamalia and Bereiter (2006) noted that epistemic artifacts, the term coined by Sterelny (2005), as one important component of knowledge building. Those artifacts might be abstract or concrete things such as abstract or concrete models. Scardamalia and Bereiter (2006) argued that knowledge building involves creating those artifacts to initiate creating and the development of new knowledge. Hence, knowledge building theoretically centers around sociocultural accounts as students use epistemic artifacts as cultural tools in a collaborative learning environment. At the same time, knowledge organization advocates creating a knowledge creating community by taking advantage of current technologies.

Knowledge organization encompasses some of the premises of the knowledge integration and knowledge building frameworks. From a cognitive constructivism's stance on learning in knowledge organization process, students reflect on their prior knowledge and views held by themselves before and during the knowledge organization process to have integrated individual understanding of the scientific concept or the phenomenon being studied similar to knowledge integration (Linn, 2006), Also students add new ideas to their repertoire during the knowledge organization process using different information sources such as internet and peers. Knowledge organization also emphasize the sorting out ideas (Linn, 2006) to make set of ideas coherent similar to knowledge integration framework. From a social constructivist standpoint, tagging, sorting, and clustering those artifacts in a way that reflects understanding scientific concepts is a core component of knowledge organization process similar to knowledge building theory's perspective on epistemic artifacts.

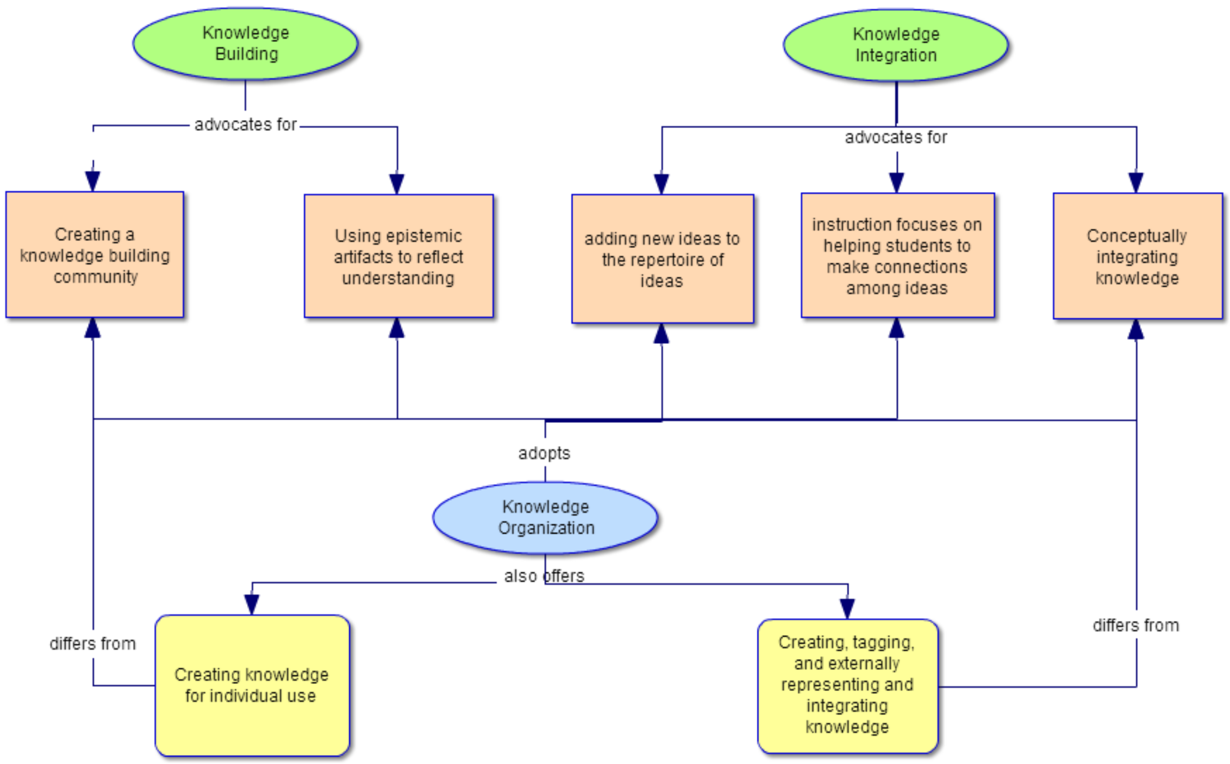


Figure 2. Theoretical consideration of knowledge organization

Although knowledge organization has roots in knowledge building and integration, it also differs from them in several aspects. In knowledge integration learner conceptually integrates the knowledge in their mind; however, knowledge organization focusses on the process of organizing knowledge externally by sorting out, creating, tagging, and grouping external representations. Additionally, knowledge organization can be a personal practice without seeking knowledge advancement in the knowledge creating society. 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 (Figure 2).

Implications: Significance of KO with MER in Arguing About SSI

Literature on knowledge integration and knowledge building incorporates interactive collaborative learning opportunities for students. Studies focusing on knowledge integration, for instance, use a web-based inquiry science environment (WISE) in which students engage in collaborative activities and build affective arguments (e.g., Bell & Linn, 2000). Similarly, in knowledge building, students can use epistemic artifacts to further advance their knowledge and build sound arguments in a computer supported collaborative learning environment. Hence, as knowledge organization builds upon the knowledge integration and knowledge building theories and these theories employ CSCL environments to promote effective argumentation, in this current study knowledge organization considers CSCL as an effective way to engage students in argumentation by the aid of external representations.

Researchers argued that argumentation can be scaffold by the aid of MER (Noroozi et al., 2012). Given the advancements in technology in learning school science, CSCL environments provide students with a space for synchronous, asynchronous and face-to-face collaboration. These environments also provide opportunities to construct MER that act as tools to store information and scientific evidence for argumentation (Matuk & Linn, 2012). Therefore, recently researchers incorporate MER in the CSCL environments, as students benefit from using them in learning school knowledge (Kozma, 2003) and using more than one representation would enhance students' effective learning (Ainsworth, 2006). As MER can also be used as a basis for argumentation, the quality of MER "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). Therefore, MER can be used to promote argumentation in CSCL environments which is called argumentation based computer supported collaborative learning.

Considering the strengths of using MER in learning, in this study, students will be engaged in activities where they will use MER to organize their knowledge to have a holistic understanding of the given SSI and also collaborate with their peers to build a knowledge web about the issue.

Computer Supported Learning

With the fast development of information communication technologies (ICT), technology enhanced learning environments have become an inherent part of everyday science instruction. ICT serves as transformative tools of learning, which not only act as an agent delivering the knowledge but also as a tool that facilitates students' collaboration and knowledge development (Sawyer, 2006). It can help student learning in many ways, including transforming abstract knowledge in a more concrete form such as visualizations, supporting learning and reflection via multiple modes and scaffolding, and enhancing the collaboration opportunities for knowledge construction and sharing (Sawyer, 2006).

Different technologies offer different affordances, compared to traditional learning environments. In the literature, several principles have been promoted to design successful technology enhanced learning environments. As the present study includes a design of a technology enhanced learning unit, next, I will talk about some of the design principles I am adopting for designing the current argumentation based computer supported collaborative learning unit.

Making Science and Technology Accessible

One of the key principles of designing a successful science learning environment is making science and technology accessible. Linn et al. (2003) noted that making science accessible means designing science content in a way that students can construct, "when science ideas are accessible, students can restructure, rethink, compare, critique, and analyze both the new ideas and their established views" (p. 525). This idea resembles with the cognitive constructivist perspective which emphasize the importance of individual construction of knowledge. Connecting instruction and student ideas via educational technologies will enable students to have deeper and more linked ideas and connected understanding of scientific phenomena (Linn, 2010). On the other hand, congruent with the sociocultural view, making technology and science accessible allow students to have access to these technologies in their own learning and create meaning in a collective fashion.

This design principle promotes different dimensions of science understanding in technology-enhanced learning environments. For instance Adams, Paulson, and Wieman (2009) investigated student engagement with interactive simulations in PhET when students provided with different levels of guidance. Their results indicated that students' engagement in this scientific exploration, and therefore science understanding, depended on the design features of simulations. The complexity of the simulations for example, altered the student engagement in the scientific exploration. As we can see from the PhET example, designers should consider the science accessibility in a way that they would make science content student friendly.

Making science accessible also promotes scientific modeling practices in science classrooms. Wu (2010), for example, reported a design of a technology enhanced learning environment: Air Pollution Modeling Environment (APoME) to teach the concept of atmosphere which is a complex scientific concept. This concept is a result of interconnected individual variables such as weather conditions, topographic effects and so on. Therefore, air quality cannot be explained by the individual variables. Based on this, Wu described the rationale behind the design of APoME as helping students to develop understanding of "how multiple variables affect the dispersion of air pollutants, which in turn influences air quality" (p. 197). As we can see from the design notion behind APoME, Wu created a technology-based environment which aims to help students grasp a systematic and interconnected understanding of scientific concepts in order to develop more holistic understanding of a scientific phenomenon. Wu adopted Taylor's (1994) instructional design approach and specified the domain specific cognitive performances, designed advanced organizers regarding experts and students, designed a range of learning activities that require students to develop and use declarative, relational, and strategic knowledge. These are the indicators of how Wu organized scientific content for students. The results of the study indicated that high school students who engaged in using this modeling tool, improved their conceptual understanding of air quality, which is a complex scientific phenomenon.

Making Thinking Visible

Linn et al. (2003) defined the three possible purposes of making thinking visible: (1) for the purpose of assessment, (2) to make teachers' thinking visible for students, and (3) using models, simulations and other representations to make scientific ideas visible to students. In my definition making thinking visible refers to the process that students explicitly represent their understanding and knowledge in the forms of different representations (Linn et al., 2003; Shen & Linn, 2011). Since some scientific ideas and concepts are abstract in nature, making thinking visible in the technology enhanced learning environments will make students' understanding accessible for researchers and teachers. Theoretically, this principle can be framed within sociocultural accounts as cultural tools that students use in the learning environment will make their thinking accessible to the other people Researchers in the field developed some technology tools to make student thinking visible. For instance, modeling and simulation tools make scientific thinking and ideas visible (White & Frederiksen, 1998). Before explaining how modeling practices make understanding visible I want to define some key terms briefly. Models are human constructs that represent physical representations (Cartier, 2000; Fretz et al., 2002), mathematical formula and equations (e.g., Lehrer & Schauble, 2006), and rules and relations between model objects and concepts (Bravo, van Joolingen, & de Jong, 2009). In the process of modeling students create, evaluate , revise and explain their models (Schwarz et al., 2009) in order to describe, explain, predict and communicate with their peers about the phenomena under investigation (Shen, 2006). Therefore, modeling processes include several practices such as planning, model creation, model testing, evaluation, explanation.

Model-It is a nice tool adopting the design principle of making thinking visible. In their study, Stratford, Krajcik, and Soloway (1998) investigated high school students' cognitive strategies when they engaged in ecosystem modeling. They identified the following five cognitive strategies 1) Analyzing: students identified the factors and objects of the ecosystem, elaborated on the relevancy of those variables, discussed issues related to the model and tried to find solutions, and critiqued whether the model worked or not. 2) Relational reasoning: Students created relations and defined the relationship between variables. They also predicted what should happen next. 3) Synthesizing: They decided how model should work as a whole and discovered and discussed the relationships between factors that they had not considered before. 4) Testing and Debugging: Students ran their models and when they found an anomaly they tried to find possible solutions. 5) Explaining: Students explained why or how parts are related, they gave examples with their explanations. They made logical arguments to support their ideas and elaborated or demonstrated their idea about the model behavior. And described what was observed. Based on these cognitive behaviors researchers were able to determine what and how students were thinking about their ecosystem model (e.g., a model of the impact of urban runoff containing human and animal waste on stream quality). The completeness and accuracy of those practices enabled researchers to make judgments about students understanding of the concepts and ecosystems as a complex scientific phenomenon. Stratford et al. (1998) concluded that "constructing dynamic models provides opportunities for them [students] to think about, use, and reflect upon the science content knowledge gained during classroom instruction and investigations" (p. 225) which makes students' thinking visible for researchers.

Making Learning a Collaborative Action

Sociocultural constructivism approaches collaboration as a practice for knowledge construction (Lemke, 2001).During this practice students engage in interpersonal activities for meaning making. Collaboration has been promoted as one of the core practices 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 delves into their own understanding of scientific phenomena (Komis, Ergazaki, & Zogza, 2007). Additionally, when students involve in collaborative learning practices, they encounter vast amount of distinct ideas and views, which enables them to establish criteria to distinguish ideas (Linn et al., 2003). Research in the field indicated that students achieve higher learning goals when they collaborate comparing to students' individual learning (e.g., Cohen & Scardamalia, 1998; Lou, Abrami, & D'Apollonia, 2001).

Since the biggest premise of collaboration is promoting deeper learning (Manlove, Lazonder, & de Jong, 2009), researchers incorporate collaboration practices as one of the core design principles of technology-enhanced learning environments/curricula. One of the technology-enhanced learning environments adopting this design principle is WISE. For instance, Show and Tell feature of WISE supports peer review of projects (Linn et al., 2003). Based on the feedback students groups get from their peers and revise their project and include their peers' comment in their final project report. Furthermore, most of the WISE projects incorporate collaborative asynchronous online discussion tool as a standard component. This feature is important in science learning because it supports students' engagement in dialogic argumentation (Clark et al., 2007). This engagement is considered one of the powerful tools for increasing students understanding of scientific concepts (Driver et al., 2000).

SMALLab is a semi-immersive mixed reality learning environment which allows students to participate in the learning space without wearing specialized display devices (Birchfield & Megowan-Romanowicz, 2009). Students interact with each other using a set of 'glowballs' as handheld devices and their actions are followed by the sensing and feedback equipment in the system. One of the design imperatives behind SMALLab is to cultivate face-to-face collaboration through the use of technology enhanced curricula.

Birchfield and Megowan-Romanowicz (2009) conducted a study using SMALLab to investigate the effect of SMALLab design on students' collaborative learning of earth science content. Students worked in groups and modeled 'layer cake' of earth crust. Research results indicated that students in the experimental group increased their interaction (face-to-face collaboration) 33% more comparing to the students in the control group who received the regular instruction. Also the results of science content test indicated that students in the experimental group increased their science content knowledge 23% in the multiple choice test items as well as 40% in the free response justification. These results indicate that collaboration as a part of technology enhanced learning environment design principle had positive effects on student learning.

Making Learning a Collective Practice

Science is a social enterprise (NRC, 2012) that "involves a process of social construction of knowledge" (Driver et al., 2000, p. 298) and scientific knowledge advances through collaboration (NRC, 2012). Hence, this design principle is framed within sociocultural accounts because it targets social aspect of learning. Therefore, as I discussed above, there is a call for incorporating collaboration in the design of technology enhanced learning environments especially in the learning sciences community.

Collective learning paradigm provides space for constructing this collaborative effort. Collective learning emphasizes the importance of the learners' social environment in the process of learning (Fadul, 2009). It shares similar roots with organizational learning theory, which advocates that organizations have similar cognitive patterns in gathering, perceiving, evaluating and interpreting knowledge similar to individuals' cognitive patterns (Schechter, 2012). Therefore, as Lipshitz, Popper, and Friedman (2002) argued, collective learning is associated with the learning by groups and organizations. Recently, studies conducted with the teachers and schools indicated a more effective learning when they engaged in the collective learning practices. Hence, designing a technology enhanced learning environment which promotes collective group learning is a desirable outcome

Researchers create an environment for the needs of community of learners when they engage in learning science through collective practices. One great example of collective learning environment that facilitates science learning is Mr. Vetro, which is a collective simulation that supports role-playing. In this environment, users can discuss relationships, make decisions regarding to, and experience interactions in a complex science systems such as a human body. For example, Ioannidou et al. (2010) conducted a study with high school students who controlled the different part of a human body in the Mr. Vetro simulation using wirelessly connected computers. The role-play aspect came into play when student groups collaborated as different organs of the human body. In this study, students collaborated and collectively tried to keep the healthy state of human body. This example illustrated that each student group contributed to the greater scientific knowledge in the class. Results showed that students in this collective learning environment outperformed their peers in the control group in terms of science content learning.

Implications: Designing the Computer Supported Learning Unit

Making thinking visible in nuclear energy unit (NEU). In the process of making thinking visible, students will represent their knowledge explicitly and in several forms such as models and explanations (Gobert & Pallant, 2004). Linn et al. (2003) described the three purposes of making thinking visible: for purposes of assessment, making scientific ideas visible to students and making teachers' thinking visible in response to students' notes or other activities. Students' thinking will be made visible for the purposes of assessing the knowledge organization and argumentation practices. Therefore, I will incorporate three modes of external representations and collaborative argumentation in the unit for students to represent their scientific understanding.

MER has been promoted for capturing students' interest (Ainsworth, 1999) and enhancing better understanding of scientific concepts (Chandrasegaran, Treagust, & Mocerino, 2011; Waldrip, Prain, & Carolan, 2010). Beyond these benefits, MER can make students' thinking visible for researchers since students can reflect on their understanding externally in the forms of text, verbal explanations, visualizations, diagrams and models. On iKOS, students can represent their understanding, in three distinct modes: Wiki, concept map and event. Students can create entries similar to widely used Wikipedia as in the forms of text representations. In the event mode student can upload a picture of a complex scientific phenomenon, label the pictures and explain the labels to develop an interrelated understanding of the phenomenon. Students can also create concept maps in the system and visualize the connections among a set of related science concepts.

Argumentation, on the other hand, is another way to make students' thinking visible. Although there are multiple definitions of an argument, I use the definition of Zohar and Nemet (2002). These researchers noted that "an argument consists of either assertions or conclusions and of their justifications, or of reasons or supports" (p. 38) and the argumentation refer to the argument creation process. Researchers argued that it is not possible for a novice or an expert to access each other's cognitive processes when performing a task (Jimenez-Alexandrie, & Erduran, 2007). Using verbal acquisitions will enable novices and experts to state and reflect on what and how they think about the task in hand. Therefore, as Duschl & Osborne (2002) stated, argumentation is a unique way to make scientific thinking visible.

Making learning a collaborative action in NEU. Second design principle of the technology-enhanced nuclear energy learning unit is to make learning a collaborative action. I will promote this in two forms. Overall, students will work in groups of three to complete this unit. Students will argue about the nuclear energy dependency as a form of energy, and the pros and cons of constructing nuclear power plants. Their initial collaborative argumentation will allow students to jointly create knowledge and acquire this knowledge individually (Stegmann, Wecker, Weinberger, & Fischer, 2011). This process will also make students to be exposed to new ideas and knowledge, as well as learning from each other (Linn et al., 2003) different aspects of nuclear energy.

Another distinct character of iKOS is that it allows users to co-create entries, comment on other students' entries and rate those. This will enable students to evaluate and revise their initial representations and form a sound understanding about the issue as they will be exposed to different ideas. Hence, collaborative actions of students will foster students' practices for understanding the nuclear energy socio-scientific issue.

Making science accessible in NEU. Linn (2010) argued that "the internet provides a rich, confusing, chaotic, informative, persuasive set of scientific information. So students need to learn to view this information critically (diSessa, 2004). Since anyone can be an author of internet material including advertisers, instructional designers, classroom teachers and, students in science classes these materials will necessarily be diverse." (p. 785). Thus, it is critical to design learning environments that can incorporate tools for students to coordinate material that they encounter. Linn also pointed out that those materials should allow students to foster "a deeper, more linked and connected understanding of scientific phenomena" (p .784).

In this unit students were asked to find information related to a science aspect of nuclear energy online. Based on what they learned from the web and using their prior knowledge students co-created entries in the forms of multiple representations. Users were able to tag their entries with the key words. When several multiple representations shared the same keywords, iKOS system automatically interlinked and connected those entries. Hence, the tool itself promotes more complete and interlinked understanding of the scientific concepts under investigation.

Another dimension related to making science accessible is that students can see the entire knowledge entries created by their peers in the classroom. Students can co-edit or read those entries and foster their scope on the issue or their understanding of the phenomenon. Overall, students can "restructure, rethink, compare, critique and analyze both the new ideas and their established views" of scientific issues (Linn et al, 2003, p. 525).

Making learning a collective practice in NEU. Final design principle of my learning unit is to make the whole learning experience a collective practice. iKOS technology has several features to support this purpose. First, students can co-edit knowledge entries in the system. In my proposed research, after students create their initial entries at home prior to coming to the class, students will be asked to co-edit entries their peers crated. Since all of the entries will be available for students' access, they will be able to choose an entry freely. Second, when students create similar knowledge entries and tag and label those, entries will be interlinked in the system. Therefore, with all the entries on one unit and interlinked entries, students benefit from all the information available from their peers instead of only getting the knowledge from the peers in their collaborative small group.

In addition to co-editing and interlinked entries in the unit, at the end of the proposed activities students presented their group entries and their knowledge about the specific science aspect related to nuclear energy to the whole class. This enabled other students in the class to learn about multiple facets of nuclear energy and be exposed to more ideas about nuclear energy. Hence, learning moved beyond being a collaborative action in small groups and became a collective experience gained through multiple practices. Collective practice differs from collaborative practice in this study as it offers ways for groups to focus on different aspects of a larger scientific phenomenon.

Implications: MER in CSCL Environments

When students involve in collaborative learning practices, they encounter a vast amount of distinct ideas and views, which enables urges them to establish criteria to distinguish ideas

(Linn, et al., 2003). Research in the field indicates that students achieve higher learning goals when they collaborate comparing to students' individual learning (see, for example, Cohen & Scardamalia, 1998; Lou et al., 2001). As computers have become important mediators of learning and collaboration a common practice, CSCL enhances our understanding of how students learn collaboratively with the aid of computers (Stahl et al., 2006). CSCL environments foster in-depth discussions (Andriessen, Baker, & Suthers, 2003), support the sharing and construction of arguments in multiple forms (Noroozi et al., 2012), and help learners to achieve a deeper understanding of and produce productive arguments on ill structured problems (Aleixandre-Jimenez, 2007; Buckingham-Shum, 2003).

Mcfarlane and Sakellariou (2002) argued that individuals are exposed to vast amount of information more than ever before and students need to know how to evaluate information while building personal knowledge. Given the expanded number of computers and the place of social networking in today's schooling, learners can access information rather easily from anywhere and anytime. Specifically, considering the controversial nature of SSI vast amount of information about the SSI has been distributed to wide network of resources and represented in multiple formats. Therefore, it is critical for students to organize their knowledge in a more coherent and holistic way to understand science and construct their arguments based on the available data and evidence. In this context, CSCL offers ways for students to create artifacts during their learning instead of learning from the texts and from the heads of students (Yoon & Brice, 2011) to critically view and organize their knowledge about a given SSI. I believe that organizing knowledge in the forms of distinct MER in a computer supported learning environment would enhance students' argumentation on given SSI (Figure 3). Hence, argumentation based CSCL environment will be the context of this study and will serve as a platform for students to have holistic understanding of SSI.

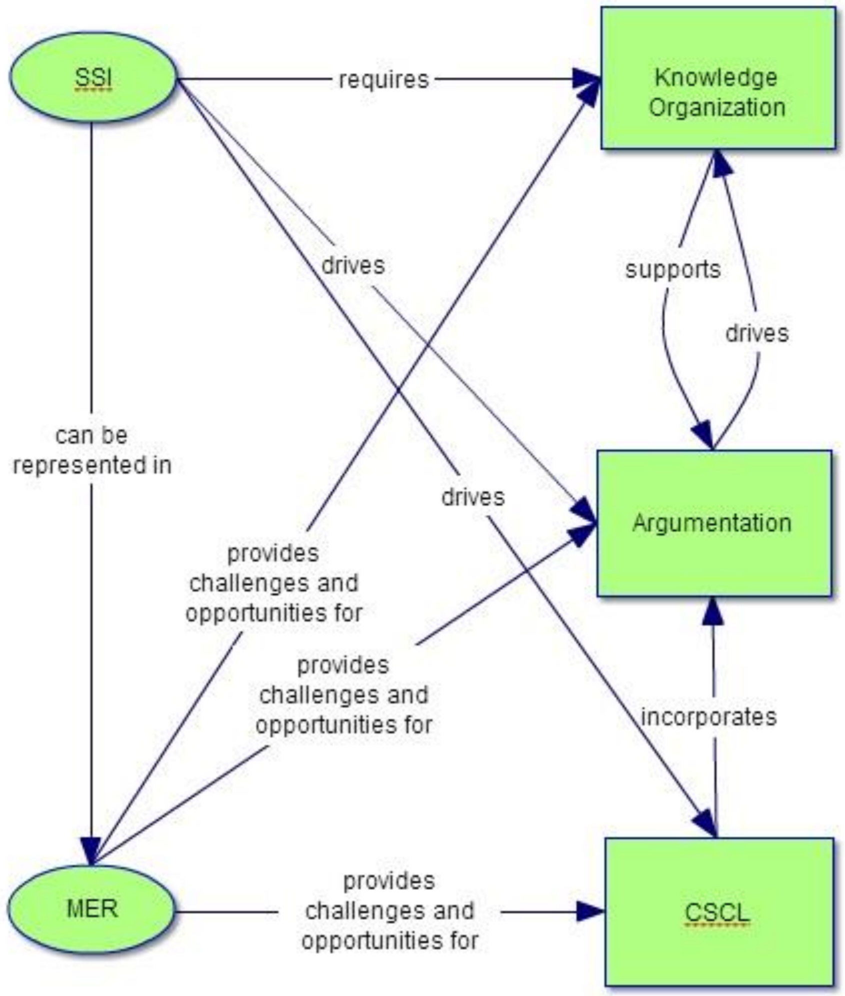


Figure 3: Knowledge organization with MER for arguing about SSI

CHAPTER 3

METHODOLOGY

This mixed methods study aims to investigate student learning in an argumentation based computer-supported collaborative learning (CSCL) environment. In this chapter, I will first describe the technology used in this study, the results of two pilot iterations, and the lesson plan of the learning unit. Then, I will describe the design of the current mixed methods study; including the paradigmatic stance, rationale, purpose, design, and the context of the study. I will also describe the data collection and analysis methods. I will conclude the chapter with the limitations of the study.

Designing and Implementing the Nuclear Energy Learning Unit

This study was a part of a larger design study that aimed to understand the theory of knowledge organization that "draws on prior research and attempts to cash in the empirical and theoretical results of that research" (Cobb, Confrey, Lehrer, & Schauble, 2003, p.10). This design study incorporated an iterative refinement process that improved the design of both the technology platform and the SSI unit as informed by the ongoing analysis of students' reasoning and the learning environment (Brown, 1992; Cobb et al., 2003; A. M. Collins, 1992). In this section, I will first introduce the technology platform students used during the unit implementations. Then, I will briefly describe two pilot iterations and the revisions of the unit after the implementations.

The innovative Knowledge Organization System (iKOS)

The technology platform used in this study was iKOS (www.ikos.miami.edu). iKOS is a web-based knowledge organization system that provides a hypertext platform for individuals and groups of learners to construct, share, and organize scientific knowledge in multiple representations. It incorporates three distinct external representations: Event, Wiki, and Concept Map. In the Event (see figure 4) mode students can upload a set of static pictures and tag them to organize and show a holistic view of a complex scientific event or phenomenon. The Wiki mode is a primarily textual representation that has an editing window similar to the popular Wikipedia. In Wiki students can insert pictures and videos next to their texts. In the ConceptMap mode, students can draw concept maps (Novak & Cañas, 2008) to visualize connections among a set of related scientific concepts.

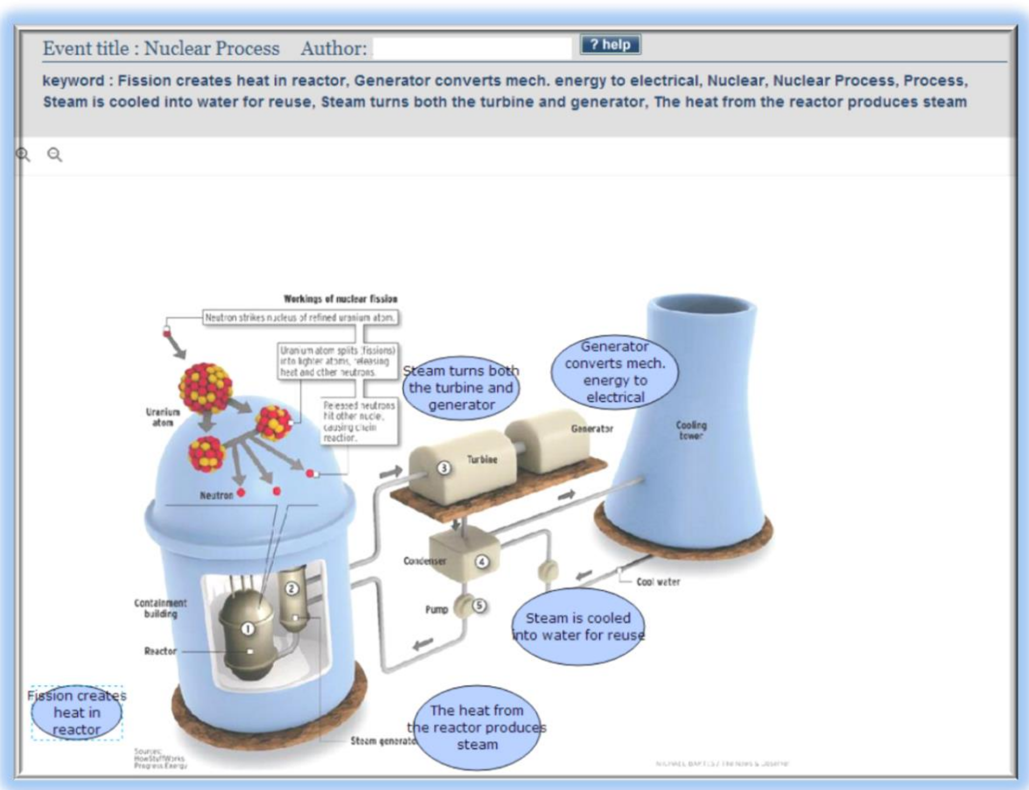


Figure 4. Event entry

Research reported that learners have difficulties in understanding the relationship between multiple external representations (MER) as they see representations in isolation, and therefore, have difficulties in integrating information (Ainsworth, 2006). iKOS was developed to help learners to overcome this barrier. What is unique to iKOS is that it automatically interlinks student-generated MERs through shared keywords and creates a web of knowledge entries. Figure 5 illustrates a web of knowledge that centered on the "Nuclear Process" Wiki entry. Each color represents a representation type: blue is for Event, green is for Wiki and red for ConceptMap. In this figure, for instance, a Wiki entry titled "Nuclear Process" is interlinked to another entry created by the same student ("Nuclear Explosion Effects on Humans") or to another entry created by a different student (e.g., Wind Energy, Nuclear Power Plant). These entries were linked because they share the same keyword of 'radiation' that students use to organize their knowledge. In this case, students can make connections between different representations and learn further information from other entries on the similar topic in the same classroom.

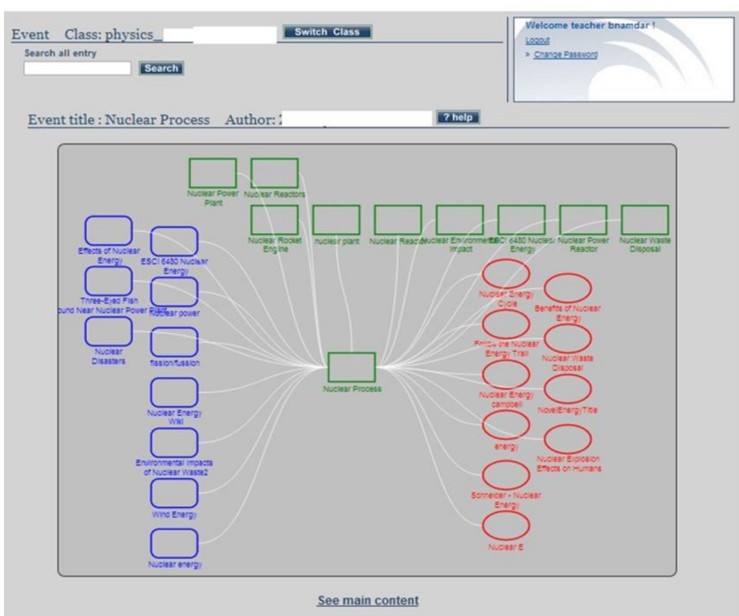


Figure 5. Knowledge Web

The platform also offers classroom management tools. First, a teacher can create multiple classes on the platform and students can sign up to one or more class sessions. When a student creates an entry, he or she can apply to make the entry open to the whole class, pending approval by the teacher. The system also automatically reports descriptive statistics of the entries status. iKOS also incorporates collaboration tools. Students can co-edit an entry, comment on an entry, and rate an entry of interest.

Design of an Argumentation-based Science Unit on Nuclear Energy

With feedback from Dr. Shen, I developed a unit on the topic of nuclear energy incorporating iKOS with the overall goal to engage students in critical thinking through argumentation (Sadler, 2004; Zeidler & Nichols, 2009; Zohar & Nemet, 2002). Specifically, the unit was designed to help students: 1) understand the science related to SSI, 2) organize knowledge effectively, 3) retrieve and identify relevant information efficiently, and 4) co-construct knowledge entries and learn from each other. I chose the topic of nuclear energy as the SSI topic because it is not only a typical SSI with the controversial and open-ended features, but also a real life problem relevant to the participating students- there was a debate on the news whether to build a new power plant 80 miles from the university that this study took place. Two pilot studies were conducted to test the SSI unit and refine the iKOS learning environment before the current study (Figure 6).

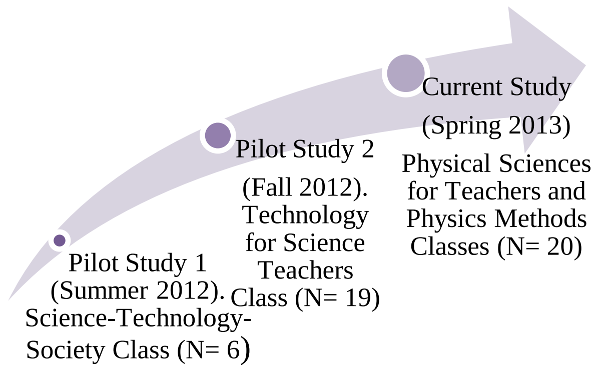


Figure 6. Iterations of nuclear energy unit

Pilot study 1. The first pilot study was conducted in a large public university with 6 graduate students (pre-service science teachers) who took a course on science-technology-society in Summer 2012 semester. The implementation of the learning unit took only 2 days. On the first day, I introduced the iKOS platform to the participants. After getting familiarized with the system, students were asked to create entries on nuclear energy to organize their knowledge. The first day activities took about 45 minutes. On the second day, I randomly assigned the participants to two groups of three and asked them the following questions: 1) Should we build nuclear power plants? 2) How far should we rely on nuclear energy as an energy source? After students argued about these two questions in their groups, I asked them to use the Internet individually to find information and create iKOS entries to organize their prior knowledge and what they learnt from the Internet. After 45 minutes, I asked the participants to discuss the same two questions in their groups for another 10 minutes. They then reported back in a whole class discussion, which took about 20 minutes.

The first pilot study provided insights on both revision of the learning unit and data collection. First, the participants were only able to create a total number of 15 entries due to limited time allocated for entry creation. I decided to give students more time for entry creation for future implementation. Second, the participants' discussion of the nuclear energy issue was devoid of local context. I went to find a news article that reported the decision making of a nuclear power plant that was planned to be built in the state. I included this article in future implementations. Third, the students' arguments lacked the use of scientific information. Therefore, I decided to instruct them to focus on one scientific aspect of nuclear energy in their small groups. Finally, I used video cameras and the built-in microphones to capture student conversations. While analyzing data I realized that the sound quality was low. Hence, I switched to table microphones attached to the cameras to get more high quality audio in later studies.

Pilot study 2. The second pilot study was conducted with 19 students (2 undergraduate, 17 graduate students who were pre-service science teachers) from the same institution. The class met once a week for 2.5 hours. I implemented the learning unit in three consecutive weeks in the middle of the semester in the Technology for Science Educators class. In week one, I introduced the iKOS platform to students and asked them to create entries related to the topic of energy. This lasted for about 45 minutes. They were then assigned as homework to read the news article on nuclear power plant construction in their state, and to create relevant iKOS entries, one per mode. In the second week, the students watched two five-minute YouTube videos focusing on the aftermath of recent nuclear power plant crisis in Fukushima, Japan and also France's nuclear energy dependency. Students were divided into four small groups randomly (i.e., two with four students each and two with five students each) and were asked the same two open ended question in the first pilot study. Students argued about those in their groups for about 15 minutes. After they finished, I asked each group to focus on one scientific aspect of nuclear energy and decide to defend or argue against using nuclear energy as an energy source. Each group was expected to create one iKOS entry in each mode. In their groups, students discussed and created their entries for an hour. After they finished entry creation I asked them to present their findings to the classroom. After each presentation students in the class were able to ask questions and the presenters were able to defend their positions about nuclear energy. Students also learned concept mapping for three hours in the class prior to this iteration.

The results of this study were reported elsewhere (Namdar & Shen, 2013). We used social network analysis to examine the features of the collective knowledge web students generated. Results showed that the Wiki mode was the most connected entry type that students created in the unit. It was interesting since the students generated their own key words in the wiki entries while the program automatically generated the keywords in other modes. Moreover, although student groups in their presentations relied on different types of MER, when they presented to the class, they incorporated their knowledge from different representational modes to construct a sound argument.

There were several constraints in this run. First, due to time constraint we did not introduce argumentation to the participants but expected them to argue on a given SSI. Therefore, their argumentation lacked the use of scientific knowledge and students had difficulties supporting their claims with accurate justifications. Hence, I decided to include argumentation session in future iterations. Second, the results suggested that the students rarely used the collaboration tools. Explicit directions on how to use these tools should be given in future iterations.

Design of the unit in the current study. Based on the findings of the first two iterations and considering the overall goal, I restructured the unit into 4 sessions (Table 2) and I taught all the sessions (i.e., 4 consecutive classes; for detailed lesson plans see Appendix A):

***The first session** (50 minutes)*. The first session included an overall introduction, obtaining consent forms, and introduction to argumentation and concept mapping.

- The first five minutes of the class were devoted to the introduction of the study and obtaining students' consent forms.
- The next 25 minutes were devoted to the introduction to argumentation. This step was to ensure that students understand the basic principles of argumentation. I gave a lecture following the claim, evidence, reasoning (CER) framework, which was proposed and used for collaborative argumentation (see Sampson & Clark, 2009a, 2009b). After the lecture, the students watched a video clip of a popular TV show (The Big Band Theory) and identified the claim, evidence, and reasoning that the actor was making about Superman's 'acceleration.' After this, I asked the question "If you drop 2 balls having the same size but different weight, which will reach the ground first? Why?" and asked students to write down their argument following the CER framework. The question was chosen because students explored the same question in their content class at the beginning of the semester.
- The last 25 minutes were devoted to concept mapping. In this step, I introduced creating a good concept map as complexity of the maps, existence of the propositions, and the quality of propositions (Vanides, Yin, Tomita, & Ruiz-Primo, 2005). Then, students were given concept maps and asked to identify better maps. I prompted students to use claim, evidence, and reasoning when they argue for the better concept map. Then, I gave students 10 minutes to create their own concept maps about energy without any content constraints. At the end of the lesson, I initiated a brief discussion about why we talked

about concept mapping and argumentation at the same time and encouraged students to think about using these two to make student thinking visible.

The second session *(50 minutes).* The second session was held in a computer lab. Each student sat in front of a computer and worked with the iKOS system individually. The session was mainly about introducing the iKOS system to the students. First, they created their student accounts and registered to the class. In order for the students to become familiar with the learning environment, I demonstrated how to create and submit iKOS entries, and use collaboration tools in the system. Then, I asked the students to create entries on energy to get familiar with the tools. At the end of this session, I assigned the students a reading from a news article that talked about a planned power plant construction in the state where the students lived. I asked them to learn about nuclear energy and create one entry on each mode (Wiki, ConceptMap, and Event) about nuclear energy before coming to the next class.

The third session *(180minutes).* This session comprised the bulk of the unit. In Chapter 4, this session will be referred to as "the third session" or "the in-class argumentation session" The session included the following steps:

- Peer critique and revision (~30 min). Students were told that they may co-edit or critique peers' entries and revise their own based on peers' feedback.
- Nuclear energy (~20 min). Students watched online videos focusing on the pros and cons of using nuclear energy. Students brainstormed initial ideas related to nuclear energy for 15 minutes based on the two questions "how far should we depend on nuclear energy as an energy source", and "is it ok to build nuclear power plants in our State?"

- Science aspects (~90 min). After the initial argumentation session, students were asked to investigate one specific scientific aspect of nuclear energy and create one entry on each iKOS mode to organize their knowledge.
- Final presentation and argumentation (~25 min). At the end of the unit, each group presented their findings and argued for their stance on building the nuclear power plant. Due to time limit, one group was not able to present their work.

The fourth session *(50 minutes).* In this session, the last group presented their findings. The class then discussed about why SSI based argumentation is important and the ways they can use this unit in their own classrooms. Students were also asked to fill out a survey on their final reflection about iKOS. Table 2 shows the overview of activities that took place in the four sessions.

Table 2.

Overview of the Activities

Session	Session 1	Session 2	Session 3	Session 4
Date	04/15/2013 Monday	04/17/2013 Wednesday	04/19/2013 Friday	04/22/2013 Monday
Class	Methods Class	Content Class	Content Class and Methods	Methods Class
Description	Introduction to argumentation and concept mapping;	Introduction to knowledge organization	Mediating the collaborative learning about nuclear energy via technology	Learning about nuclear energy: Collective practice.
Place	Meet at regular classroom	Meet at computer lab	Meet at computer lab	Meet at regular classroom
Duration	50 minutes	50 Minutes	165 minutes	50 minutes

Participants and Context of the Study

This study was implemented in two bundled courses in spring 2013 in a large public southeastern university in the United States. The two courses were “Physical Sciences for

Teachers" (i.e., henceforth, content class) and "Physical Science Methods" (henceforth, methods class). The content class met three times a week for 115 minutes daily and the methods class met right after the content classes for 50 minutes. The unit was implemented in 2 methods classes (50 minutes each) and 2 content classes towards the end of the semester (see Table 2). A total of 23 students consented to participate in the study and 20 students, 4 male and 16 female, were present during the study. Two participants (1 male and 1 female) were master's students in the science education program and the remaining 16 students were in the middle grades education program. Among the students from the middle grades program, only two students had science as their primary concentration and the others had social studies and mathematics as primary and science as secondary content areas. All of the students who participated in this study took both the content and the methods courses. The students were randomly assigned (Teddlie & Yu, 2007) to four groups: two groups had five students each, one group had 6 students, and one group had 4 students due to students who were absent during the implementation.

Although we focus on the learning aspect in the study, there are two main reasons to recruit pre-service teachers. First, I 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.

A Mixed Methods Research Design of the Current Study

"*Educational phenomena are too complex to restrict the researcher to a single method no matter how technically elegant or theoretically pure"* (Smith, 2006,p. 470).

Paradigmatic Stance

The research methodology selected in this study is influenced by the *alternative paradigm stance* on pragmatism (Greene, 2007). This popular stance considers paradigms for influencing practice decisions. This paradigmatic stance responds to the challenges of incommensurability of methods and seeks to find a common ground for a mix of methods. Greene argued that "alternative paradigm offers its own internal coherence and integrity and so does not present the tensions and challenges that can accompany the joint use of two or more traditional paradigms" (p. 82). Teddlie and Tashakkori (2003) suggested pragmatism as the most suitable paradigm for conducting a mixed methods study. One of the reasons is that it provides rationale for using qualitative and quantitative research in a single study. Johnson and Onwuegbuzie (2010) noted that:

> "it [pragmatism] offers an immediate and useful middle position philosophically and methodologically; it offers a practical and outcome-oriented method of inquiry that is based on action and leads, iteratively, to further action and the elimination of doubt; and it offers a method for selecting methodological mixes that can help researchers better answer many of their research question" (p. 17).

Onwuegbuzie and Johnson (2006) pointed out that "by pragmatism we mean to search for workable solutions through the practice of research…to help answer questions that we value and to provide workable improvements in our world" (p. 54). The research practice itself philosophically allows me to find a workable solution for our understanding about how students' knowledge organization with MER interacts with their argumentation practices on SSI. Methodologically, pragmatism enables me to use mixed methods to find a middle position between my quantitative and qualitative oriented questions to investigate the process of knowledge organization with MER in an argumentation-based CSCL environment. The results could provide practical implications for teachers and researchers to incorporate knowledge organization practices with MER to foster students' argumentation practices in science learning. Hence, the research was *for* education instead of *about* education (Biesta & Burbules, 2003, emphasizes original).

Rationale

Researchers argued that educational and social phenomena cannot be truly understood using a single method and pointed out the need for multiple data sources and analyses techniques (Smith, 2006; Teddlie & Tashakkori, 2003). In this study, I investigated the multilayered, complex learning processes students experience in the context of the designed unit. I zoomed into three aspects. The first two aspects were students' knowledge organization and their argumentation processes, as these aspects instantiate students' conceptual understanding. The third aspect focused on the interaction between knowledge organization and argumentation in order to better understand the dynamics between the two (Figure 7). The interaction referred here includes the instances in which students' argumentation practices lead to knowledge organization, and also the instances in which students' argumentation was mediated by students' knowledge organization with MER.

As the phenomenon under investigation was a multilayered one, using mixed methods allowed me to intentionally incorporate multiple ways of knowing to better understand this complex phenomenon (Greene, 2007). What is meant by *better understand* is getting greater comprehensiveness, enrichment, and contingencies of findings by capturing different aspects (i.e., knowledge organization, argumentation, and the interaction between the two) of the phenomenon (Greene, Benjamin, & Goodyear, 2001).

Purpose

I used mixed methods for a complementarity purpose. A *complementarity mixed method study* enabled me to use both quantitative and qualitative methods to analyze different facets of the phenomenon, which in this process yielded to an enriched, elaborated understanding of it (Greene, Caracelli, & Graham, 1989).

The three different aspects of the phenomenon under investigation were approached by different methods. The knowledge organization aspect was investigated by using quantitative methods (i.e., representations students mostly relied on, key actors in the knowledge web) and quantizing qualitative data (i.e., knowledge organization quality); the argumentation aspect was investigated by quantizing qualitative data (Tashakkori & Teddlie, 1998), and the interaction between knowledge organization and argumentation was investigated by using qualitative and quantitative methods (Figure 7).

Recall there are three research questions associated with the three aspects of learning: In an argumentation based CSCL environment

1. How do learners organize knowledge effectively with MER?
    a. How they organize their knowledge with MER?
    b. What are the key actors in the network?
    c. What is the quality of knowledge organization with MER?
2. What is the quality of students' arguments on a given SSI?

3. How does learners' knowledge organization with MER interact with their argumentation practices?

Results from the first research question enabled me to understand the most prominent type of MER students utilized during their knowledge organization, key actors in the network, and the quality of knowledge organization; results from the second research question reported the quality of arguments during the learning unit; and the results from the third question investigated how knowledge organization and argumentation interacted with each other.

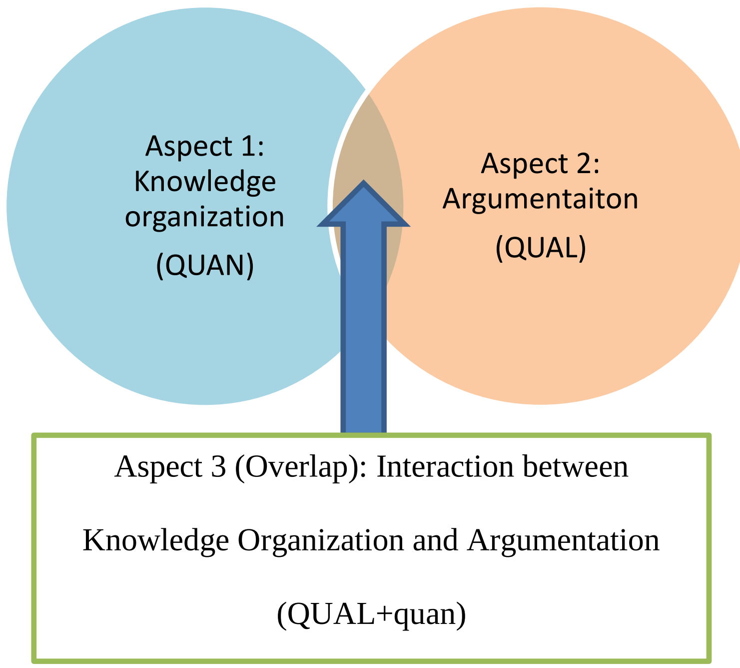


Figure 7. Three aspects of the phenomenon under investigation

Design

In this study, I employed a *blended mixed methods study design* (Greene, 2007). Figure 8 is a graphic design of this study. This method enabled me to collect both QUAN and QUAL data concurrently while gaining different perspectives from different methods. The rationale for choosing this design was twofold. 1) Blended design is a type of *integrated mixed methods design* (Greene, 2007). In integrated mixed methods design, methods assess the different or overlapping aspects of one particular phenomenon and serve for the purpose of complementarity or initiation (Greene, 2007). In this study, blending QUAL and QUAN served to the purpose of complementarity (Greene, 2007) as I seek information for one phenomenon that included three aspects (i.e., knowledge organization with MERs, argumentation, and interaction between knowledge organization and argumentation). 2) In a blended design, Greene (2007) stated that the sequence of the implementation is concurrent and the status of methods has equal weight. Therefore, in this study, both QUAL and QUAN methods had equal weight and they were implemented concurrently.

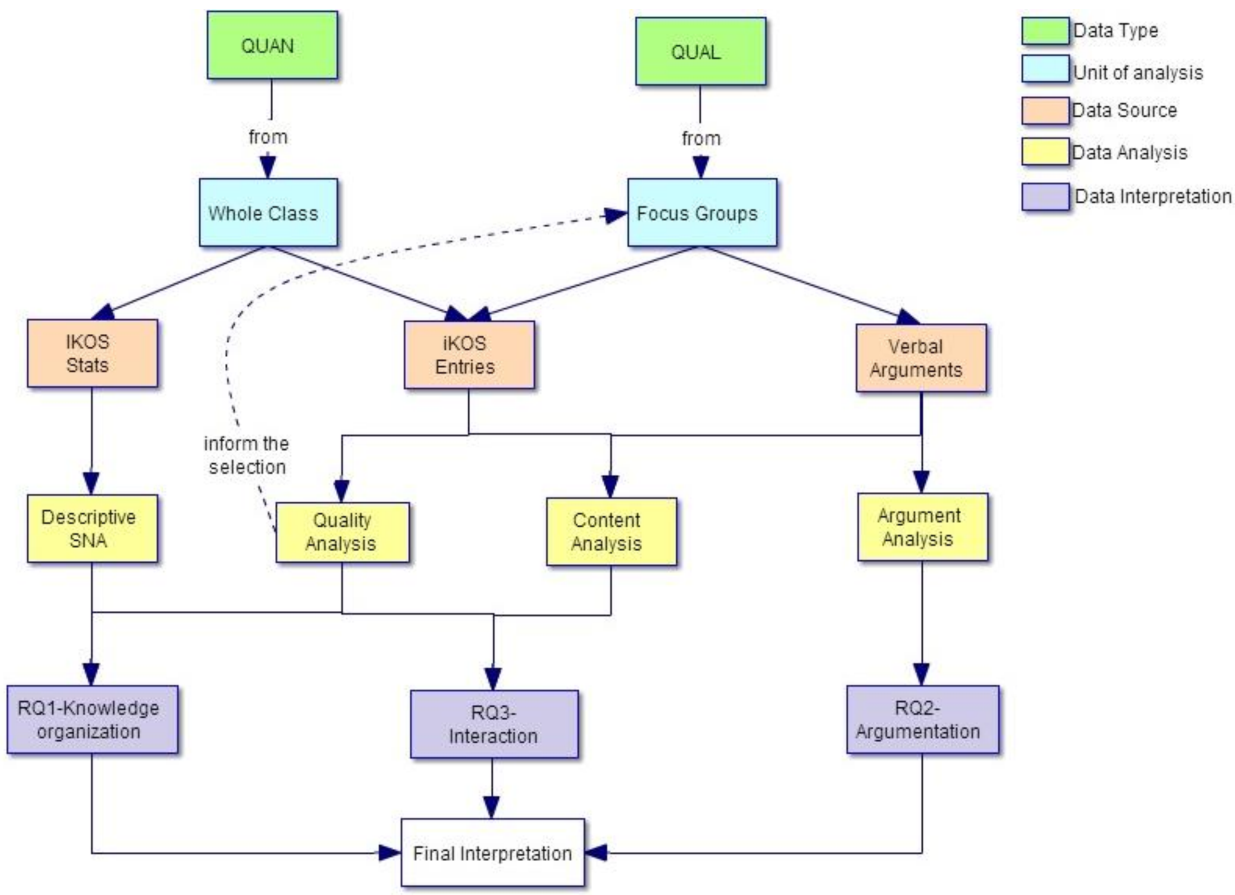


Figure 8. Mixed methods design of the current study.

Teddlie and Tashakkori (2006) argued that a mixed methods study should include integration across stages. In the figure 8 the abbreviations of the qualitative and quantitative is capitalized; meaning that qualitative and quantitative methods were considered as having equal weights. Additionally, plus sign indicates that both QUAL and QUAN data were collected concurrently (Sandelowski, 2003). Mixing occurred during research questions, data collection, data analysis, and data interpretation stages. Specifically, the research questions one and two were quantitative, and the research question three was qualitative in nature. iKOS statistics constituted quantitative data sources; students' verbal arguments and iKOS entries constituted qualitative data sources for this study. In data analysis I benefited from quantitative methods to answer the first research questions, quantitized data for the second question, and benefited from summative content analysis and video recordings for the third research questions. All findings were integrated and interpreted.

Data Collection

The data collected for the current study included iKOS statistics generated by iKOS server, iKOS entries generated by individual students or groups; students' videotaped classroom activities during the unit, and field notes. In the following I explain each data collection in detail.

iKOS Entries and Statistics Table

The students created iKOS entries individually and collaboratively. Before coming to the third session, the students created at least one entry per mode individually (see Table 2). In the third session, the students worked in small groups on a specific scientific aspect related to nuclear energy (e.g., radiation). The groups were also asked to create together at least one entry on each mode.

The students were able to tag their knowledge entries with keywords they generated in the system to organize those across the representational modes. As the system automatically interlinked student-generated entries based on shared keywords, it also reported in an excel file the descriptive statistics tables including the number of entries, the number and direction of the links between entries. For instance, Figure 9 shows a part of an excel sheet of an Event Mode Statistic page. The system reports the name of the entry, the student ID, keywords assigned by the creator and the numbers of direct and indirect links that the specific entry has with other entries in the classroom. iKOS server also keeps all of the entries created by the students and the groups. These two data sources were used as primary data sources to answer research question 1 and 3; questions about knowledge organization and argumentation aspect.

Event		Editor	Rating		description	keywords	Event	Wiki	ConceptM
Title	Open to Class	teamMem	average Score	total persons			Links	Links	Links
Group 2	yes	1	0	0		2, Become	0	0	0
Group Awesome	yes	1	0	0		Awesome,	2	6	2
Map of Nuclear Power Plants	yes	1	0	0	Most of the US	Earthquak	6	16	14
Nuclear Energy Pic	yes	1	0	0		Energy, N	7	18	12
nuclear energy2	yes	1	0	0		nuclear en	0	0	0
Nuclear Power	yes	1	0	0		It adds mil	6	14	8
nuclear power plant	yes	1	0	0	A: protects aga	A concrete	6	15	10
Nuclear_power	yes	1	0	0		accidents,	0	3	6
power plant	yes	1	0	0		power plar	0	0	0
Radiation and Cancer	yes	1	0	0	A: UV light hits	A normal I	0	5	5

Figure 9. Event mode statics page

Participant Observation and Field Notes

I taught the unit for this study. I used participant observation as a data collection strategy (Suzuki, Ahluwalia, Arora, & Mattis, 2007). DeWalt and DeWalt (2002) proposed several activities for participant observation including having contact with the participants, gaining understanding of culture of the observed group, participating in activities that participants engage, observing participants in different contexts, recording observations and constructing field notes. First, I attended several sessions of the classes at the beginning and middle of the semester to get to know the students. Second, during the study, I was actively engaging in students' conversations. When students engaged in argumentation during the learning unit, I rotated between groups and asked students elaboration and clarification questions. I also helped them if they had any questions regarding the unit or the iKOS platform (i.e., try to solve problems associated with the platform while creating accounts, entries).

I also kept brief field notes at the end of each lesson. Field notes were written in a Microsoft word document and the notes included the summary of observations at the end of the each class period, issues encountered during the learning unit such as the problems occurred in the iKOS, and significant instances during the activities such as collaboratively creating entries in each mode or dividing the task of entry creation among group members.

Video Recordings

The whole class events and all individual group activities were video recorded. Two teaching assistants in the classroom helped to set and check the video cameras. Video recordings provided rich and detailed explanations related to the actions of the participants (A. Collins, Hawkins, & Frederiksen, 1993). Collins et al (1993) argued that

> Video can record how students explain ideas and answer questions that challenge their understandings. Oral presentation is critical to many aspects of life, and video enables us to capture student presentations in the same way we capture written presentations with paper and pencil. With video we can see how well the students integrate words and diagrams as they explain things. It is also possible to see how they answer challenging questions their audience poses to them, how they deal with counterexamples and counterarguments, and how they clarify points that are unclear to the audience (p. 210).

Based on this notion, video recordings along with the verbal transcripts provided key information when investigating how students engaged in the activities, especially using MERs in their argumentation and their collaborative knowledge organizations. Video records were crucial to show the specific entries to which individual students or each group referred when presenting to their peers during each group presentation. Video recordings were used as a secondary data source to identify the instances when students use their iKOS entries during the whole class level argumentation, the way groups collaboratively organize knowledge and explicit verbal back channeling events occurred during argumentation sessions. Nonetheless, I was 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 the minimum level to ensure the ecological validity.

Data Analysis

After all the data were collected, the data were analyzed through data reduction, transformation, consolidation, and integration (Li, Marquart, & Zercher, 2000; Onwuegbuzie & Teddlie, 2003). Figure 10 depicts the analysis sequence used in this study.

1) *Data reduction* was necessary to have the data in manageable pieces. At the beginning of the analysis, irrelevant student conversations as well as data from the students who did not give consent were excluded from the data set. For QUAN data descriptive statistics and social network analyses were used for data reduction. For QUAL data, based on the QUAN analysis two students in different groups were identified to have deeper understanding of the processes of knowledge organization and argumentation. These two students were identified based on their contrasting positions about the issue, and the different knowledge organization quality of the students in each group who presented their groups' final argumentation. I, then, identified the interaction between students' knowledge organization and verbal arguments through summative content analysis and video data and identified the themes to depict the interaction between knowledge organization and argumentation practices.

2) Although data reduction was applied to all the data, *data transformation* was performed to QUAL data only. Using conceptual and technical quality scoring rubrics (see Appendix C), student-created iKOS entries were scored and QUAL data was *quantitized* (Tashakkori & Teddlie, 1998) to determine the knowledge organization quality of entries. Similarly, students' verbal arguments were also *quantitized* to determine the quality of students' arguments using a framework suggested by Tal and Kedmi (2006).
3) *Data consolidation*: Based on the different knowledge organization quality scores created by two groups that had two students with contrasting knowledge organization, these two students' data along with their groups were identified as their actions and conversations were situated in their groups (Shen & Confrey, 2007). . This new data set was considered to be consolidated subset of QUAL and QUAN data.
4) *Data integration:* The final step in the analysis was *data integration.* This process aimed at weaving the bulk of findings into a coherent piece to depict the knowledge organization with MERs phenomenon. Descriptive statistics, centrality measures, key actor analysis and knowledge organization quality scoring for the all entries were interpreted to answer the question related to knowledge organization. Based on the results of the consolidated data, knowledge organization scores and content analysis of the verbal arguments were integrated to answer third research question. Finally, all data compared and integrated to write final interpretation in order to give a holistic picture of the knowledge organization phenomenon.

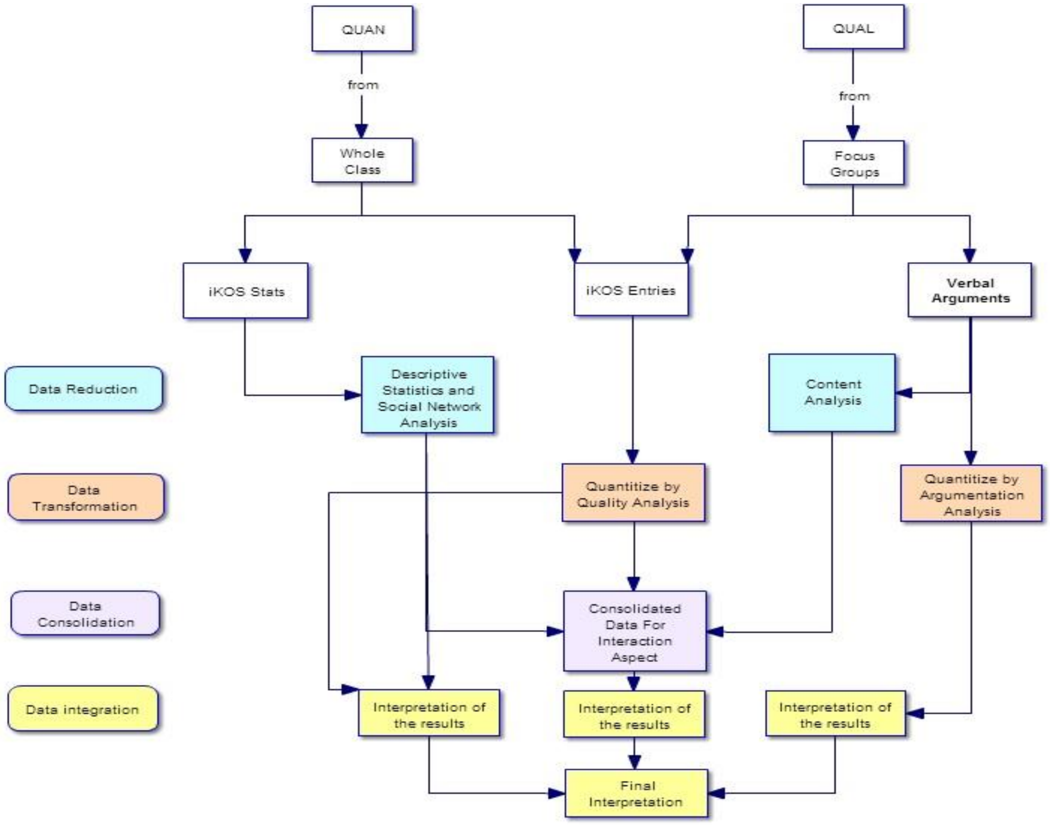


Figure 10. Mixed methods data analysis

Sampling of the Students with Contrasting Knowledge Organization Qualities Situated in their Groups

As a sampling method, two students were identified. Next, their knowledge organization and argumentation practices situated in their group were analyzed. These two students situated in their groups revealed contrasting episodes in terms of their individual knowledge organization quality prior to the third session of nuclear energy unit. These two students with high and low knowledge organization scores were chosen as I wanted to understand the similarities and differences in terms of the interplay between knowledge organization and argumentation practices. During this sampling, first, for all four groups the students who created one entry on each mode were identified. This was important as I wanted to depict the argumentation and knowledge organization process for students who actively participated in the study. Then among those four students, one student with the highest knowledge organization score and one student with the lowest knowledge organization score was identified. Haley in Group 4 with the highest knowledge organization and Elizabeth in Group 2 with the lowest knowledge organization scores were identified. Haley and Elizabeth also had contrasting positions about nuclear energy.

Analyses for the First Research Question: The Knowledge Organization Aspect

The first aspect of the phenomenon deals with knowledge organization. iKOS statistics and the entries created were used as data sources to understand the nature of knowledge organization in the learning environment. *Social network analysis* was applied along with the descriptive statistics to understand the most centralized representation type. *Knowledge organization quality scores* were assigned to students' entries to have a better understanding of the conceptual and technical quality of the entries.

Social network analysis. Social network analysis assumes that actors participate in the social settings and their relationships with each other determine the group dynamics and influence each other's behavior in the network (Knoke & Yang, 2007). Each social network (a graph) comprises actors (vertices, nodes) and relations (edges, links). Actors can be in the forms of individuals or groups. Relation refers to specific connection or a tie between two actors. Hence, a social network can be defined as a structure that comprises actors and some of whom are connected to others by a set of one or more relations (Knoke & Yang, 2007). In this study, actors refer to the individual entries students generated in iKOS. These entries were interlinked through their shared keywords. Together, they created a knowledge web (the social network).

Normalized degree centrality. The iKOS data logs report the number of entries as well as their links created in a class. Network measures of centrality, more specifically the normalized degree centrality for each iKOS entry were also calculated (Wasserman & Faust, 1994). I used degree centrality to understand the prominence of entry modes. At the same time, I calculated the descriptive statistics to calculate the means and standard deviation of the links.

Degree centrality measures how well a node connects to other nodes in the network. Assume that there are g actors in the network. The degree centrality for actor *i* is calculated by summing *i'*s direct links to the rest *g*-1 actors. X_{ij} refers to the number of direct ties *i* has to the g-1 other j actors.

$$C_D\ (N_i) = \sum_{j=1}^{g} x_{ij} (i \neq j)$$

Actor degree centrality depends on the size of the network as it is calculated by adding all the possible links in the network. Therefore, the larger the network, there is a higher chance to be more connected and higher maximum possible degree centrality. To eliminate this affect, I summed all the links associated with one entry and divided this number by the possible number of links this entry could have in the knowledge web to calculate *normalized degree centrality.*

$$C'_D\ (N_i) = \frac{C_D(N_i)}{g-1}$$

Then, all 'individual mean normalized degree centralities' that were associated with one mode of MER were added together. The scores were normalized by dividing it by the possible number of links that entries of particular mode have in the network to calculate mean normalized degree centralities for each iKOS mode. Based on the results, a one way analysis of variance was conducted to evaluate the relationships between the entry modes and their mean normalized degree centralities. Follow up tests were conducted to evaluate pairwise differences among the means associated with each iKOS mode.

Key actor analysis. In a social network, not all connections have equal importance. First, the number of shortest paths between entries and also connections to the representations that is most influential is important. Therefore, key actor analysis was conducted to better understand how different representation types contribute to the knowledge web in different ways. In other words, betweenness and eigenvector centrality measures together reported how these entries play an important role in either bridging different clusters of entries or having ties with other highly linked entries in the network.

To have a better understanding of the actors in the network, I ran the key actor analysis using *R i386 3.0.0* statistical package. Key actor analysis was conducted by calculating two measures: betweenness centrality and eigenvector centrality. *Betweenness centrality* measures the number of shortest paths between pairs of actors in the network (Knoke & Yang, 2007), which makes an actor important in the network by controlling the flow of the information. Assume that we have three actors in the network: *i, j, and k* and *i* wants to communicate with k but it needs to go through *j.* Actor *j* in our case then has the role to control over the content passing to *k.* If the j is in between shortest paths for two other different actors, it has higher potential to control over the network interactions (Knoke & Yang, 2007). Suppose that g_{ik} is the shortest paths between actors *i* and k, and g_{ik} (N_j) is the shortest paths that go through j. Then dividing g_{ik} (Nj) by g_{ik} measures the proportion of shortest paths connecting *i* and *k; where j* is located in between those actors. Then, we sum all the dyads not including the *j*, which indicates how well *j* controls the flow of information in the network (see Knoke & Yang, 2007, p. 67-69 for detailed explanations). Hence, betweenness centrality of j is C_B (N_j):

$$C_B\ (N_j) = \sum_{j<k}^{n} \frac{g_{ik}\ (N_j)}{g_{ik}}$$

Eigenvector centrality on the other hand, measures how central an actor is and how central the ties of this actor are in the network (Bonacich, 2007). Assume that *i and j* are connected by a link a_{ij}=1, if not it is a_{ij}=0. Bonacich (2007) noted that "the centrality of a j is proportional to sum of the centralities of vertices (actors) it is connected. λ is the largest eigenvalue of A and n is the number of vertices" (p. 556). Therefore, eigenvector centrality is calculated by the following formula:

$$\lambda x_i = \sum_{j=1}^{n} (a_{ij} x_j)$$

Betweenness and eigenvector centralities together indicate how well an actor is connected to other actors in the network. Key actor analysis, therefore, is weighted by betweenness and eigenvector centralities, meaning that betweenness and eigenvector centralities were multiplied to calculate a final score for each representation created by a student or students. Appendix B includes the R codes that I used to indicate key actors in this study. Using R, key actor analysis results were reported in a figure. Pearson correlation coefficient was calculated to investigate the relationship between key actor analysis results and mean normalized degree centralities.

Knowledge organization quality analysis. To make a quality judgment about student-created iKOS entries two measures were used: conceptual quality (Linn & Eylon, 2011) and technical quality. The conceptual quality rubric scored the ideas incorporated in the entries. In other words, it indicated the quality of the content in each representation created by students. Technical quality rubric was used to score how well each representation was created to reflect an understanding of the content being organized in the form of a specific representation. These two measures together indicated the Knowledge organization score, in other words quality of the entries were calculated by:

Knowledge Organization Score = Conceptual Quality Score + Technical Quality Score

Conceptual Quality Score. Students' iKOS entries were scored using a specific conceptual quality scoring rubric based on students' normative ideas and elaborated links between these ideas related to content of their entries (Linn, Lee, Tinker, Husic, & Chiu, 2006). The framework used in this current study was modified from Ryoo and Linn (2012). The framework consisted of 5 levels of reasoning. Higher scores indicated more scientifically or socioscientifically elaborated/linked ideas. Appendix C includes scoring rubrics and examples for each entry mode.

Technical quality score. Using keywords for tagging the representations was the fundamental practice for both building knowledge network and organizing knowledge in iKOS system. Students were reminded to use at least 5 keywords to organize knowledge in the specific entry mode. Hence, one point was awarded if the entry did not include any or included 1 keyword, two points for 2-3 keywords, and three points for 4-5 keywords. On the other hand, in Wiki if most of the keywords were related to the content the entry was awarded 3 points, if some of the keywords were related the entry was awarded 2 points and if none of the keywords were related the entry was awarded 1 point. For Event, tags should have been placed accurately in order to depict an understanding of the (socio) scientific phenomenon. Therefore, I used the number of accurately placed key words as an indicator. If most of the keywords were placed accurately, the entry was awarded 3, if some of the keywords were placed accurately the entry was awarded 2 and if none of the keywords were placed accurately the entry was awarded 1 point. For ConceptMap, accuracy of the prepositions was used as an indicator as they connected concepts to depict meaningful understanding of the (socio) scientific ideas. If most of the propositions were accurate the ConceptMap received 3 points, some were accurate awarded 2, and none was awarded 1 point.

A technical quality score was calculated for an entry by adding the score from the number of keywords, and the score from the specific technical quality dimension (Appendix C). Overall, the knowledge organization quality score was calculated as the sum of technical and conceptual quality scores for an individual entry. Then, mean and standard deviations were calculated for knowledge organization quality scores for each entry mode and also for each group in the class. A one-way analysis of variance was conducted to evaluate the relationships between the entry modes and knowledge organization quality scores. Follow-up tests were conducted to evaluate pairwise differences among the means. Finally, Pearson correlation coefficients of knowledge organization quality scores mean normalized degree centralities, and key actor analysis results were calculated.

Analysis for the Second Research Question: The Argumentation Aspect

The second aspect of the phenomenon deals with students' argumentation. There are several frameworks used in science education literature for the argumentation analysis. In this study, I adopt the argumentation analysis framework that was used specifically in prior research investigating the argumentation qualities during SSI learning (e.g., Tal & Hochberg, 2003; Tal & Kedmi, 2006; Zohar & Nemet, 2002). In this framework, argumentation was assessed in terms of (a) the number of justifications, (b) the extent of using scientific knowledge in the arguments, (c) the number of aspects incorporated, and (d) synthesis of counterarguments and rebuttals. I followed the scoring rubric suggested by Tal and Kedmi (2006). Argumentation quality scores can range from 1 to 12 (Table 3).

Student' individually created Wiki entries constituted a data set. Although they were not instructed to do so, students included their arguments to the questions of nuclear energy in their Wikis. Hence, each individual written argument in Wiki was analyzed for each student in two focus groups. Then for each group, mean individual argumentation scores were calculated based on the individual written argumentation scores.

In this part of the study, I focus on two students with different individual knowledge organization scores. These two students were chosen as they were active participants in the unit (i.e., created one iKOS entry on each mode, participated in group argumentation, and presented their groups' final arguments to the class) and had different position on nuclear energy. These two students' written arguments in their wiki and the final arguments they presented on behalf of their groups were analyzed to give a better picture of the improvements on their arguments.

Table 3

Argumentation Quality Analysis Rubric

Criteria	Degree and score			
Number of justifications	None [0]	One [1]	Two [2]	≥ Three [3]
Use of scientific knowledge		Superficial [1]	General [2]	Specific [3]
Number of aspects	One [1]	Two [2]	Three [3]	Four [4]
Synthesis of counter arguments and rebuttals	None [0]	Two counter ideas coexist separately but are not rebutted [1]	A counter argument exists and rebutted yielding a complex coherent idea [2]	

Analysis for the Third Research Question

To understand whether there is an interaction between students' collaborative knowledge organization practices and their argumentation and the nature of such interactions, I used video recordings of group interaction and student created iKOS entries and conducted content analysis.

Summative Content Analysis. Historically, content analysis has been used both for quantitative and qualitative purposes (Berelson, 1952; Neuendorf, 2002). Weber (1990) described quantitative content analysis as "a research method that uses a set of procedures to make valid inferences from text "(p. 9). It aims at categorizing text data into numbers that represent common meanings (Weber, 1990). Recently, there is an increased interest using content analysis as a method of qualitative analysis (Hsieh & Shannon, 2005). Mainly, qualitative content analysis is method of analyzing text data that is in various forms such as in verbal, print, or electronic forms (Hsieh & Shannon, 2002).

In this study, I adopt the perspective of qualitative content analysis suggested by Hsieh and Shannon (2002). They defined the qualitative content analysis as "a research method for the subjective interpretation of the content of text data through systematic classification process of coding and identifying themes and patterns" (p. 1278). Hsieh and Shannon (2002) categorized qualitative content analysis in three categories. 1) Conventional content analysis: The purpose of using this method is to describe a phenomenon using deductive approaches by avoiding preconceived categories (Kondracki & Wellman, 2002 as cited in Hsieh & Shannon, 2002). 2) Directed content analysis: The purpose of using this method is to validate and extend conceptually a theory or a framework. In this process, researchers use deductive approaches. This method is more structured than the conventional analysis as it is guided by preexisting theories or research (Hickey & Kipping, 1996). 3) Summative content analysis: This method involves the quantifying and comparing keywords or content of text and follows a process of interpretation of the content. Hsieh and Shannon (2002) noted that

> The summative approach to content analysis is fundamentally different from the prior two approaches. Rather than analyzing the data as a whole, the text is often approached

as single words or in relation to particular content. An analysis of the patterns leads to an interpretation of the contextual meaning of specific terms or content (p. 1286).

Table 4.

Major Coding Differences among Three Approaches to Content Analysis. From Hsieh & Shannon (2002) (p. 1286)

Type of content analysis	Study Starts With	Timing of Defining Codes or Keywords	Sources of Codes or Keywords
Conventional Content Analysis	Observation	Codes are defined during data analysis	Codes are derived from data
Directed content analysis	Theory	Codes are defined before and during data analysis	Codes are derived from theory or relevant research findings
Summative content analysis	Key words	Keywords are identified before and during data analysis	Keywords are derived from interest of researchers or review of literature

In this study, I used summative content analysis. First, the “text” in this part of the research refers to the student created entries in three iKOS modes and also students’ verbal arguments. To have a better understanding of the interaction aspect, individual entries of focus groups students’ prior to the third session of the study was identified. Then, the content of the entries were identified for wiki and event entries and key words/phrases were identified. As the concept map already included keywords in the nodes, those were directly adopted as keywords.

Figure 11 depicts the process of the interaction analysis. First the content of the representations before the argumentation session were identified for each representation. Then, students’ arguments were transcribed.

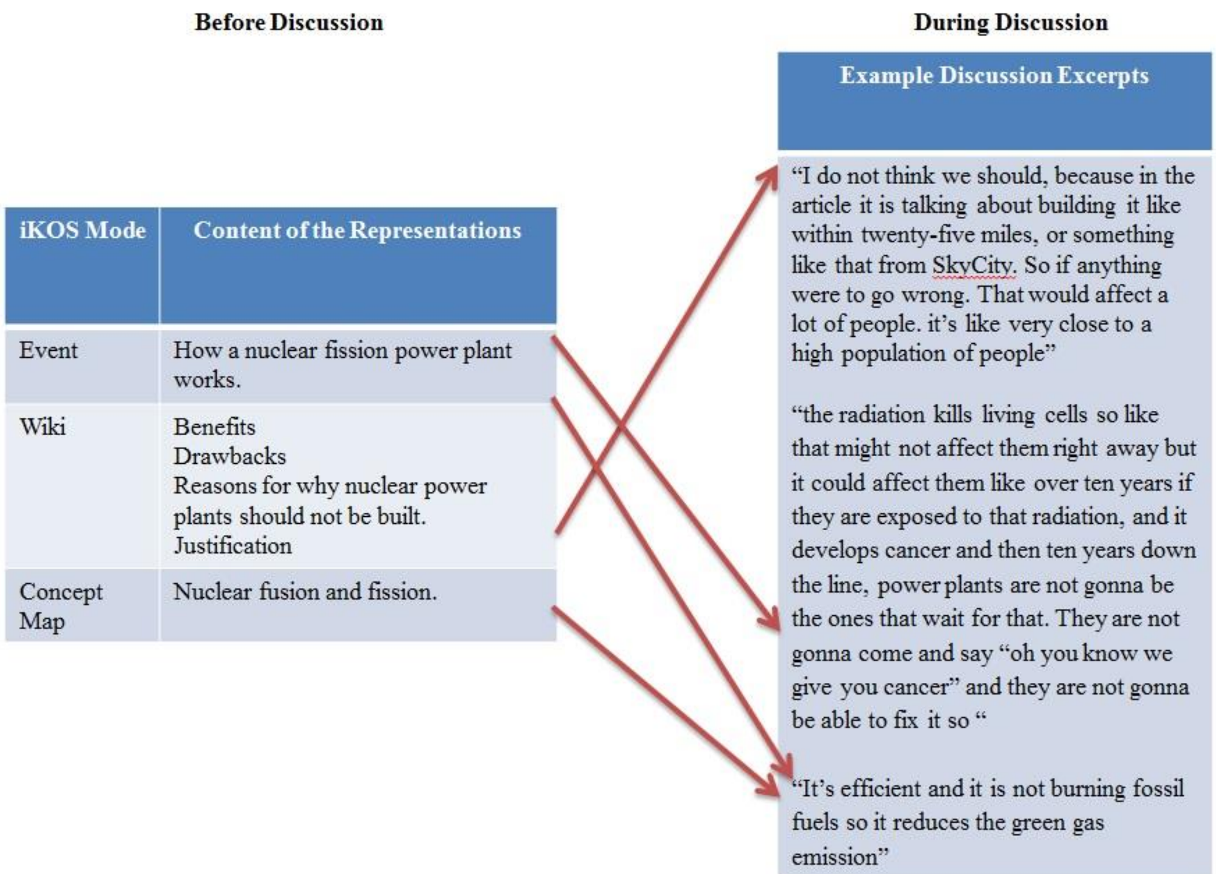


Figure 11. Example coding for the interaction aspect for Haley

Then, the turns identified for each student’ verbal argument. A turn constituted a time frame when a student initiated presenting an idea and finished it. For each turn, the content was coded in a single phrase or a keyword. Then for each possible interaction point, a code for the verbal argument and the codes for the student’s entries were compared. Then based on the similarity of the content, a revised code was generated for the interaction (Table 5). Finally, to understand the interaction between argumentation and knowledge organization, keywords derived from a student’s entry compared to the one in her or his verbal argument, and a code for the interaction was generated. Along with students’ entries and their argumentation, I conducted the same analysis for their collaborative argumentation where they stated their groups’ knowledge organization entries and groups’ final argument.

Table 5.

Example of a Summative Content Analysis Coding

	Student's words	Code for the interaction
Wiki	"the potential release of *radiation* from nuclear power plants is a huge *risk*,"	Risk of radiation release
Verbal argument	"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*"	

For instance, Haley's ConceptMap included a node and wrote "clean energy" Therefore this was used as a key word. In her verbal argument, for instance, she noted

> It [nuclear reactor] is not burning fossil fuels so it reduces like all the green gas emission. But like they said France has the cleanest air out of all the industrialized countries because there are so many power plants.

For this excerpt the keyword "clean energy" is also generated as it talked about the reduction of green gas emission and France is having the cleanest air based on the high percentage of nuclear energy use. Therefore, the interpretation based on this coding was Haley acquired information from her ConceptMap entry and used it in her argument.

Additionally, in this study verbal back channeling instances were identified and number of instances was calculated. Verbal back channeling referred to the instances where a mediated or a non-mediated turn was interrupted verbally by another student. These instances signaled for social interaction during argumentation. As argumentation was approached from a collaborative perspective through the sociocultural lenses in this study, these instances in a way signaled for a social interaction. Here, verbal back channeling instances, therefore, will demonstrate "attentiveness, involvement and alignment with the speaker" (Sawyer & Berson, 2004, p.395)

Overall, different data sources and analysis techniques were used to understand this complex educational phenomenon. Table 6 reports the alignment of research questions, data sources and analysis methods.

Table 6.
Aligning Research Questions, Data Sources, and Analysis Methods

Research Questions	Data Source	Analysis
1.Knowledge organization	iKOS statistical page	1.Descriptive Statistics 2.Cenrality Analysis 3.Key Actor Analysis 4-Quality analysis
2.Argumentation	Transcribed verbal arguments	1.Socio scientific argumentation analysis
3.Knowledge Organization vs Argumentation	iKOS entries Transcribed verbal arguments	1.Knowledge organization analysis 2.Content analysis

Limitations of the Study

This study has several limitations. First, in order to fully understand the nature of knowledge organization with MERs, more complex data analysis strategies should be employed to capture specific actions that were taken by students during the process. Future studies should consider educational data mining and learning analytics strategies to depict this dynamic process in more detail (Gobert, Sao Pedro, Raziuddin, & Baker, 2013).

There are also several limitations in terms of the study design. First, in order to fully understand the progression of students' argumentation, pre-post measures could have been obtained either in the written format or through interviews. Hence, to answer the argumentation aspect of the phenomenon I only relied on those students who represented their groups' final argumentation. On the other hand, the argumentation scoring rubric used for this study does not provide a fine grained analysis for the student who already has a high argumentation quality and what kind of changes occurred in her argument. Also, the sample size is very small, which limits the possible statistical analyses.

There are also several limitations associated with data collection strategies. A limitation associated with video recording as a data collection strategy is that it may alter the naturalistic behavior of participants. Another limitation is the audio quality. The cameras I used built-in microphones and I used table microphones. However, due to the small classroom space and the relatively large number of students, the students' conversations were overlapped in some cases. Another limitation is associated with participant observation. Although there is a direct benefit of participating in the activities from first hand, the limitation associated with this type of observation is that it may have affected the situation being observed and it was limited to what people externally reflect without giving insights about what happens in their minds (Patton, 2002).

One limitation associated with iKOS technology is that it only creates links between two entries when they share the exact same keyword/tag. It cannot interlink entries when they conceptually share the same idea. Future technology design should consider Semantic Web technologies in iKOS (Guarino, Oberle, & Staab, 2009).

CHAPTER 4

FINDINGS AND INTERPRETATIONS

The purpose of this study was to examine the complex educational phenomenon of knowledge organization with multiple external representations (MER) in an argumentation based computer-supported collaborative learning (CSCL) environment. As three aspects were considered in the complex phenomenon, this dissertation study included three research questions (for analyses methods, see Chapter 3). This chapter reports findings to these questions, each in a single section. To answer the first question about the knowledge organization aspect, I mainly describe the phenomenon at the whole class level, including the descriptive statistics of the iKOS entries generated, which included the normalized degree centralities and the key actor analysis results of the iKOS entries, as well as the knowledge organization scores. To answer the second research question about the argumentation aspect, I report two examples of individual students' argumentation performance in different groups and different contexts. To answer the third research question, based on the summative content analysis and using video data as a secondary source, I report the interaction of argumentation and knowledge organization practices employed by two students with different knowledge organization qualities and positions on nuclear energy that situated in two different groups. At the end of this chapter, findings from different research questions are synthesized and interpreted together in order to depict a more holistic picture of the phenomenon investigated.

Research Question 1: Knowledge Organization Aspect

The first research question is “How do learners organize knowledge effectively with MER?” This question includes three sub-questions:

a. What is the most prominent representation type learners create?

b. What are the key actors in the knowledge network?

c. What is the quality of representations created by the students on a given SSI topic?

To answer these questions, I examined the knowledge network in terms of the connectedness of entries using different network indicators and the knowledge organization quality of the entries, based on the conceptual and technical quality measures.

Descriptive Statistics and Normalized Degree Centralities (RQ1a)

A total of 20 students participated in this study. They created 17 Event, 23 Wiki, and 20 ConceptMap entries. The total number of external links for each iKOS mode was as follows: Wiki, 418; ConceptMap, 386; and Event, 180. The result shows that in this sample, the most centralized entry mode was the Wiki mode (mean normalized degree centrality (MNDC) = 0.51, *SD=0.21),* the second most centralized entry mode was the ConceptMap mode (MNDC = 0.49, *SD=0.22),* and the least centralized entry mode was the Event (MNDC= 0.33, *SD*=0.28).

A one-way analysis of variance was conducted to evaluate the relationships between the entry modes and MNDC. The independent variable, iKOS modes, included three levels: Event, Wiki, and ConceptMap. The dependent variable was NDC. The ANOVA was significant F (2, 59) = 5.844, p= .05, meaning that there was a significance difference between centralities of iKOS modes.

Follow-up tests were conducted to evaluate pairwise differences among the means. Because the variances across iKOS modes was somewhat different from each other, I chose not to assume that the variances were homogenous and conducted post hoc comparisons with the use of Dunnett's *C* test, a test that does not assume equal variances across groups. There was a significant difference between MNDC of Event and MNDC of Wiki, also between the MNDC of Event and MNDC of ConceptMap. However, there was no significant difference between MNDC of Wiki and MNDC of ConceptMaps (Table 7); meaning that Wiki and ConceptMap modes served as better representation types to connect entries in the knowledge web.

Table 7.
95% Confidence Intervals of Pairwise Differences in Mean Changes Across iKOS mode MNDC

iKOS Modes	*MNDC*	*SD*	Event	Wiki
Event	.33	.28		
Wiki	.56	.21	-.42 to -.05	
ConceptMap	.55	.25	-.42 to -.04	-.18 to .16

In addition to normalized degree centralities, the density of the network was calculated. The density of a network indicates how well all the actors in the network are connected, suggesting overall connectedness of the network. The density is calculated as the proportion of present links in the network to the total number of links possible. Ideally, if all the 60 entries created in this study would have links (relationships) with each other, there would be 1770 possible links in the network (*d*=1) because in this study the links are undirected [(60*59)/2]. In this knowledge network, *d* was 0.55, meaning that 55% of all the possible links were present. Overall, this result suggested a well-connected knowledge network in this study.

Key Actor Analysis (RQ1b)

MNDC gave an idea about which representation types students mostly relied on in this learning unit as well as the number of entries. They also provided insights about how well those representations are connected in the knowledge network. However, MNDC is limited in the sense that it relies on how many links each entry has without taking into consideration that these links may serve different roles in the whole network. The key actor analysis was conducted to acquire more detailed understanding of the connective features of the knowledge network. Figure 12 shows the results of the key actor analysis weighted by betweenness and eigenvector centralities. Each numbered actor in the figure (e.g., A131) represents an iKOS entry created by a student or students in their groups, and each grey line represents a link between 2 entries. Each iKOS *mode* was represented with a color: Event is red, Wiki is green, and ConceptMap is yellow. Additionally, the diameter of each actor (i.e., entry) was proportional to the product of its eigenvector and betweenness centralities.

The key actor analysis results indicated that 7 Event, 3 Wiki, and 2 ConceptMap entries' centralities were equal to zero, meaning that they were not key actors in distributing the knowledge between entries or having central ties to the important entries in the network (A100=A101=A104=A107=A109=A112=A114=A122=A132=A133=A142=A153=0).

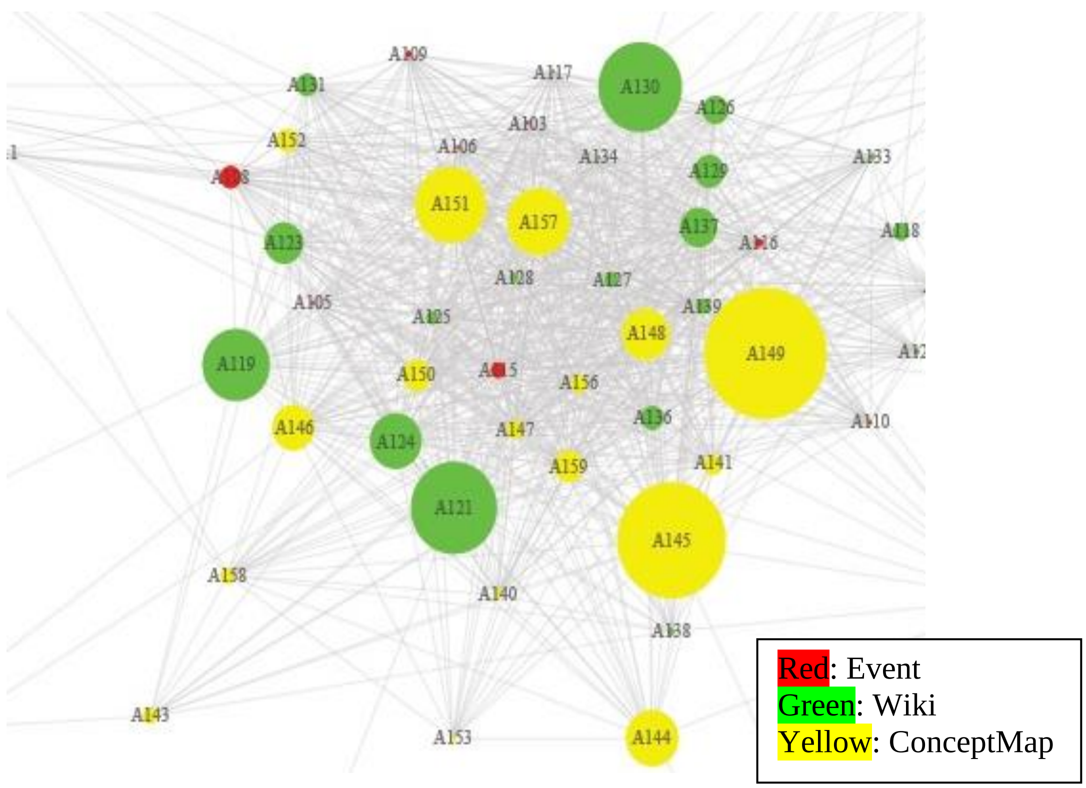


Figure 12. A snapshot of the key actor analysis weighted by betweenness and eigenvector centralities.

The top three key actors in the network were Kristina's ConceptMap, Haley's ConceptMap, and Daphne's Wiki entry. The reason for these representations to be key actors in the network was twofold. First, these entries included popular concepts used frequently by all other students in the classroom. For instance, Haley's ConceptMap included nuclear energy as the central concept, and energy, nuclear fission and nuclear fusion being the branching concepts. Second, these actors were also connected to other key actors in the network. For instance, Daphne's Wiki entry was connected to Group 1's Wiki entry and Haley's ConceptMap, both of which were in the top key actor list. Additionally, the majority of these entries used single words for keywords compared to some other entries that used phrases. In fact, most Event entries included phrases. As phrases varied drastically, even though some of the Event entries demonstrated accurate scientific understanding they were not connected to other entries in the network.

Correlation coefficient was computed among the key actor analysis and MNDC results, $r(58) = .56$, $p<.005$. A p value of less than .005 (.01/2) was required for significance. The result of the Pearson product-moment correlation was significant, indicating that higher or lower degree centralities similarly indicated higher or lower key actor analysis results.

There was a non-linear relationship between these two measures. Close examination of the results for key actor analysis and degree centralities, however, depicted different results. For instance, the normalized individual degree centralities of the top 25% of the entries in the key actor analysis were identified. Results indicated that out of 15 key actors 8 of them also had the highest degree centralities.

Knowledge Organization Quality Analysis (RQ1c)

Even though the centrality measures and the key actor analysis indicated the connectedness of entries and the most prominent representation types that the students created, they did not reveal whether the students incorporated scientifically valid and elaborated ideas in these entries. Hence, each entry was assessed based on two measures to calculate knowledge organization quality: conceptual and technical quality (Appendix C).

The knowledge organization quality score ranges from 3 to 11. The possible maximum score was 11: 5 points from conceptual quality scoring and 6 points from technical quality scoring. As long as an entry was created, the minimum score was 3: 1 point from conceptual quality and 2 points from technical quality scoring (1 from the number of keywords, and 1 from the attribute of a specific entry).

The mean knowledge organization quality scores were calculated for each iKOS mode. Overall, the mean knowledge organization scores were 5.76 (*SD*=3.11) for Event, 7.70 (*SD*=2.07) for Wiki, and 7.65 (*SD*=2.67) for ConceptMap modes for this study.

A one-way ANOVA was conducted to evaluate the relationships between the entry modes and knowledge organization quality scores. The independent variable, iKOS modes, included three levels: Event, Wiki, and ConceptMap. The dependent variable was knowledge organization quality score. The F test was significant F (2, 59)= 3.36, p= .042, meaning that the knowledge organization scores differed across iKOS modes.

Follow-up tests were conducted to evaluate pairwise differences among the means. Because the variances across iKOS modes was somewhat different from each other, I chose not to assume that the variances were homogenous and conducted post hoc comparisons with the use of Dunnett's *C* test, a test that does not assume equal variances across groups. The mean knowledge organization quality (MKOQ) scores for Event and ConceptMap, and Event and Wiki differed significantly at $p < .10$; the score for ConceptMap and Wiki was not significantly different from each other.

Table 8

90% Confidence Intervals of Pairwise Differences in Mean Changes Across iKOS mode Mean Knowledge Organization Quality (MKOQ)

iKOS Modes	*MKOQ*	*SD*	Event	Wiki
Event	5.76	3.11		
Wiki	7.70	2.07	-3.84 to -.02	
ConceptMap	7.65	2.67	-3.97 to .20	-1.61 to 1.52

For each group, the students' mean *individual* knowledge organization quality scores prior to the third session were calculated (Table 9). These scores did not include entries students created in the class collaboratively. Due to the number of students who did not create Event entries prior to the third session of this study, the mean knowledge organization quality score for Group 1 was 0.7 for the Event entries. On the other hand, 5 of the 6 students in Group 2 created Event entries and all of them received the lowest knowledge organization quality score of 3 because they did not include tags to organize knowledge. The highest mean knowledge organization quality score for Wiki entry was 8.8 for Group 3 and 9.2 for ConceptMap entry in Group 2. Only one student in Group 3 created a ConceptMap prior to class session. Therefore, the mean knowledge organization quality score was 2.2.

Table 9.

Mean Individual Knowledge Organization Quality Scores for Each Group

Groups	Event	Wiki	ConceptMap
Group 1	0.7	6.0	5.0
Group 2	2.4	7.8	9.2
Group 3	5.0	8.8	6.6
Group 4	4.4	4.2	2.2

Interpretation

Overall, the knowledge web generated as a result of this intervention was highly connected. The result suggests that the students may be mindful in inserting keywords or tags for the entries they created. However, this could also be a natural outcome of the iKOS design. In other words, the findings of the social network measures are constrained by the design of iKOS. One of the design principles of the iKOS technology and the nuclear energy unit was to engage a community of students in creating a well-connected knowledge web. Accordingly, the iKOS environment automatically linked students' entries based on the shared tags and keywords. As long as the same word is shared by two entries as keyword, they are considered "connected." These keywords could be any words (as they were ultimately generated by the users), therefore increasing the likelihood of entries being connected. On the other hand, two entries are connected if and only if they share at least one *exact* keyword. The system cannot interlink two conceptually similar/linked entries if they do not use the same words as keywords. For instance, if a student created an entry on nuclear fission and used the tag 'fission' and another student created the same entry but used the tag 'splitting' these entries would not be linked to each other. This will, in fact, decrease the likelihood of entries being connected. This technical deficiency may be resolved in the future by incorporating the Semantic Web technologies in iKOS (Gruber, 1993; Guarino, Oberle, & Staab, 2009). In sum, future research and development should attend to more meaningful connections among entries.

The descriptive statistics results showed that Wiki was the most created entry type, followed by ConceptMaps. This suggests that Wiki may be the most preferred representational mode among the three for this class. This makes sense because technically, Wiki is the easiest and most familiar entry type (i.e., essay writing) for students. Although all of the three iKOS modes were introduced from the technical aspect, concept mapping was emphasized in the unit from a pedagogical aspect (see Table 2). Therefore, the students were also familiar with creating concept maps. Future design needs to make the Event entry easier to generate and future instruction need to help students better utilize this mode. For instance, students should be instructed to how to tag and annotate the pictures; how to use these annotations to highlight the important parts of the picture and use these annotations as evidence for generating arguments.

Although the number of entries created was very close to each other for the three modes, the number of links was not: Wiki and ConceptMap mode had more links than the Event mode. Moreover, both ConceptMaps and Wiki entries were more central than the Event entries based on mean normalized degree centrality measures (Table 7). This result is almost natural as Wiki and ConceptMap representation types are fundamentally lexicon-based, whereas Event representations are picture-based. Practically, Wiki and ConceptMap are better means for students to integrate ideas that are expressed in words. Considering that picture is an important medium in knowledge acquisition (Mandl & Levin, 1989), more instruction needs to be devoted to help students better incorporate pictorial representations in knowledge organization and expression. For instance, as pictures are more concrete than words, students may think it is unnecessary to explicitly tag them to point out the important aspects in the picture. But they need to realize that pictures are vaguer than words.

The results of key actor analysis showed that similar to the degree centrality measure, ConceptMaps and Wiki entries included more popular tags and keywords that created shortest links and connected important actors in the overall knowledge web. The reasons for this finding might bethe same as Event being least connected in terms of the degree centralities.

Further analysis indicated that there was a medium correlation between MNDC and key actor analysis results. Close examination of the findings indicated that the top entries in based on these two different measures were also different. This finding is important because it suggests students' contribution to the knowledge web that was created.

Epistemic artifacts such as external representation has been promoted to further knowledge creating in CSCL environments (Scardamalia & Bereiter, 2006). This practice challenges the constraints of verbal and written contributions to the conceptual understanding in science classrooms. Hence, it becomes important to apply different techniques to look at different levels of contributions to creation of a knowledge web. Therefore, the results suggested that although the students' entries did not have the highest degree centralities in the network, key actor analysis results indicated that they could be important entities that bridge knowledge representations, have important connections with the other key actors, and make significant contribution to the overall knowledge network.

A student who has inaccurate information on his or her entry may include popular keywords (i.e., central keywords that are highly relevant to the topic of the study such as fusion, fission, energy etc.), which can make it a highly centralized entry in the network. Hence, knowledge organization quality analysis was conducted to provide further insights about students' knowledge organization. The quality analysis indicated that, overall, the students organized knowledge with Wiki and ConceptMap entries were significantly better than in their knowledge organization with Event entries. This result might have emerged from students' familiarity with these two tools as discussed. Moreover, most of the Wiki entries included students' arguments. As students instructed on argumentation, this might have increased the quality of knowledge organization in Wiki mode. Overall, there were no significant correlations between either knowledge organization quality and MNDC or knowledge organization quality and key actor analysis results.

Research Question 2: Argumentation Aspect

This section reports relevant findings to answer the second research question of this study, the argumentation aspect: What is the quality of student generated arguments on a given SSI topic? To accommodate the complexity of the learning unit that involved argumentation at multiple levels (the individual and group), I focused on the argumentation of selected individual students situated in groups to address this research question.

To assess the argumentation quality prior to group discussion (i.e., the third session of the study), I relied on the students' Wiki entries since most students wrote their arguments in their Wiki entries despite the fact that they were not instructed to do so. I scored each individual student's Wiki entry based on the criteria proposed by Tal and Kedmi (2006): (a) the number of justifications; (b) the extent of using scientific knowledge in the arguments; (c) the number of aspects incorporated; and (d) synthesis of counterarguments and rebuttals (p. 634). The total score may range from 0 to 12; each criterion ranging from 0 to 4. The mean score was calculated for each group to provide a context of the class to the reader (Table 10).

Table 10.

Mean Individual Written Argument Qualities Prior to Group Discussion

Groups	Number of justifications	Scientific knowledge used	Number of aspects	Synthesis of counterarguments	Total (out of 12
Group 1	1.0	1.7	1.2	0	3.9
Group 2	1.3	1.8	2.1	0.1	5.3
Group 3	1.3	2.0	1.8	0.8	5.9
Group 4	2.0	1.7	3.0	1.0	7.7

Results indicated that the average written argumentation quality score was the highest for Group 4 (*M=7.7)* and the lowest for Group 1 (*M= 3.9*). It is apparent from the results that the use of scientific knowledge was superficial and students' written argumentation lacked synthesizing of counterarguments.

To give a better picture of how the students' argued in different contexts, two students were identified: one from Group 2 and one from Group 4. One criterion was that they created entries on all three iKOS modes before coming to the class in each group. This was necessary because I wanted to depict the changes in these two students' argumentation, who actively participated in the unit based on the given instruction. The other criterion was that the students represented their group for their final presentation. This criterion was also necessary to capture students' argumentation qualities after their engagement in collaborative knowledge organization. As a result, I identified Elizabeth (Group 2) and Haley (Group 4).

It happened that Elizabeth had the lowest knowledge organization quality score (i.e., 3 for Event, 4 for Wiki, and 7 for ConceptMap) (see the section on research question 3) in Group 2, and Haley had the highest knowledge organization quality score (i.e., 9 for Event, 11 for Wiki, and 11 for ConceptMap) in Group 4. Interestingly, it also happened that the mean individual knowledge organization score for Elizabeth's group (Group 2) was the highest and Haley's group (Group 4) was the lowest among the four groups. Haley's ConceptMap entry was also one of the top key actors in the knowledge network whereas Elizabeth's was not. This is analogous to scenarios of a "high-performing student" (Haley) in a low-performing group and a "low-performing student" (Elizabeth) in a high-performing group (here, "high/low-performance" only refers to students' behaviors and practices related to knowledge organization and argumentation relevant to the unit).

In the following sections I examine these two students' argumentation practice one after the other. First, Elizabeth and Haley's written arguments in their individually-created Wiki entries were further analyzed to illustrate their argumentation quality before they engaged in the group activity in the third session. Then, the students' final verbal arguments during their group presentation were analyzed. I want to make it clear that the examination of these two instances (pre-discussion and final presentation) aimed to depict the argumentation quality the students exhibited at two different times with very different contexts in the unit. This did not mean to attribute any changes in the pre/post comparison to the effect of the unit, but hopefully gave a more holistic picture of student generated arguments based on the knowledge organization practices that took place in different contexts: individually at home and collaboratively in the classroom.

Elizabeth's Argumentation

In Group 2, Elizabeth was one of the students who actively participated in the group discussion, presented her group's collaborative knowledge organization entries to the class, and finally stated the group's position about the construction of the proposed nuclear power plant in their State. Prior to the class before the third session, Elizabeth claimed in her Wiki "I think that nuclear power is good as an alternative energy source. It shouldn't be our only source of power, just as coal should not be our only source of power." [Elizabeth, Wiki, Prior to class discussion]. For this claim she included one justification in her argument "I believe *it is most sustainable to have a variety of energy sources"* (1 point for number of justification). In terms of the use of scientific knowledge this argument was very superficial as she did not support her justification with specific scientific knowledge (1 point for use of scientific knowledge). This argument only included one aspect of the nuclear energy issue, namely the environmental aspect (1 point for number of aspects included). The argument did not consider any counter arguments and rebuttals (0 point for synthesis of counterarguments and rebuttals). Overall, the argumentation quality (a score of 3) was very low for this written argument.

In the fourth session of this unit, Elizabeth presented Group 2's position to the class. After she gave specific and scientific details about the *fission process* (3 points from use of scientific knowledge), she stated her group's argument as "so the nuclear fission is a source of clean energy, when it happens it releases heat and energy. *We are pro nuclear energy."* She used three justifications for her argument in addition to the scientific explanation of nuclear fission: "*clean burning energy source," "readily accessible" and "good alternative energy source"* (3 points from the number of justifications). The aspects she included in her argument were safety and environmental aspects (2 points from the number of aspects). Finally, Elizabeth's argument included one counterargument. She stated, "*I think yes, there is a probability of some things bad might be happening.*" Elizabeth continued to rebut the counterargument as she noted " … *but like she [Haley] said, they have measures in place for safety and quite honestly ones that happened are freak accidents that can happen to us any time and place, it does not have to be nuclear power."* This argument indicated that Elizabeth was able to use a counterargument to rebut the ideas to yield a complex and a coherent position of why her group is pro-nuclear energy (2 points from synthesis of counterarguments). Overall, the final argument was scored 10 out of possible 12 points. This final argument of Elizabeth indicated that Elizabeth, while presenting to the whole class and representing her group, incorporated more scientific ideas and justifications including a counterargument to make the argument more convincing.

In sum, Elizabeth improved her argument about the use of nuclear energy from when she was writing her individual Wiki entry to when she was reporting her group's position to the whole class. The improvement included the following aspects: incorporating more specific scientific knowledge (nuclear fission process), including additional justification (nuclear energy being a clean energy source) without abandoning her own justification (nuclear energy being a sustainable energy source), and integrating a counterargument (risk of nuclear energy) and its rebuttal.

Elizabeth had the lowest knowledge organization score initially, and her individual argument in her wiki had superficial use of scientific knowledge. The collaborative knowledge organization on the nuclear fission topic specifically enabled Elizabeth to consider nuclear fission process and support her argument with specific scientific knowledge. Prior to collaborative knowledge organization her argument included a justification about the sustainability of nuclear energy. However, when she was presenting her groups' argument she was able to incorporate an idea about nuclear energy being a clean burning energy source based on their collaborative knowledge organization about fission. She incorporated this idea based on her groups' knowledge organization on nuclear fission without abandoning her individual justification about nuclear energy being an *alternative energy source*.

Haley's Argumentation

In Group 4, Haley was the person who dominated the group discussion and stated the groups' final argument to the whole class. In her Wiki, which she created before coming to the class in the third session, she stated that she was against the nuclear power plant construction in the state she lived. She listed multiple justifications to her claim: difficulty storing the radioactive waste, danger of nuclear weapons, and the effect of low-levels of toxins are released in the ground that could affect drinking water and cause health problems to the people living around the power plant, potential accident can release lethal amounts of radiation (3 points from the number of justifications). She also included four aspects in her argument about the construction of a power plant: economical, biological, social and cost (3 points from the number of aspects included). She also noted that nuclear energy "*eliminates burning fossil fuels which decreases the amount of carbon dioxide release in the atmosphere."* Haley used this justification as a counter argument that yielded a complex idea. She stated "*while nuclear energy is a relatively clean energy source,* the potential release of radiation from nuclear power plants is huge risk" (2 points from synthesizing counterarguments in the argument). The only weak area in her argument was that in terms of using scientific knowledge, she did not include specific scientific details in her argument (1point from the use of scientific knowledge). Overall, this argument was a high quality one (11 out of 12 points from the argument quality scoring).

The final presentation was dominated by two students in this group, Raina and Haley, while other students were participating in the explanation phase and technical issues such as showing the entries to the class. In their final presentation, Haley argued that her group was against nuclear power and she included multiple justifications such as *risking a lot for a little amount of energy, cause of cancer, danger of natural disasters* (3 points from number of justifications). In her argument she used specific scientific knowledge about ionizing and non-ionizing radiation and how those caused cancer (3 points from use of scientific knowledge). For instance Haley stated that

[Excerpt 1. Transcripts 09/04/2013. Video Group Presentation: 21:51-22:00]

> Ionizing radiation, which is present in the nuclear reactors, will cause cancer because it's such a high frequency that has power to alter cells, either kill them completely or just damage them to form mutations, which will cause cancer.

In terms of the aspects included in her argument she mentioned the *health issues, physical and biological aspects* (3 points from number of aspects). She included a counterargument and mentioned that

[Excerpt 2. Transcripts 09/04/2013, Video Group Presentation: 21:04-21:18]

> Not all the radiation necessarily cause cancer or kill you. So there are two types [of radiation]: ionizing and non-ionizing. Non-ionizing is the type we are mostly familiar with, like the microwave or the radio waves, and because it is *such a low frequency it is not enough energy to penetrate through your skin cells* and damage your DNA.

This counterargument rebutted the initial argument (2 points from synthesizing counterarguments). Overall her argument was scored 12.

In sum, Haley improved her argument about the use of nuclear energy from her written argument in her wiki to when she was reporting her group's position to the whole class. The improvement included the following aspects: incorporating more specific scientific knowledge (the ionizing and non-ionizing radiation). Haley also did not abandon her initial justifications about nuclear energy. She incorporated her initial ideas about *health issues, amount of energy generated* by this process, and the *potential hazards* into her final argument for the group.

Interpretation

Table 11 summarizes the two students' argumentation performance in two different contexts. Overall, the results indicated that prior to the small group discussion, the students' often failed to incorporate specific scientific knowledge in their individual argumentation when they were not specifically instructed to do so. However, when the students were instructed to focus on a scientific aspect of the given SSI and engaged in collaborative knowledge organization and argumentation practices, they used specific scientific knowledge during their final presentation.

In both cases, the students were incorporating ideas and justifications from their individual knowledge organization into their final argumentation. The result may suggest that with the help of collaborative knowledge organization and argumentation students were able to incorporate distinct ideas and use them in their final argumentation without abandoning their initial justifications about the issue. Then, they were able to synthesize their knowledge from individual and collaborative knowledge organization to present a more holistic argument considering different perspectives and scientific knowledge.

Table 11

Elizabeth and Haley's Argumentation in Different Contexts

	Argumentation prior to group discussion	Argumentation in class presentation
Elizabeth in Group 2	-The group had a mean argumentation score of 4.4 -Her Wiki entry received an argumentation score of 3 -Her argument included 1 justification, generic use of scientific knowledge, and one aspect. No counterargument incorporated.	-Her group Wiki entry only incorporated a scientific explanation about nuclear fission -Her verbal argumentation received an argumentation score of 10 -Her verbal argument increased the number of justifications and multiple aspects included, incorporated a counterargument, and used specific scientific knowledge
Haley in Group 4	-The group had a mean argumentation score of 7.7 -Her Wiki entry received an argumentation score of 10 -Her argument included 3 justifications, generic use of scientific knowledge, and multiple aspects. Counterargument incorporated	-Her group Wiki incorporated examples and scientific explanations. -Her verbal argumentation received an argumentation score of 11 -Her verbal argument used specific scientific knowledge.

Overall the two contrasting episodes, namely the students with high and low knowledge organization qualities were examined under different contexts to depict potentially different argumentation practices employed by the students. Results indicated that the student with the initial low argumentation and knowledge organization quality (Elizabeth) was able to incorporate more justifications, aspects and a counterargument in the argument when she was presenting her group's position. On the other hand, both students used more specific scientific knowledge in their final arguments. Haley, who had high knowledge organization score, was also able to maintain her high argumentation quality score when she was presenting her groups' argument.

Research Question 3: Interaction Aspect

The results of this section will be reported in four subsections regarding the interaction between knowledge organization and argumentation. In terms of how knowledge organization mediates argumentation, I report the ways students used MER to mediate argumentation. Also, I report how mediated turns by MER support argument components. Next, I report how argumentation fosters knowledge organization practices. Finally, verbal back channeling events were identified. Results are interpreted at the end of this section.

Theme 1. Different ways of using MER to mediate argumentation

The results of the content analysis and the video data indicated that the students benefitted from knowledge organization to mediate argumentation practices in three different ways. First, the students' argumentation in these groups was implicitly mediated by the information included in individually created iKOS entries. During these instances the students were not looking at their entries but drawing information from their entries when arguing. Second, the students' argumentation in these groups was explicitly mediated by the information included in collaboratively-created entries when these students were asked to present groups' arguments to the class. Third, the ways in which the students coordinated information in different representational modes differed in two different contexts: creating representations individually when they were asked to learn and organize knowledge about nuclear energy without any topic constraints, and creating entries collaboratively to learn more about a specific scientific aspect of nuclear energy.

Implicitly mediated argumentation with MER

The students were asked to argue on the following two questions in their small groups: 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 3. Transcripts 09/01/2013: Group 4 Video: 04:35-05:32; Italicized texts indicate where Haley was drawing information from her Wiki entry she created prior to class]

(1) 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 very close to a high population of people*.

[Ashley: Yeah]

Haley: That would affect a lot of people.

Researcher: What would be the effect?

(2) 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.

Although video data showed that none of the students in Haley's group were looking at their individual iKOS entries on the computer screen during this conversation, careful content analysis indicated that the students' argumentation was mediated by the information contained in their iKOS entries. For instance, in excerpt 3 it can be inferred that Haley drew information (Turn 1 and 2) from the Wiki entry she created prior to class in which she mentioned "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 miles from Sky City makes it a potential hazard to a large population of people."

Similarly, Haley's turns were also mediated by the information that she included in her ConceptMap.

[Excerpt 4. Transcripts 09/01/2013 Video Group 4: 2.26-3.14; 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 gonna think that it is ok and are gonna develop the ways to

Melissa: Destroy us

(8) Haley: Yeah, like, you know, obviously atomic bomb is created from the process of *nuclear fission* so if you now if people that's gonna end 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* like all the *green gas emission* and all that [in audible]. But like they said France has the cleanest air out of all the industrialized countries because there are so many power plants.

Excerpt 4 illustrates that Haley also acquired information from her ConceptMap entry (turns 8 and 9) when they were asked to argue on the given open ended questions. In her ConceptMap she included “plentiful electricity” and “clean energy” as the benefits of 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.

Whereas Haley was dominating the group discussion by presenting claims and justifications to her argument in Group 4, there were three students who actively participated in the argumentation in Group 2: Elizabeth, Brandon, and Tim. Results showed similar patterns in term of implicitly mediated turns during the small group argumentation. When the students were asked to argue on the two open-ended questions about nuclear energy in their small groups, Brandon initiated the group argumentation and Elizabeth was an active participant in the discussion.

[Excerpt 5. Transcripts 09/04/2013 Video Group 2.2 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 of *alternatives* to go with, *solar*, *wind*, *and geothermal*.

(2) Elizabeth: I think that it is a good “*alternative” energy source*. It s*houldn’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 like we can't depend on one thing. Some coal, some hydro, some wind, some thermal

Excerpt 5 indicates that Brandon (Turn 1) and Elizabeth's (Turn 2) turns were implicitly mediated by their individual knowledge organization entries. Brandon (i.e., who included the ideas of alternative energy sources of solar, wind, and geothermal in his Wiki entry) started the group discussion with the same argument. Elizabeth, on the other hand, brought her ideas that she included in her Wiki: 1) nuclear energy being an alternative energy source and 2) having a variety of energy sources for making energy use sustainable. Similarly, the students' argumentation was also mediated by their concept maps.

Tim, for instance, was able to acquire some information from his ConceptMap, as in turn (13), in which he included the ideas of nuclear energy being clean and safe, even though he could not fully elaborate on the idea.

[Excerpt 6. Transcripts 09/04/2013 Video Group 2.2 03:45-03.55 Italicized texts indicate where Tim was drawing information from his ConceptMap entry he created prior to class]

(13) Tim: I did a research and I typed nuclear energy for kids just to go down to basics. I don't know much about nuclear energy. But I found it was *safe, clean*. There is more natural ways than burning coal. I don't know if you all talked about this so far.

Overall, implicitly mediated turns only occurred in Haley's turns in Group 4. Her argumentation included seven Wiki-mediated and four ConceptMap mediated turns. There were also five non-mediated turns, meaning that the turns did not include any information that was already embedded in her entries. In Group 2, on the other hand, Elizabeth's argumentation included one Wiki mediated and five non-mediated turns; Brandon's included two Wiki mediated and one ConceptMap mediated turns, and six non-mediated; Tim's included one ConceptMap mediated and one non-mediated turns.

Explicitly mediated argumentation with MER

After the students finished organizing their knowledge collaboratively on a specific scientific aspect of nuclear energy, the students were asked to present their findings and their final arguments on the issue to the whole class. Raina started to present her groups' arguments by stating how ionizing radiation damages DNA and causes cancer. Moving to their Wiki entries Raina started to talk about the radiation emitted from nuclear power plants and how that causes cancer. She also gave some examples to further support their groups' position about the radiation and cancer.

[Excerpt 7. Transcripts 09/04/2013 Video Group Presentation 19:09-20:41 Italicized texts indicate where Raina was drawing information from her groups' Wiki entry explicitly]

> (2) Raina: The *radiation emitted from a nuclear power plant is ionizing radiation* and it is high frequency radiation that removes electrons from atoms or molecules. It can mainly *damage DNA causing cancer or death of the cell*. It can happen within split seconds. Cancer can take years to fully develop. And then we talked about exposure to radiation and how workers at the nuclear plants are more exposed and the areas around the nuclear plants are more exposed [to radiation] and then the areas around nuclear sites are exposed. Back in the *60s prior to military did nuclear testing exercises out in the west and those military people and personals were exposed to high levels of radiation*. There was so much radiation it can still be detected in the soil today. There are small amounts of radiation in house hold appliances. If you use tobacco there can be little bits of radiation there. Because of the soil that is growing in. There are also small amounts of

radiation in smoke detectors but it's sealed in a little container so it is not supposed to be leaking so they do not cause cancer.

After Raina finished explaining how radiation caused cancer on a molecular and cellular level (turn 2), she gave examples for radiation types and argued that a small amount of radiation does not cause cancer. Raina's turns were explicitly-mediated by the entries created by the group. When Haley was presenting the group arguments to the class her turn was mediated by the ConceptMap entry she created for her group.

[Excerpt 8 Transcripts 09/04/2013, Video Group Presentation 20:51-21:58 Italicized texts indicate where Haley was drawing information from her groups' ConceptMap entry explicitly]

(3) Haley: Not all the radiation necessarily cause cancer or kill you. So *there are two types [of radiation]: ionizing and non-ionizing*. Non-ionizing is the type we are mostly familiar with like the *microwave or the radio waves* and because it is such a *low frequency* that it is not enough energy to penetrate through your skin cells and damage your DNA. Ionizing radiation which is present in the nuclear reactors will cause cancer because it's such a *high frequency* that has a power to alter cells, either like kill them completely or just damage them that form mutations, which cause cancer. Most common affected cells are *bone marrow cells and your thyroid gland cells* which is like right here, which is the most exposed to, closest to your skin and um so like the most common type of cancers are leukemia.

Excerpt 8 indicated that Haley was able to draw information from her group's ConceptMap in which they stated that ionizing radiation causes cancer, and high frequency radiation has enough energy to damage DNA in cells (turn 3). She used the information in the entry to convey her group's message about their argument on nuclear energy use. Haley, then, explicitly stated her groups' claim based on my instruction.

[Excerpt 9 Transcripts 09/04/2013 Video Group Presentation 23:16-23:41]

Researcher: Do you have any sort of consensus?

(9)Haley: We are against it.

Researcher: Is it because of the radiation effect?

(9)Raina: Yeah and it is like one of the things we read is that a very small percent of the energy is produced [by nuclear power plants] so it seems like you are risking so much for not a lot of energy.

Different from their individual practice, Raina and Haley were showing their entries during their presentations as reference points. This practice constituted the explicitly-mediated argumentation. Overall, Rachel continually pointed to the pictures that her group included in their Event entry. As the event entry included multiple pictures and Rachel pointed to those during her discourse, her turns were explicitly mediated 4 times by her group's Event entry. On the other hand, when she was presenting the Wiki, there was only one turn she took without any back channeling instances where the students' turns were verbally interrupted by another student. When Haley presented the ConceptMap, she also took 2 turns and these turns were mediated by the collaborative knowledge organization entries. However, the students were not instructed to do so during their individual argumentation at the beginning of this session. The non-mediated turns occurred after Haley finished presenting her group's ConceptMap. During this time, she took 4 non-mediated turns.

Group 2 also showed similar instances in terms of explicitly mediated turns. Elizabeth initiated the group's presentation and explained the process of nuclear fission. First, she started showing the Event entry and explaining the process. However, when she opened her group's Wiki entry, she remembered that she forgot to mention about chain reaction.

[Excerpt 10 Transcripts 09/06/2013 Video Group 2.4 00:15-01.29 Italicized texts indicate where Elizabeth was drawing information from her groups' Event and Wiki entries explicitly]

(2)Elizabeth: You start off with *uranium 235* and then y*ou 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.* So that is the basic principle we put in our Event. The same thing but in a Wiki, if you better in reading, this will do the work. Oh I forgot to mention, *when it splits it releases heat and energy where nuclear energy comes* from but then I forget what was it called, there is a principle that where it continues splitting.

Students: Chain reaction.

Instructor of the course: So the nuclear fission is a source of clean energy. When it happens it releases heat and energy so now you have a crash course on nuclear energy.

Excerpt 10 indicates that Elizabeth was able to draw information from her group's knowledge organization and use it in her explanations (turn 2). Elizabeth finally stated:

[Excerpt 11 Transcripts 09/01/2013 02:31-03.05]

Elizabeth: We are pro nuclear energy. I think it is a clean burning energy source. I think yes, there is a probability of some things bad happening but like she [Haley] said, they have measures in place for safety and like quite honestly ones that happened freak accidents that can happen to us any time and place, it does not have to be nuclear power. I think it is a good alternative energy source. I don't think it should be the only thing we are dependent on but we should not only be dependent on coal and oil. I think, you know, we need an energy source, it is clean burning and readily accessible.

Excerpt 11 also indicates that the students not only benefited from their individual and collaborative knowledge organization in their scientific explanations, they also use those knowledge entries to further argue their stance on a given SSI. However, the quality of the argumentation practice varied.

Elizabeth was the only student who presented Group 2's knowledge entries to the class. Video data indicated that her turns were explicitly-mediated 2 times by Event, 2 times by Wiki, and 2 times by ConceptMap; as she was explicitly showing these entries to the class and pointing to the representations as she talked. She had 4 non-mediated turns during this final presentation.

Coordinating information across different representations

The analysis also showed interesting results in terms of how the students organized knowledge in two different times and contexts with MER. When the students were asked to organize knowledge as homework, each student included different information across different iKOS modes. For instance, Haley created one entry on each iKOS mode. In her Event entry, she inserted a picture of a nuclear power plant and focused on how this power plant worked. The picture already included tags showing the parts of the power plant. Instead of using keywords for her tags, Haley used phrases. She used her own tags to further explain some of the keywords included and processes depicted in the picture (Figure 13).

For instance, the picture itself included a keyword: 'fuel rods.' Haley inserted a tag and used an arrow pointing to the rods, and wrote 'Uranium 235, source of fuel.' Although some of her tags specifically elaborated on the parts of the nuclear power plant, she also included one tag to elaborate on a scientific phenomenon. She explained that through the heat exchanger, "heat is transformed into electrical energy.” However, one of her tags was inaccurate: She tagged the transformer in the picture and wrote “transforms electrical energy into power;” but in fact, a transformer functions as a voltage converter. Therefore, the conceptual quality score for this Event entry was 3 as the entry included appropriately placed tags and the ideas displayed in the tags were partially correct. The Event entry included a total of five tags and all the tags were accurately placed in the picture. She received the maximum score of 6 for the technical quality. Overall, the knowledge organization quality score for her entry was 9 out of 11.

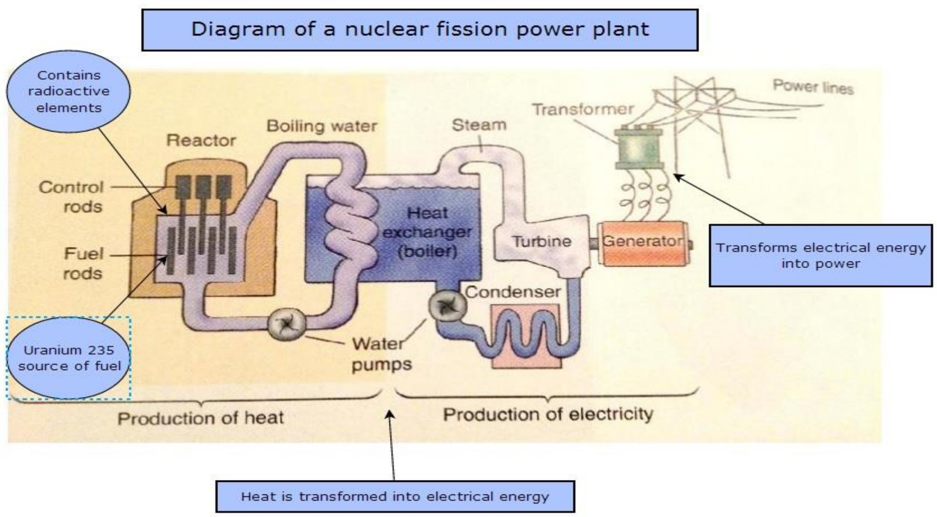


Figure 13. Haley’s event entry prior to the group discussion

In her long Wiki entry, Haley listed the benefits and drawbacks of nuclear energy, and wrote her claim to answer 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].

The conceptual quality score for this Wiki entry was 5, as she connected her scientific ideas about radiation and socioscientific ideas of having inadequate safety measures and technological support to integrate her multiple accurate ideas in her argument. The technical quality score was 6 as it included more than 5 tags relevant to the content of the Wiki entry. Overall, the knowledge organization quality score was 11 for Haley's Wiki entry.

Haley's ConceptMap entry (Figure 14) included in the center the topic "nuclear energy" and two core ideas "nuclear fission" and "nuclear fusion" were directly linked to "nuclear energy." She elaborated on the nuclear fission concept by indicating that it causes nucleus of an atom to separate and releases an enormous amount of energy in the form of kinetic energy. She also listed creating clean and plentiful electricity as the benefits of nuclear energy, and nuclear weapons and risk of releasing radioactivity as the drawbacks of the nuclear fission. She elaborated on the nuclear fusion concept that it causes two nuclei to fuse together which requires an extremely high temperature and also which releases energy. She also inserted a crosslink between nuclear fission and fusion concepts and wrote that nuclear fusion is the opposite of nuclear fission. The conceptual quality score for this entry was 5 (complex link) as two scientific ideas were linked and accurately elaborated. The technical quality score was 6 as it included more than 5 concepts and all the propositions (i.e., a proposition consists of the two adjacent concepts and the linking phrase) were accurate. Therefore, the knowledge organization score was 11 out of 11.

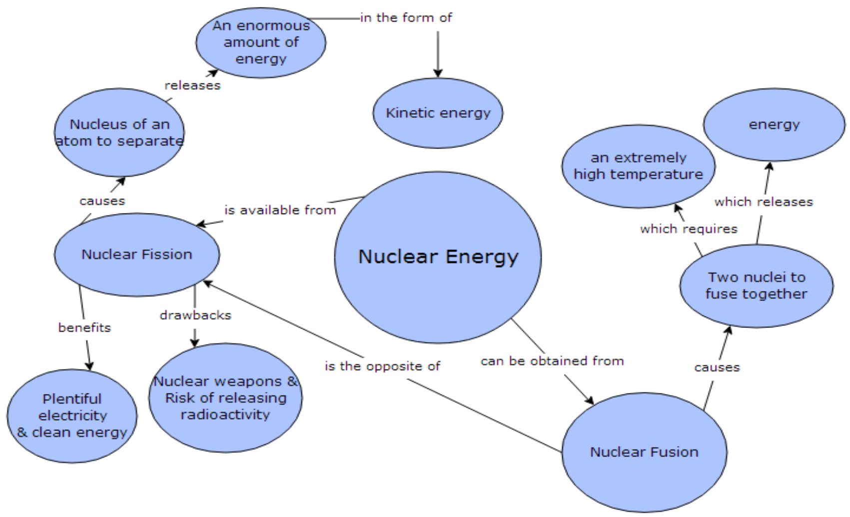


Figure 14. Haley's ConceptMap entry prior to group argumentation

Haley's entries were compared with her teammates'. Her group had 5 students. Two students, Ashley and Melissa, did not create any entries prior to the class; the other two students, Raina and Daphne, each created an Event and a Wiki entry. Haley was the only student who created one entry on each iKOS mode.

Elizabeth also coordinated different information across different iKOS modes when she individually organized knowledge with MER. In her Wiki entry, Elizabeth talked about that nuclear power should not be the only energy resource that we depend on and claimed that "it is most sustainable to have a variety of energy sources, nuclear power being one of them" [Elizabeth, Wiki entry, prior to group argumentation]. In this entry she only used one keyword and did not include scientifically or socioscientifically accurate links between her ideas. Therefore, Elizabeth's Wiki entry received 2 points from conceptual quality scoring and 2 points from technical quality scoring totaling to 4 points in knowledge organization quality scoring. Her ConceptMap did not show conceptually valid and elaborated links between ideas and scientific concepts. Technically, her ConceptMap also did not include accurate prepositions. The ConceptMap included renewable and clean as positive aspects of nuclear energy as an energy source. Elizabeth included “argument” as a linking word and incorporated two ideas “likelihood of radiation is low” and “valuable source of infrastructure”.

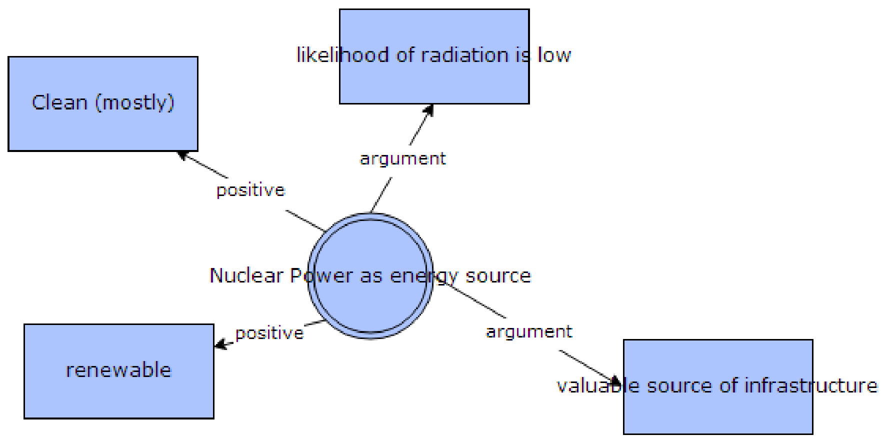


Figure 15. Elizabeth’s ConceptMap entry prior to group argumentation.

Analysis indicated that the content of the students’ collaboratively created entries in their small groups included similar information. As a result of the argumentation, 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 the three modes. This may be because the three entries were created by different students: Haley created the concept map, Raina created the Wiki, and Daphne created the Event on different computers. Haley physically moved to the computers that Raina and Daphne were using and checked all the entries created by these students.

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 cancerogenic 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. The conceptual quality score for this entry was 5 as it incorporated the ideas of ionizing and non-ionizing radiation and elaborated on those ideas to tie to cancer. The technical quality score for this entry was 6 as it included more than 5 accurate keywords. Therefore, the knowledge organization score for this entry was 11.

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. The knowledge organization score was 5 and technical quality was 6 as they inappropriately placed more than 5 tags.

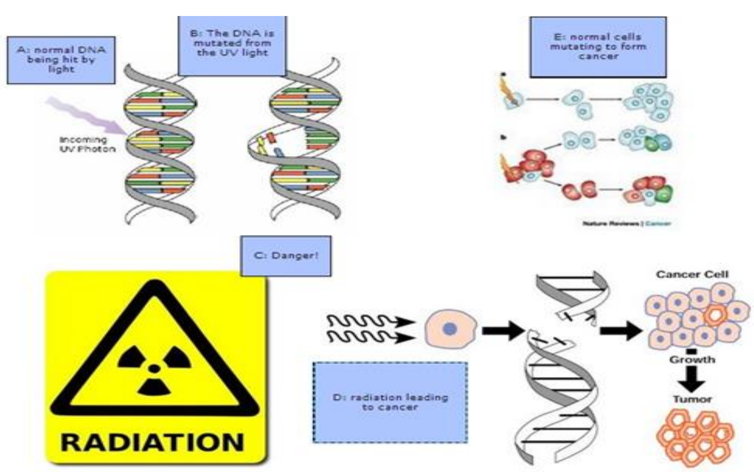


Figure 16. Event entry created by Group 4

In the ConceptMap, they summarized the types of radiation and tied those to the cause of cancer. The total knowledge organization score for this ConceptMap was 11 as it connected two scientifically elaborated ideas and appropriate prepositions (Figure 17).

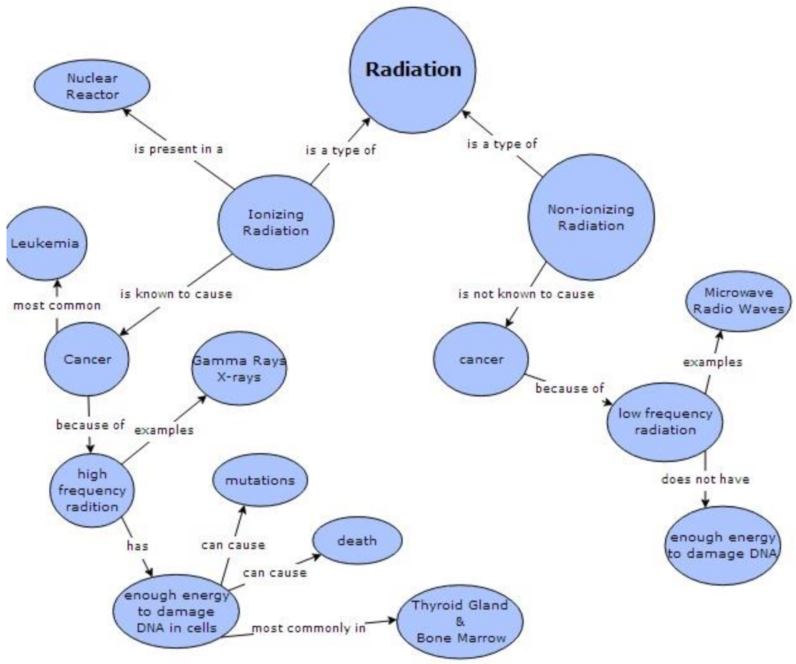


Figure 17. ConceptMap created by Group 4

Overall, even though the students' individual entry scores varied, when students worked together to organize their knowledge, knowledge organization score for all the entries created were 11 out of 11. Different form the students' individual knowledge organizations (i.e. Haley, Daphne and Raina), collaboratively created entries in this group incorporated similar content but they focused on biological aspect and how it caused cancer in their Event while they described the types of radiation in ConceptMap entries and how ionizing radiation causes cancer in their Wiki (Figure 17).

Video data indicated that the students in Group 2 were working on only Elizabeth's computer. All students in this group gathered around the computer and they gave instructions to Elizabeth on what to include in the entries. Brandon, on the other hand, used his own mobile device to explain the fission process to the group and Elizabeth created the Wiki entry accordingly. As a result, Group 2 created one entry on each mode and all the entries focused on the process of nuclear fission without much difference in terms of the information included in the representations. In the Wiki, they simply stated how fission begins and how it creates heat and energy. This Wiki entry received 4 points from the conceptual quality scoring because the scientific idea of nuclear fission was fully elaborated but was not connected to another socio-scientific idea. In terms of technical quality it received 5 points as it included only three tags. In their Event entry on the other hand, students included a picture depicting the process of nuclear fission. Knowledge organization quality score for this entry was 7; receiving 4 points from conceptual quality scoring and 3 points from technical quality scoring as it included three tags and those were not accurately placed. Finally, in their ConceptMap they included the how nuclear fission works and included an idea about the clean energy. This ConceptMap entry was scored 4 in the conceptual quality as it accurately elaborated on the fission concept, and three from the technical quality scoring as it included inaccurate prepositions.

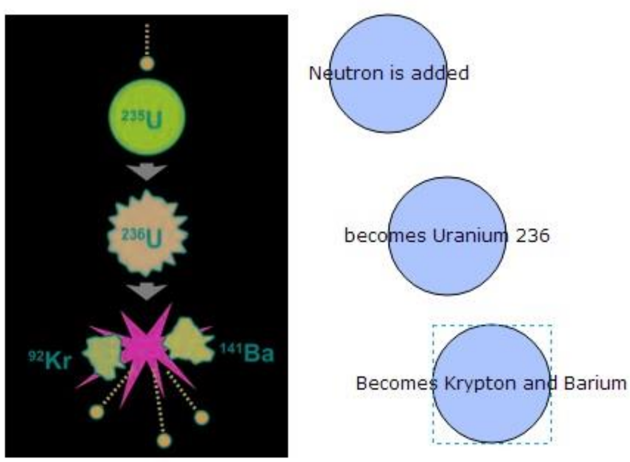


Figure 18. Event entry created by Group 2.

Overall, the collaboratively created entries had higher quality for Event entry but maintained the average score for the Wiki and ConceptMap. In Haley's group all three representations were created by different students. In Haley's group, the students decided to create entries on one computer and Elizabeth was the one who created all entries. During the process other students were commenting on the entries and searching information from their own computers and informing Elizabeth about the knowledge that they found. Moreover, students coordinated different information in their individually created entries when they were asked to learn about nuclear energy SSI and they incorporated similar information on a scientific aspect of the nuclear energy.

Theme 2. The ways mediated turns support argumentation

This theme indicates the specific ways that the students' implicitly and explicitly mediated turns supported their argumentation. Results indicated that the students were using explicitly mediated turns to provide scientific explanation to the audience and used this explanation later in the argumentation as evidence to support their groups' final claims about the nuclear energy issue.

Using implicitly mediated turns to recite claims and provide justifications. Investigating the students' implicitly mediated turns indicated that they used information from their entries to recite their individual claims. 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 Augusta makes it a potential hazard to a large population of people" Similarly she mentioned the same justification in her argument again. "Because one in the article is talking about building it within 25 miles, or something that from Skycity". She continued her justification with her reasoning that "So if anything were to go wrong. That would affect, it's *very close to a high population of people*."

Similarly, Elizabeth, even though she had a low quality argument written in her Wiki entry (Argumentation quality of 5 out of 12), she made the same claim 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 s*houldn't be our only one*, but I think we'll do the best *using variety of source"* Although Elizabeth mentioned her claims again, she did not provide any evidence to support her claim and provide final reasoning to her claims that she included in her Wiki that she brought to the small group argumentation.

Using explicitly mediated turns to provide scientific explanations.

During explicitly mediated turns the students were specifically providing scientific explanations, which differed from their implicitly mediated turns. For instance, Haley's group started with providing scientific explanation on how radiation affects DNA, cells, and cause tumors in turns 1 and 2. Then, they continued explaining the effects of ionizing and non-ionizing radiation and how this caused cancer. They finally used this scientific explanation as evidence of why we should not use nuclear energy.

(1) Raina: The radiation emitted from a nuclear power plant is ionizing radiation and it is high frequency radiation that removes electrons from atoms or molecules. It can mainly damage DNA causing cancer or death of the cell. It can happen within split seconds. Cancer can take years to fully develop.

(2) Haley: Not all the radiation necessarily cause cancer or kill you. Ionizing radiation which is present in the nuclear reactors will cause cancer because it's such a high frequency that has a power to alter cells, either like kill them completely or just damage

them that form mutations, which cause cancer. Most common affected cells are bone marrow cells and your thyroid gland cells which is like right here, which is the most exposed to, closest to your skin and um so like the most common type of cancers are leukemia.

Similarly, Elizabeth also started presenting the scientific explanation to the audience.

(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.

She finally stated that based on the nuclear fission process they were pro nuclear energy because of the fact that it is a clean burning energy source.

Theme 3. Argumentation on personal experience (non-mediated talk) drives further knowledge organization

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. The plant contaminated the ground water and caused cancer in the community. After giving this example, Haley turned the group’s conversation in a direction where they started to talk about cancer and radiation.

[Excerpt 12.Transcripts 09/01/2013: Video Group 4 15:30-15:41]

(32) Haley: It [nuclear power plant] contaminates…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 ten minutes into their small group discussion, the 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 13).

[Excerpt 13.Transcripts 09/01/2013: Video Group 4 17:35- 18:05]

Ashley: Why do not we do radiation and cancer, so we do not want it

Raina: [Inaudible]

Ashley: We are done. We are gonna do radiation and cancer

Haley: How radiation kills cells?

Ashley: Yeah.

Haley: Radiation exposure and cancer.

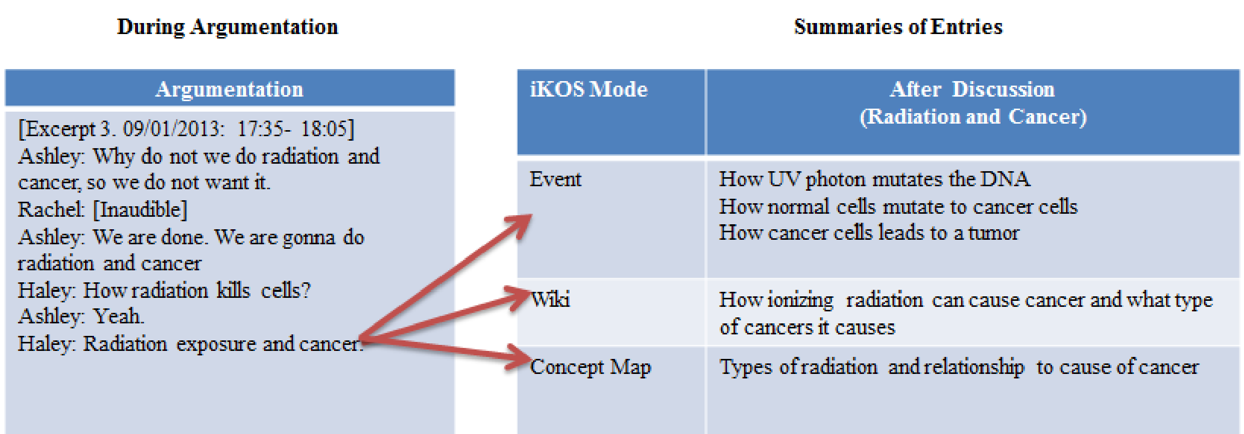


Figure 19. Argumentation drives knowledge organization

Haley was still dominating the group argumentation session. She mentioned her justification about cancer and she tied this to a daily life example. Her argumentation directed her group so that their conversation revolved around a radiation and cancer topic. This episode occurred before the students were instructed to focus on a specific scientific aspect of nuclear energy. After the instruction, the students inherently stated that they wanted to do their collaborative knowledge organization on a ‘radiation and cancer’ topic (Figure 19). As indicated previously, Haley’s argumentation at the beginning of the third session was implicitly-mediated by the information she wrote in her Wiki and ConceptMap entries. She also included turns that were not mediated by her knowledge organized in iKOS. These constituted the non-mediated turns. For instance, after she stated her initial arguments, she talked about France’s dependency on nuclear energy and compared it to US.

Similar to Group 4, this group also talked about a popular TV show that was about after effects of Chernobyl disaster.

[Excerpt 14. Transcripts 09/01/2013 Video Group 2.2 06:38-08:35]

(22) Elizabeth: I was just watching this show. It is on animal planet, it is called River Monsters. It is really cool

[Tim: It is a good show]

(22) Elizabeth: He 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 like granted, there are mutations but they are not like mutated into a monster.

Brandon: Yeah, there are probably fish with more than two eyes

(23) Elizabeth: He put, only be there for certain amount of time yet he could not go to certain areas, he had this device like a meter that counter his radiation and he was so close to super radioactive place. It was so weird because like he been one spot, he moved 5 feet over there would be much more radioactive spot. People in charge would be like “no no you get away from it” because it concentrates in the certain areas. But no it was so weird. Oh my god. Because I guess I have never really thought about the upper effects of

nuclear thing. There were abandoned buildings, shoes on the ground, because it was, like nobody has left.

Tim: It is blocked off

(23)Elizabeth: It was just like wild I was like oh wow but he was out there fishing. Although he said normally he catches and releases but in Russian site has made him they keep them all for his research so could not put them back.

(24)Brandon: Chernobyl is gonna be, you know, you can't go there hundreds and thousands of years. It just gonna sit there and rod?

(25)Elizabeth: I wonder what the difference is between the numbers of radiation release there and the radiation release in Fukushima.

Following this conversation I participated in the conversation and asked the group if they were against nuclear energy or not.

[Excerpt 15. Transcripts 09/04/2013 Video Group 2.2 10:54]

(34) Brandon: We are saying that it's good but, it's good in terms of it creates a lot of, good amount of energy, but America is bigger than France lot bigger.

(35) Elizabeth: It is good as an *alternative energy source* but not the main one

Researcher: So still do you think that US should not depend on nuclear energy in the future.

(36) Brandon: I think it is good stepping away from coal and oil

Researcher: Why should we avoid coal and oil?

(37)Brandon: Because we are using earth's natural resources and eventually we will run out of coal. But how do we get the energy from nuclear power plants?

Excerpt 15 indicates that the students' argumentation regarding nuclear power made them curious about nuclear power as an alternative energy source. Elizabeth was specifically holding onto her idea about nuclear energy being an alternative energy source (turn 35). Moreover, the students wanted to learn more about the nuclear energy creation process (turn 37). After about ten minutes into their small group argumentation, students were asked to choose one scientific aspect associated with nuclear energy and create iKOS entries to explain it. Group 2 decided to focus on the topic of fission and how energy is created by this process (see excerpt 10 below).

[Excerpt 16. Transcripts 09/04/2013 Video Group 2.2 15.45-16.01]

Brandon: We can do fission and fusion.

Elizabeth: Sure.

Tim: Sounds good to me.

Researcher: What did you guys decide on?

Brandon: Specific reactions

Researcher: What do you mean?

Brandon: How fission works!

The students in Group 2 also brought daily life examples into their argumentation. Then, they talked about a TV show. Their conversation was directed to a certain point and the collaborative knowledge organization decision came out naturally. Therefore, similar to Haley's group, when I asked students to decide on a scientific aspect that they wanted to learn more about, Group 2 had already decided to focus on fission.

Theme 4. Verbal Back Channeling

In this study, verbal back channeling referred to the instances when a mediated or a non-mediated turn was interrupted verbally by another student. As argumentation was approached from a collaborative perspective through the sociocultural lenses in this study, these instances in a way signaled for a social interaction. Here, verbal back channeling instances, therefore, will demonstrate “attentiveness, involvement and alignment with the speaker” (Sawyer & Berson, 2004, p.395).

The results indicated that there was less back channeling during mediated talk in both Haley’s and Elizabeth’s turns. Back channeling occurred 1 time during mediated and 7 times during non-mediated turns in Elizabeth’s turns; and 6 times during mediated and 11 times during non-mediated turn in Haley’s turns. Similar patterns existed for their groups. Note that italicized text refers to the mediated instances.

The verbal back channeling instances occurred when a student’s turn was interrupted by another student while the speaker tried to finish her sentence (Turn 2) or made brief comments on the speaker’s unfolding utterance such as ‘yeah ‘ as in turn (2) in Group 2. The mediated turn of Elizabeth received back channeling when Ben agreed with her, as in turn (2).

(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 like we can’t depend on one thing...

Ben: [Yeah]

Elizabeth: …some coal, some hydro, some wind, some thermal

Elizabeth’s non-mediated talk in contrast, received more back channeling. She mentioned a TV show and talked about radiation in Chernobyl. Back channeling occurred 4 times during her 8 non-mediated turns. These instances also signaled for attentiveness, as in turn 23.

(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 like granted, there are mutations but they are not like mutated into a monster.

Ben: Yeah, there are probably fish with more than two eyes

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 turns were also indicators of attentiveness, as can be seen in Haley's turn (3)

(3) Haley: People are gonna lose their lives in the expense of you know

Ashley: [Efficient energy]

Her non-mediated talks on the other hand received 11 back channeling instances. These instances occurred 10 times when Haley mentioned the movie which was related to nuclear energy. Turn (33), for instance, received 3 back channeling instances.

(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

[Ashley: yeah]

[Raina: And the company was paying for these doctors to tell their community that they were fine] [Ashley: Oh my gosh]

During group presentations on the other hand, the turns were not interrupted. Of course, during a presentation back channeling would not be effective, as the presentations took a formal format, where students stood in front of the class, showed their iKOS entries to the class, and explained the scientific aspect their group focused. The results I believe would be different if the presentation was in a poster presentation format where students could interact with the presenter more freely. Hence, during the final presentation there was only one back channeling instance in

Elizabeth's group presentation, which indicated that a student in the audience was helping her to find an answer to a question she was struggling with in turn (2).

(2)Elizabeth: Oh I forgot to mention, when it splits it releases heat and energy where nuclear energy comes from but then I forget what was it called, there is a principle that where it continues splitting. Like it does not stop…

Nathan: Chain reaction

Towards the end of the presentations, students from the audience asked questions to the presenters to gain further understanding of the issue. Mary for instance inquired about the reason of leukemia in children as a result of radiation.

(5)Haley: Also when there is a disaster, something happens; *children are gonna be the first ones getting affected*. You will lose your kids before you lose your own life.

(6) Mary: What makes children more susceptible to leukemia than others?

(7) Haley: Because their bone marrow cells are not fully developed.

[Daphne: It is not fully developed so it's like…]

(7)Haley: And leukemia is more common in children anyways.

Interpretation

First, the results indicated that students' argumentation in their small groups were mediated by the information embedded in their Wiki and ConceptMap entries. These implicitly mediated turns occurred when the students organized knowledge before coming to the class and when they did not look at their representations during the time of speaking. Of course, drawing information from a pictorial representation requires another level of interpretation. The students in this study showed their entries to the class when presenting their collaborative knowledge organization entries. They were able to look at their entries so that they could show the parts of their Event entry and make scientific explanations based on the pictures. Therefore, Wiki gave students a space to embed text that can reflect their understanding of the scientific phenomena and write their arguments on a given SSI. ConceptMap mode, on the other hand, allowed students to connect multiple concepts that would sometimes make full sentences. Therefore, these two representational modes were more approximate to verbal arguments than pictorial representations. In this current research setting, the picture tagging mode, Event works as a platform in which students can highlight important parts of the visual and tag the evidence incorporated in the pictures. iKOS technology itself limits students to include only 50 characters per tag. Therefore, this representational mode requires another level of interpretation and explanation when drawing information from pictorial representations.

Second, the ways in which students coordinated information with MER were different in both contexts. The students were incorporating different information across different representational formats in iKOS when they were asked to organize knowledge individually. One reason might be students' unfamiliarity with the subject and that they did not restrict their individual knowledge organization practices in terms of a topic, in order to learn more about the issue. Also, the instruction that I gave them did not specify what kind of information they had to incorporate in their entries when they organized knowledge individually. However, when they were asked to focus on a specific scientific aspect of the nuclear energy topic they coordinated the same information across different representational modes. The reason might be that the students wanted to convince their audience of their position about the issue. For instance, after Elizabeth presented her group's Event entry to the class she switched to the Wiki and said: "the same thing but in a Wiki, if you are better in reading, this will do the work" (4).Hence, they may have wanted to repeat the information across different modes to expose the audience to the same idea in multiple modes.

Third, the results indicated that the students in both groups started their small group argumentation with implicitly mediated turns and switched to the non-mediated turns. The switch was driven by real life examples and personal experiences. These non-mediated turns drove the group's conversation to a certain point where they channeled their knowledge organization in a specific direction. Using non-mediated turns is natural during socioscientific argumentation as SSI are a complex real life phenomena that are relevant to students' lives. Hence, the students organized their knowledge on a real life related topic.

Another interpretation that I can derive from the result is that, as the non-mediated turns received more back channeling than the mediated talk, it had more divergent ideas than the ones incorporated in the individual entries. For instance, as in Haley's situation, she organized her individual knowledge on the pros and cons of nuclear energy, but the example on radiation and cancer she brought in the group conversation drove her group to organize knowledge on this scientific phenomena. Similarly, in Elizabeth's situation the non-mediated turns on a TV show drove the group to wonder about the process of nuclear energy creation so they decided to focus on nuclear fission.

Fourth, the results suggested that different than implicitly-mediated turns, the students used explicitly mediated turns to present scientific explanations. However, they presented their position and group's argument after explaining the scientific principles by using implicitly mediated turns. Hence, the students in this setting used the representations to explain scientific principles/phenomena and used explicitly mediated turns to present justifications and claims about the given SSI.

Fifth, the results indicated that there were more back channeling instances during non – mediated talk than mediated talk. There are two points I want to make here. First, back channeling instances indicate students' attentiveness in this study. As the back channeling instances occurred more during non-mediated talk, it indicates that students were more attentive in non-mediated talk than mediated talk. Another interpretation regarding this finding might be that the mediated talk provided students with opportunities to present more complete ideas and arguments that these turns followed by another turn, instead of receiving back channeling instances. Of course, the context of the small group argumentation might have affected this outcome, as students initially are asked to present their ideas about the nuclear energy issue. Given the fact that they had organized their knowledge prior to the small group discussion, they had already brought their preconceived ideas about the issue. Therefore, the other students in the group might have listened to the speaker to finish her turn to present his idea. However, during non-mediated talk they are either questioning or trying to understand the SSI. During this time, they might have attended to the conversation by back channeling in order to participate in this social interaction.

Overall, the results suggested that the interaction between knowledge organization and argumentation in this study was bi-directional. Here, students used external representations to draw information in order to support their arguments, present justifications and claims, and present scientific explanations to the class. On the other hand, students' argumentation practices drove them to a certain point where they wanted to organize further knowledge on a specific topic. Therefore, providing students with technologies to support knowledge organization practices in a CSCL environment becomes important to scaffold further argumentation in science classrooms.

Overall Interpretation

Integrating findings related to the three research questions, I discuss three points here.

1) The results suggested that Wiki and ConceptMap entries were the most centralized entry types in the knowledge network. At the same time these representation types had higher knowledge organization quality scores. In conclusion, results of the degree centralities, key actor analysis indicated that Event was the least centralized representation type in this setting. The results suggest that Wiki and Concept Map entries acted as better tools for knowledge organization and the students better reflected their conceptual understanding using these tools.

The interaction analysis indicated that the students' argumentation was implicitly-mediated by Wiki and ConceptMap entries. However, when the students were asked to organize information collaboratively in their small groups and present their arguments; they were also explicitly-mediated by the Event entries. Video recordings showed that each group started to present their information from their Event entries. The reason for this might be that Event entries were more appealing to the audience as these included colorful pictures instead of long text. At the same time, since the collaborative knowledge organization focused on a specific scientific aspect of nuclear energy, Event entries might act as a better tool to focus on a specific aspect rather than organizing knowledge on a broad SSI. In other words, pictorial representations might have been more suitable to organize specific scientific knowledge in this particular setting.

2) There was no discernable pattern for having a high quality knowledge organization and being a key actor in the knowledge network. However, the key actor analysis suggested that even though the actors in the network did not have a high knowledge organization quality, these entries were important players in the knowledge network in terms of creating the overall knowledge web by connecting entries.

3) Knowledge organization score looks at the conceptual accuracy of the information included in the entry and how technically accurate those entries were. Argumentation quality scoring in this study considered the use of scientific knowledge, presence of justification, number of aspects incorporated and the use of counterarguments. Results for those students who presented their groups' final argument indicated that the students with higher argumentation quality had higher individual total knowledge organization scores from their entries (Table 14). This may suggest from a conceptual perspective that accurately linked and elaborated ideas in the representations might have fostered students' argumentation quality.

Table 12.

Group Representatives' Individual Argumentation Quality Score Prior to Third Session vs Total Individual Knowledge Organization Score

Student	Argumentation Quality Score	Total KO Score for all entries
Elizabeth (Group 2)	3	14
Haley (Group 4)	10	31

This study also suggests some positive outcomes when students collaboratively organized their knowledge on the nuclear energy issue. First, knowledge organization quality scores for Event entries increased for each group in this study. Overall, knowledge organization quality scores for group-created entries ranged from 7-11 which suggests good conceptual and technical quality for those entries. In addition, after students worked in their small groups, there was an increase in some aspects of the students' argumentation qualities. For instance, Elizabeth increased the total argumentation quality score from 3 in her individual argumentation to 10 out of 12 possible points. Although Elizabeth was not very proficient in her individual argumentation she showed positive outcomes in her final argumentation. Haley, on the other hand, used only superficial scientific knowledge in her individual argument but in the final presentation she incorporated specific and extensive scientific knowledge in her argument. Elizabeth and Haley’s written arguments before coming to the class in the third session lacked the use of specific scientific knowledge. When the students were asked to organize further knowledge and present those in the classroom, results revealed that their argumentation was mediated explicitly by the information that was incorporated in those representations. Hence, the students’ verbal arguments, in which they stated their groups’ position about the nuclear energy, incorporated specific scientific knowledge and distinct aspects. This result may suggest that when students are provided with the opportunities to organize their knowledge with MERs and present their findings to their audience; their argumentation is explicitly mediated; hence leading to better arguments.

CHAPTER 5

DISCUSSION, IMPLICATIONS, AND FUTURE DIRECTIONS

Summary and Findings

In this mixed methods study, an argumentation based unit on nuclear energy was developed and implemented in a computer supported collaborative learning (CSCL) environment for pre-service teachers. The new CSCL environment provided students with an online hypertext platform to organize their knowledge in multiple external representational formats (MER): Wiki, ConceptMap, and Event. Through multiple iterations the design of both the technology and the unit were altered and improved.

The current study examined a group of pre-service science teachers' (n=20) knowledge organization practices when arguing on a given SSI- nuclear energy. Three aspects associated with students' learning processes in the unit were identified and examined using a blending mixed methods design (Greene et al., 1989; Greene, 2007): knowledge organization with MERs, argumentation on the SSI, and interaction between knowledge organization and argumentation.

The study was implemented in four sessions in the Physical Sciences for Middle Grades Content and Methods courses. In the first two sessions of the unit learners were instructed on argumentation, concept mapping, and knowledge organization with iKOS. As homework the students read a news article about the planned nuclear power plant construction and organized their knowledge about nuclear energy individually before coming to the class. In the class, students were engaged in small group argumentation about nuclear energy dependency and their positions toward a newly proposed nuclear power plant construction close to where the study took place. In the final stage of this study, students presented their groups' arguments about the nuclear energy dependency to the whole class.

Three research questions guided the study:

1. How do learners organize knowledge effectively with MER?

    a. What is the most prominent representation type learners create?

    b. What are the key actors in the knowledge network?

    c. What is the quality of representations created by the students on a given SSI topic?

2. What is the quality of student generated arguments on a given SSI topic?

3. How does learners' knowledge organization with MER interact with their argumentation practices?

Descriptive statistics and social network analysis (SNA) were employed to understand the nature of knowledge organization to address the first two sub-questions of the first research question. The results indicated that the most created and well-connected (i.e., therefore, centralized) representation types were Wiki and ConceptMap. Event entries, however, were used less for knowledge organization and were not as centralized as Wiki or ConceptMap.

Although visual representations provide opportunities for students to communicate their ideas, attract attention, and motivate students in their own learning (Cook, 2006), the lack of pictorial representational practices in science classrooms have been previously noted by researchers in the field. According to Erduran and Evagorou (2012), educators should make the best use of visual representations as these are fundamental objects for enhancing scientific knowledge and students' lives. This is particularly true for novice learners who had difficulties in representing their understanding about the scientific and socioscientific ideas and concepts with pictorial representations in this study. The results of knowledge organization quality analysis indicated that the students were more proficient in organizing knowledge in textual (Wiki) and textual-visual (ConceptMap) representations than in pictorial representations. This result suggests that the students incorporated more scientifically and socioscientifically accurate information in their Wiki and ConceptMap entries. The students had difficulties in organizing knowledge by tagging and conceptually integrating valid ideas in their Event entries.

Another interesting finding was that different representations in MER can be used to complement or constrain each other because each representation can be used to contain different information (Ainsworth, 2008). For instance, when the students in the study organized their knowledge individually, they included different aspects of the topic in different representational formats. Together, these representations help document and explain the topic in a complementary way. When their groups were asked to organize knowledge collaboratively and present their final arguments, the students included similar information in their MER on the same topic or positions, making sure these representations together convey the same message.

To address the second research question, two students (Haley and Elizabeth) were identified and their argumentation practices in different contexts were described. Haley initially had high individual knowledge organization quality scores and was against nuclear energy; Elizabeth on the other hand initially had low individual knowledge organization quality scores and was pro-nuclear energy.

The argumentation quality analysis (Tal & Kedmi, 2006) results showed that when the students engaged in collaborative knowledge organization practices, the student initially with low argumentation quality, Elizabeth, incorporated more justifications, aspects, and a counterargument when she was asked to present her groups' argument. On the other hand, the student with an initial high argumentation score, Haley, maintained the high quality argumentation when she was engaged in the collaborative knowledge organization practice and presented her groups' argument. She also incorporated specific scientific knowledge in her arguments. This result is important as researchers pointed out the concern that SSI-based curriculum would sacrifice the integrity of science content (Klosterman &Sadler, 2010). This result suggests that with appropriate scaffolding, students are able to make sound arguments with specific scientific knowledge.

The interaction aspect of the study (i.e., the third research question) was investigated using summative content analysis (Hsieh & Shannon, 2005) and video data from Haley and Elizabeth's groups. Overall, the two groups showed similar patterns in which their argumentation and knowledge organization practices interacted bi-directionally.

The results indicated that the students' argumentation in this study was mediated by the information in iKOS entries that they created. There were two design features that allowed students to do so. First, the design of the learning unit allowed the students to individually organize their knowledge with MER. Then the students were asked to argue about the issue in their small groups based on their individualized knowledge organization. Second, knowledge organization in MER allowed the students to utilize information from different sources for different purposes. For instance, the results indicated that the students were acquiring information mostly from their Wiki and ConceptMap entries during small group argumentation. These two representational formats, approximate to verbal argumentation, might have provided the students with a space to easily reference relevant information. During the final presentation, however, Event entries were also referenced. This is because pictorial representations can easily be more appealing to the audience during a presentation instead of a Wiki which require the audience to read. Specifically, a tagging system could allow presenters to highlight important parts of the picture and use them as evidence during argumentation.

Additionally, the students' argumentation also encouraged them to further organize knowledge. During non-mediated turns, the students talk about real life experiences regarding the given SSI. Of course, this is almost natural to learning with SSI as students come to the classroom with preconceived ideas and experiences with these complex real life phenomena. While arguing, the students' argumentation drove them to learn more about a specific scientific aspect of the SSI. Although the instruction also asked them to organize knowledge on a specific scientific aspect of nuclear energy, the students automatically chose their topics based on their argumentation and especially their non-mediated turns. As we provided them with the iKOS tool and the unit design asked them to specifically focus on a scientific aspect of the SSI, the design might have enabled students to easily store, sort and cluster information in MER.

Significance and Implications

Argumentation from evidence has been promoted as one of the core practices of science education (NRC, 2012; NGSS Leads State, 2013). However, researchers pointed out the lack of argumentation in science classrooms (Newton et al., 1999; Osborne, 2010). Recently, incorporating SSI has been advocated for both motivating students in their own learning and engaging them in argumentation. Hence, there is a pressing need to develop curricula that can engage students in argumentation practices in SSI. However, there are several challenges associated with this. First, there is a vast amount of information on SSI that is distributed in multiple resources and in MER. Second, students' argumentation has been influenced by the opinions published in popular press. Hence, students need to develop criteria to distinguish relevant/irrelevant information as well as search, sort, and cluster this information to develop understanding about today’s complex SSI and argue about them.

Researchers argued that students are competent in creating their own external representations to reflect their understanding on SSI and scientific concepts (diSessa, 2004). Therefore, curriculum developers need to design science curricula that meet both the students’ needs in terms of knowledge organization and also consider their abilities in creating representations. The findings of this study may inform curriculum designers in several ways. First, students should be given opportunities to create their own representations to reflect their understanding on a given SSI and create a knowledge web. As such, iKOS was used in this study by the students to organize their knowledge.

Recently, annotation received significant attention in CSCL environments and inquiry based curriculum design. Matuk and Linn (2012) argued that “annotation has communicative, discursive, and cognitive functions in scientific inquiry” and annotated materials can be used as evidence in scientific arguments. Therefore, annotation serves as a tool for students to both highlight important ideas and write their ideas to store information and reflect understanding of scientific concepts, principles, and phenomena. However, in this setting, results indicated that the students did not organize their socio-scientific knowledge with the Event annotation tools. The results of summative content analysis with the aid of video data indicated that the students in this setting used Event to highlight the important parts of the picture and explain the scientific phenomena by showing the parts of the picture to the audience, instead of reading from the text or interpreting the ConceptMap that includes multiple connected ideas. Hence, for formal presentation purposes, where a presenter stands in front of the class and explains the subject matter and presents an argument, Event entries might serve as a better means to appeal audiences' attention and again highlight the important information and evidence.

The social network analyses results suggested that students may contribute to the knowledge building practices in different ways. Traditionally, students' contribution in a classroom has been evaluated by looking at their written or verbal input, either in terms of the amount or the scientific quality of such input. However, from a collective perspective, the results of the current study suggested that various SNA measures can be used to assess students' contribution to a collective knowledge building process in terms of how students' individual input are interconnected with their peers'. Hence, researchers can benefit from these new techniques to identify those students who do contribute to the collective knowledge creation processes, but may be otherwise left out by traditional means. Second, the results suggested that students benefited from their MER in their argumentation and they supported their claims by extracting information from their representations. Hence, curriculum developers should consider creating an environment for students to organize their knowledge for their individual learning purposes. Results also showed that through the collaborative knowledge organization practices students were able to incorporate more specific scientific knowledge in their argumentation in a collaborative setting. Hence, curriculum developers should give direct instructions for collaborative knowledge organization on scientific aspects associated with SSI.

This study has implications for science teachers. Since MER can be used for complementary or constraining purposes, based on how students used different representations in different processes and settings, teachers should combine different functionalities of MER to support students' argumentation in science classrooms. During individual knowledge organization teachers might remind students to use MER to organize different information across different formats to enhance their understanding of the subject and learn more about a given SSI. During collaborative knowledge organization and following argument presentation purposes teachers can ask students to incorporate the same information across different MER to emphasize the importance or make the subject more appealing for students with diverse representational interests.

Findings of this study also suggest that teachers should give more explicit instruction on how to tag and annotate pictures to organize knowledge in a more effective way and create a knowledge web that is more accurately linked. Researchers noted that tagging and annotation are important in science and science learning as individuals use these to highlight important pieces of information embedded in the visual. Additionally, annotated material can be used as evidence when creating arguments (Matuk & Linn, 2012). Results indicated that students did not acquire information or evidence from their Event entries when their argumentation was implicitly mediated by the information embedded in this mode. Particularly, students should be taught how to use their annotated pictorial representation as data sources for their arguments. Also, the knowledge web as a new construct in this learning environment was not explained in detail and, therefore, the students might not have grasped the importance of using tags to contribute to this knowledge web. Teachers should give direct instruction about how to make quality tags and create a more connected knowledge web where students learn from each other's representations.

Teachers should take advantage of technology resources to support students' argumentation practices. Specifically, teachers should ask students to use such technologies and generate their own representations to cluster and store information. Next, they should remind students how they can use the information as evidence sources when building sound arguments, especially on complex SSI. Engaging students to create their own representations and make them use these in their argumentation will allow students to embrace the scientific culture. Hence, teachers should incorporate such technologies and knowledge organization practices in their own classrooms

This study offers a distinct way to support students' argumentation practices in a newly developed CSCL environment. Therefore, the significance of this study lies in uncovering the process of knowledge organization with MER for collaborative argumentation in a technology mediated classroom, which is an important, but relatively unexplored area in science education. Since engaging learners in argumentation as well as creating a collaborative environment in learning is one of the key components of a deeper understanding and a fundamental of learning science (NRC, 2012), this study will contribute to the knowledge base about how those two aspects are being created by the learners in the presence of technology mediating this process.

The results of this study, from a pragmatic stance, will contribute to the practical understanding of educators and curriculum designers, and allow them to make adequate changes in their programs to incorporate collaborative argumentation practices as well as MERs in technology environments. Since the technology presented here will enable us to understand students' knowledge organization processes, educators will be able to create better environments for students to use MERs as their data source when they collaboratively argue and learn about the scientific concepts and socio-scientific issues. On the other hand, this study has some practical implications for teachers on how to incorporate MERs in learning SSI. This study also advances our understanding of the purpose of using MERs in science learning. Additionally, teachers can use the nuclear energy unit in their classrooms to teach science from an interdisciplinary perspective, since this issue is also interdisciplinary in nature.

From a design perspective, the technology used in this study is aimed at offering a solution to students' difficulties in integrating information in different formats and seeing representations in isolation. The unit design itself offers a space for students to organize their knowledge and argue about a given SSI individually first. Then, it asks students to collaboratively deepen their understanding about a specific scientific aspect of the issue. This design principle is important as there is a critique about SSI sacrificing the integrity of science content (Klosterman & Sadler, 2010).

Directions for Future Research

In this study, the social network analysis methodologies were used to give a portrait of individual and group level influences in the group behavior. In education literature there are few studies that provided students with the social network tools that they would analyze their own behavior (Yoon, 2011). Informed by Yoon's (2011) study, a future study will explore how the information based on an SNA of the knowledge web should be delivered to participating students to enable them to access others' ideas and initiate collaboration across different groups. In the current study, due to time limitation, I did not ask students to explicitly use the knowledge web to learn more about others' ideas. Therefore, the question "In what ways do generating a knowledge web with multiple external representations support collaborative argumentation?" still remains unanswered. In future research, before and during the collaborative argumentation activities, students should be provided with a knowledge web created by the students and with appropriate scaffolds for them to benefit from it.

I focused on one of the eight core practices promoted in the Next Generation of Science Standards (NGSS Leads States, 2013). I wanted to support students' argumentation practices by providing them with a CSCL technology that they can organize their knowledge. As scientists constantly use MER in their daily work, it is important to enhance other scientific practices by employing knowledge organization practices. As students are expected to be proficient with those practices we need to provide them with appropriate tools to excel in these practices. Therefore, another possible research question needs to be asked is “How does knowledge organization help students with other scientific practices?”

In recent technology design activities researchers started to incorporate visualization annotation tools in inquiry based science settings. For instance, *Image Annotator* has been incorporated in web-based inquiry science environment (WISE). The tool allows students to label the parts of given visual evidence (Matuk & Linn, 2013). Although I hypothesized that the students will be proficient using the Event mode in iKOS as well as the ConceptMap and Wiki modes, the results indicated that students were more proficient using Event mode when organizing scientific knowledge instead of socioscientific one. The knowledge organization quality was also higher in Wiki and ConceptMap modes. The reason here might be two fold. First, the tool itself might have been harder for students to manipulate. Second, in the unit design the time allocated for the Event instruction was less than the time allocated for the other two representational formats. Hence, in the future design of the unit, students should be taught how to tag and extract information from this visual evidence explicitly. Third, iKOS currently cannot interlink two conceptually similar entries. The tool is limited to interlink entries based on the same keywords/tags. Hence, in the new technology design, Semantic Web technologies should be incorporated, which can specify the conceptualization for iKOS to reason (Gruber, 1993; Guarino, Oberle, & Staab, 2009). Through this technology, fine grained results can be obtained from the social network analysis and knowledge web created can have links that are conceptually more accurate.

REFERENCES

Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education*, *82*(417), 436.

Ainsworth, S. (1999). The functions of multiple representations. *Computers & Education*, *33*(2-3), 131–152. doi:10.1016/S0360-1315(99)00029-9

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

Ainsworth, S. (2008). The educational value of multiple-representations when learning complex scientific concepts. In J. K. Gilbert, M. Reiner, & M. Nakhleh (Eds.), *Visualization: Theory and practice in science education* (pp. 191–208). London: Springer.

Aleixandre-Jimenez, M. P. (2007). Designing argumentation learning environments. In S. Erduran & M. P. Aleixandre-Jimenez (Eds.), *Argumentation in science education: Perspectives from classroom-based research* (pp. 91–115). New York: Springer.

Andriessen, J. (2006). Arguing to learn. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 443–459). New York, NY: Cambridge University Press.

Andriessen, J., Baker, M., & Suthers, D. (2003). Argumentation, computer support, and the educational context of confronting cognitions. In J. Andriessen, M. Baker, & D. Suthers

(Eds.), *Arguing to learn: Confronting cognitions in computer-supported collaborative learning environments* (pp. 1–25). Dordrecht, Netherlands: Kluwer Academic Publishers.

Barth, E. M., & Krabbe, E. C. W. (1982). *From axiom to dialogue. A philosophical study of logics and argumentation* (p. 337). Berlin, NY: Walter de Gruyter.

Bell, P., & Linn, M. C. (2000). Scientific arguments as learning artifacts: Designing for learning from the web with KIE. *International Journal of Science Education, 22*(8), 797–817.

Berelson, B. (1952). *Content analysis in communication research.* Glencoe, IL: Free Press.

Besnard, P., & Hunter, A. (2008). *Elements of argumentation*. Cambridge, MA: MIT Press.

Biesta, G. J. J., & Burbules, N. . (2003). What is pragmatism? In *Pragmatism and educational research.* (pp. 1–23). NY: Rowman & Littlefield Publishers, Inc.

Birchfield, D., & Megowan-Romanowicz, C. (2009). Earth science learning in SMALLab: A design experiment for mixed reality. *International Journal of Computer-Supported Collaborative Learning*, *4*(4), 403–421. doi:10.1007/s11412-009-9074-8

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

Bravo, C., van Joolingen, W. R., & de Jong, T. (2009). Using Co-Lab to build system dynamics models: Students' actions and on-line tutorial advice. *Computers & Education*, *53*(2), 243–251. doi:10.1016/j.compedu.2009.02.005

Brown, A. L. (1992). Design experiments:Theoretical and methodological challenges in creating complex interventions in classroom settings. *Journal of Learning Sciences*, *2*(2), 141–178.

Buckingham-Shum, S. (2003). *The roots of computer supported argument visualization, Visualizing argumentation: Software tools for collaborative and educational sense-making*. London: Springer-Verlag.

Cartier, J. (2000). *Assessment of explanatory models in genetics: Insights into students' conceptions of scientific models.* (pp. 1–25).

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.

Clark, D. B., & Linn, M. . (2003). Scaffolding knowledge integration through curricular depth. *Journal of Learning Sciences*, *12*(4), 451–494.

Clark, D. B., Sampson, V., Weinberger, A., & Erkens, G. (2007). Analytic frameworks for assessing dialogic argumentation in online learning environments. *Educational Psychology Review*, *19*(3), 343–374. doi:10.1007/s10648-007-9050-7

Cobb, P., Confrey, J., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher*, *32*(1), 9–13.

Cohen, A., & Scardamalia, M. (1998). Discourse about ideas: Monitoring and regulation in face-to-face and computer-mediated environments. *Interactive Learning Environments*, *6*, 93–113.

Collins, A., Hawkins, J., & Frederiksen, J. R. (1993). Three different views of students : The role of technology in assessing student performance. *The Journal of the Learning Sciences*, *3*(2), 205–217.

Collins, A. M. (1992). Towards a design science of education. In E. Scanlon & T. O'Shea (Eds.), *New directions in educational technology* (pp. 15–22). Berlin: Springer.

Corradi, D., Elen, J., & Clarebout, G. (2012). Understanding and Enhancing the Use of Multiple External Representations in Chemistry Education. *Journal of Science Education and Technology*, *21*(6), 780–795. doi:10.1007/s10956-012-9366-z

Dawson, V. M., & Venville, G. (2010). Teaching strategies for developing students' argumentation skills about socioscientific issues in high school genetics. *Research in Science Education*, *40*(2), 133–148. doi:10.1007/s11165-008-9104-y

DeWalt, K. M., & DeWalt, B. R. (2002). *Participant observation: A guide for fieldworkers.* New York: Altamira.

DiSessa, A. (2004). Metarepresentation:Native competence and targets for instruction. *Cognition and Instruction*, *22*(3), 293–331.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*(3), 287. doi:10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.3.CO;2-1

Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education*, *38*(1), 39–72. doi:10.1080/03057260208560187

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).

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's Argument Pattern for studying science discourse. *Science Education*, *88*(6), 915–933. doi:10.1002/sce.20012

Evagorou, M., & Osborne, J. (2013). Exploring young students' collaborative argumentation within a socioscientific issue. *Journal of Research in Science Teaching*, *50*(2), 209–237. doi:10.1002/tea.21076

Fadul, J. A. (2009). Collective learning : Applying distributed cognition for collective intelligence. *The International Journal of Learning*, *16*(2), 211–220.

Fretz, E. B., Wu, H., Zhang, B., Davis, E. A., Krajcik, J. S., & Soloway, E. (2002). An investigation of software scaffolds supporting modeling practices. *Research in Science Education*, *32*, 567–589. doi:10.1023/A:1022400817926

Gerard, L. F., Spitulnik, M., & Linn, M. C. (2010). Teacher use of evidence to customize inquiry science instruction. *Journal of Research in Science Teaching*, *47*(9), 1037–1063. doi:10.1002/tea.20367

Gobert, J. D., Sao Pedro, M., Raziuddin, J., & Baker, R. (2013). From log files to assessment metrics: Measuring students' science inquiry skills using educational data mining. *Journal of the Learning Sciences*, *22*(4), 521–563.

Gray, L., Thomas, N., and Lewis, L. (2010). Teachers' use of educational technology in U.S. public schools: 2009 (NCES 2010-040). National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education. Washington, DC.

Greca, I. M., & Moreira, M. A. (1997). The kinds of mental representations--models, propositions and images--used by college physics students regarding the concept of field. *International Journal of Science Education*, *19*(6), 711–724. doi:10.1080/0950069970190607

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

Greene, J. C., Benjamin, L., & Goodyear, L. (2001). The merits of mixing methods in evaluation. *Evaluation*, *7*(1), 25–44.

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.

Grice, H. (1975). Logic and conversation. In D. Davidson & G. Harman (Eds.), *The logic of grammar* (pp. 64–75). Encino, CA: Dickenson.

Griffin, P., Care, E., & McGaw, B. (2012). The changing the role of education and schools. In P. Griffin, E. Care, & B. McGaw (Eds.), *Assessment and Teaching of 21st Century Skills* (pp. 1–16). Dordrecht ; New York: Springer.

Guarino, N., Oberle, D., & Staab, S. (2009). What is an Ontology? In S. Staab & R. Studer (Eds.), *Handbook on Ontologies* (Second Edi., pp. 1–17). Springer-Verlag.

Hsieh, H.-F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research*, *15*(9), 1277–88. doi:10.1177/1049732305276687

Hsu, Y.-S. (2006). "Lesson Rainbow": the use of multiple representations in an Internet-based, discipline-integrated science lesson. *British Journal of Educational Technology*, *37*(4), 539–557. doi:10.1111/j.1467-8535.2006.00551.x

Ioannidou, A., Repenning, A., Webb, D., Keyser, D., Luhn, L., & Daetwyler, C. (2010). Mr. Vetro: A Collective Simulation for teaching health science. *International Journal of Computer-Supported Collaborative Learning*, *5*(2), 141–166. doi:10.1007/s11412-010-9082-8

Jiménez-aleixandre, M. P., & Erduran, S. (2007). Argumentation in science education : An overview. In S. Erduran & M. P. Jimenez-Aleixandre (Eds.), *Argumentation in science education: Perspectives from classroom-based research* (pp. 3–27). Dordrecht, Netherlands: Springer.

Johnson, R. B., & Onwuegbuzie, A. J. (2010). Mixed methods research : A research paradigm whose time has come. *Educational Researcher*, *33*(7), 14–26.

Johnstone, A. H. (1982). Macro- and micro-chemistry. *School Science Review*, *64*, 377–379.

Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning*, *7*, 75–83.

Johnstone, A. H. (1993). The development of chemistry teaching: a changing response to a changing demand. *Journal of Chemical Education*, *70*(9), 701–705.

Jonassen, D. H., & Kim, B. (2009). Arguing to learn and learning to argue: design justifications and guidelines. *Educational Technology Research and Development*, *58*(4), 439–457. doi:10.1007/s11423-009-9143-8

Kelly, G. J. (2008). Inquiry, activity, and epistemic practice. In R. A. Duschl & R. E. Grandy (Eds.), *Teaching scientific inquiry: Recommendations for research and implementation* (pp. 99–117). Rotterdam, The Netharlands: Sense Publishers.

Klosterman, M. L., & Sadler, T. D. (2010). Multi-level assessment of scientific content knowledge gains associated with socioscientific issues-based instruction. *International Journal of Science Education*, *32*(8), 1017–1043. doi:10.1080/09500690902894512

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

Komis, V., Ergazaki, M., & Zogza, V. (2007). Comparing computer-supported dynamic modeling and "paper & pencil" concept mapping technique in students' collaborative activity. *Computers & Education*, *49*(4), 991–1017. doi:10.1016/j.compedu.2005.12.007

Kondracki, N. L., & Wellman, N. S. (2002). Content analysis: Review of methods and their applications in nutrition education. *Journal of Nutrition Education and Behavior*, *34*, 224–230.

Kozma, R. (2003). The material features of multiple representations and their cognitive and social affordances for science understanding. *Learning and Instruction*, *13*(2), 205–226. doi:10.1016/S0959-4752(02)00021-X

Kuhn, D. (1992). Thinking as arguments. *Harvard Educational Review*, *62*(2), 155–178.

Lehrer, R., & Schauble, L. (2004). Modeling natural variation through distribution. *American Educational Research Journal*, *41*(3), 635–679.

Lehrer, R., & Schauble, L. (2006). Cultivating model-based reasoning. In K. R. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp. 371–387). New York, NY: Cambridge University Press.

Leitão, S. (2000). The potential of argument in knowledge building. *Human Development*, *43*(6), 332–360. doi:10.1159/000022695

Lemke, J. L. (1998). Multiplying meaning: visual and verbal semiotics in scientific text. In J. R. Martin & R. Vell (Eds.), *Reading science: critical and functional perspectives on discourses of science.* (pp. 87–113). New York: Routledge.

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

Li, S., Marquart, J. M., & Zercher, C. (2000). Conceptual issues and analytic strategies in mixed-method studies of preschool inclusion. *Journal of Early Intervention*, *23*(2), 116–132. doi:10.1177/105381510002300206

Linn, M., Lee, H., Tinker, R., Husic, F., & Chiu, J. L. (2006). Teaching and assessing knowledge integration in science. *Science*, *313*(5790), 1049–1050. doi:10.1126/sciencce.1131408

Linn, M. C., Clark, D., & Slotta, J. D. (2003). WISE design for knowledge integration. *Science Education*, *87*(4), 517–538. doi:10.1002/sce.10086

Linn, M. C., & Eylon, B.-S. (2011). *Science learning and instruction: Taking advantage of technology to promote knowledge integration* (p. 340). Florence, KY: Routledge, Taylor & Francis Group.

Linn, M. C., & Eylon, B.-S. (2011). *Science learning and instruction: Taking advantage of technology to promote knowledge integration*. New York: Routledge.

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

Lipshitz, R., Popper, M., & Friedman, V. J. (2002). A multifacet model of organizational learning. *The Journal of Applied Behavioral Science*, *38*(1), 78–98. doi:10.1177/0021886302381005

Lou, Y., Abrami, P. C., & D'Apollonia, S. (2001). Small group and individual learning with technology: A meta-analysis. *Review of Educational Research*, *71*, 449–521.

Mandl, H., & Levin, J. R. (1989). *Knowledge acquisition from text and pictures*. (H. Mandl & J. . Levin, Eds.). Amsterdam, Netherlands: ElsevierScience Publishers B.V.

Manlove, S., Lazonder, A. W., & de Jong, T. (2009). Collaborative versus individual use of regulative software scaffolds during scientific inquiry learning. *Interactive Learning Environments*, *17*(2), 105–117. doi:10.1080/10494820701706437

Marchand, H. (2012). Contributions of Piagetian and post-Piagetian theories to education. *Educational Research Review*, *7*(3), 165–176. doi:10.1016/j.edurev.2012.04.002

Matthews, M. R. (1994). *Science teaching: The role of history and philosophy of science.* New York: Routledge.

Matuk, C., & Linn, M. (2012). Technology integration to scaffold and assess students ' use of visual evidence in science inquiry. In *American Educational Research Association (AERA) Conference, Vancouver, April* (pp. 1–8).

Mayer, R. E. (2003). The promise of multimedia learning: using the same instructional design methods across different media. *Learning and Instruction*, *13*(2), 125–139. doi:10.1016/S0959-4752(02)00016-6

Mcelhaney, K. W., Matuk, C. F., Miller, D. I., & Linn, M. C. (2012). Using the idea manager to promote coherent understanding of inquiry investigations. In *International Conference of Learning Sciences 2012* (pp. 1–8). Sydney, Australia.

Mcfarlane, A., & Sakellariou, S. (2002). The role of ICT in science education. *Cambridge Journal of Education*, *32*(2), 219–232. doi:10.1080/0305764022014756

Moskaliuk, J., Kimmerle, J., & Cress, U. (2009). Wiki-supported learning and knowledge building: effects of incongruity between knowledge and information. *Journal of Computer Assisted Learning*, *25*(6), 549–561. doi:10.1111/j.1365-2729.2009.00331.x

Namdar, B., & Shen, J. (2014). Knowledge organization with multiple external representations for socioscientific argumentation: A case on nuclear energy. Polman, J. L., Kyza, E. A., O'Neill, D. K., Tabak, I., Penuel, W. R., Jurow, A. S., O'Connor, K., Lee, T., and D'Amico, L. (Eds.). (2014). Learning and becoming in practice: The International Conference of the Learning Sciences (ICLS) 2014, Volume 1. Boulder, CO: International Society of the Learning Sciences. pp. 254-261.

Namdar, B., & Shen, J. (2013). Knowledge organization with multiple external representations in an argumentation based computer supported collaborative learning environment. In N. Rummel, M. Kapur, M. Nathan, & S. Puntambekar (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). Madison, WI: International Society of the Learning Sciences.

Neuendorf, K. A. (2002). *The content analysis guidebook.* Thousand Oaks, CA: Sage.

NGSS Lead States (2013). *Next generation science standards: For states, by state*s. Washington, DC: The National Academies Press.

Newton, P., Driver, R., & Osborne, J. (1999). The place of argumentation in the pedagogy of school science. *International Journal of Science Education*, *21*(5), 553–576. doi:10.1080/095006999290570

Noroozi, O., Weinberger, A., Biemans, H. J. A., Mulder, M., & Chizari, M. (2012). Argumentation-based computer supported collaborative learning (ABCSCL): A synthesis of 15 years of research. *Educational Research Review*, *7*(2), 79–106. doi:10.1016/j.edurev.2011.11.006

Novak, J. D., & Cañas, A. J. (2008). *The theory underlying concept maps and how to construct and use them* (pp. 1–36).

NRC. (2012). Framework for K-12 science education : Practices , crosscutting concepts , and core ideas. Social Sciences. Washington, DC: The National Academies Press.

Onwuegbuzie, A. J., & Johnson, R. B. (2006). The validity issue in mixed research. *Research in the Schools*, *13*(1), 48–63.

Onwuegbuzie, A. J., & Teddlie, C. (2003). A framework for analyzing data in mixed methods research. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of mixed methods in social and behavioral research* (pp. 351–383). Thousand Oaks, CA: sage.

Osborne, J. (2010). Arguing to learn in science: the role of collaborative, critical discourse. *Science (New York, N.Y.), 328*(5977), 463–6. doi:10.1126/science.1183944

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching*, *41*(10), 994–1020. doi:10.1002/tea.20035

Patton, M. Q. (2002). *Qualitative Research and Evaluation Methods* (3rd ed.). Thousand Oaks, CA: Sage.

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

Prain, V., & Tytler, R. (2012). Learning through constructing representations in science: A framework of representational construction affordances. *International Journal of Science Education*, *34*(17), 2751–2773. doi:10.1080/09500693.2011.626462

Reike, R. D., & Sillars, M. O. (1993). *Argumentation and critical decision making* (3rd ed.). New York, NY: Harper-Collins College Publishers.

Rodriguez, A. J. (1998). Strategies for counterresistance: Toward sociotransformative constructivism and learning to teach science for diversity and for understanding. *Journal of Research in Science Teaching*, *35*(6), 589–622. doi:10.1002/(SICI)1098-2736(199808)35:6<589::AID-TEA2>3.0.CO;2-I

Ryoo, K., & Linn, M. C. (2012). Can dynamic visualizations improve middle school students' understanding of energy in photosynthesis? *Journal of Research in Science Teaching*, *49*(2), 218–243. doi:10.1002/tea.21003

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching*, *41*(5), 513–536. doi:10.1002/tea.20009

Sadler, T. D. (2011). Situating socio-scientific issues in classrooms as a means of achieving goals of science education. In T. D. Sadler (Ed.), *Socio-scientific Issues in the Classroom Teaching, Learning and Research* (Vol. 39, pp. 1–9). Dordrecht: Springer Netherlands. doi:10.1007/978-94-007-1159-4

Sadler, T. D., & Donnelly, L. A. (2006). Socioscientific argumentation: The effects of content knowledge and morality. *International Journal of Science Education, 28*(12), 1463–1488. doi:10.1080/09500690600708717

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

Sampson, V., & Clark, D. (2009a). The impact of collaboration on the outcomes of scientific argumentation. *Science Education*, *93*(3), 448–484. doi:10.1002/sce.20306

Sampson, V., & Clark, D. B. (2009b). A comparison of the collaborative scientific argumentation practices of two high and two low performing groups. *Research in Science Education*, *41*(1), 63–97. doi:10.1007/s11165-009-9146-9

Sandelowski, M. (2003). Tables or tableaux: The challenges of writing and reading mixed methods studies. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of mixed methods in social and behavioral research* (pp. 321–350). Thousand Oaks, CA: Sage.

Sawyer, R. K., & Berson, S. (2004). Study group discourse: How external representations affect collaborative conversation. *Linguistics afile:///C:/Users/Baja/Desktop/1-s2.0-S0898589805000288-Main.pdfnd Education*, *15*(4), 387–412. doi:10.1016/j.linged.2005.03.002

Sawyer, Keith, R. (2006). Preface. In R. Sawyer, Keith (Ed.), *The Cambridge handbook of the learning sciences* (pp. xi–xiv). New York, NY: Cambridge University Press.

Scardamalia, M., & Bereiter, C. (2003). Knowledge building. New York: Macmillan. In J. W. Guthrie (Ed.), *Encyclopedia of education* (2nd ed., pp. 1370–1373). New York: Macmillan.

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.

Schechter, C. (2012). Developing teachers' collective learning: Collective learning from success as perceived by three echelons in the school system. *International Journal of Educational Research*. doi:10.1016/j.ijer.2012.06.005

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., … Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching*, *46*(6), 632–654. doi:10.1002/tea.20311

Shen, J. (2006). *Teaching strategies and conceptual change in professional development program for science teachers of K-8. Unpublished doctoral dissertation*. Washington University in St. Louis.

Shen, J., & Confrey, J. (2007). From conceptual change to transformative modeling: A case study of an elementary teacher in learning astronomy. *Science Education*, *91*(6), 948–966. doi:10.1002/sce

Shen, J., & Linn, M. C. (2011). A technology-enhanced unit of modeling static electricity: Integrating scientific explanations and everyday observations. *International Journal of Science Education*, *33*(12), 1597–1623. doi:10.1080/09500693.2010.514012

Simmoneaux, L. (2007). Argumentation in socio-scientific contexts. In S. Erduran & M. P. Jimenez-Aleixandre (Eds.), *Argumentation in Science Education: Perspectives from Classroom-based Research* (pp. 179–199). Springer.

Simons, K., & Clark, D. (2005). Supporting inquiry in science classrooms with the web. *Computers in the Schools*, *21*(3-4), 23–36. doi:10.1300/J025v21n03_04

Smith, M. . (2006). Smith_2006_Multiple methodology in education research.pdf. In J. L. Green, G. Camilli, & P. B. Elmore (Eds.), *Handbook of complementary methods in education research* (pp. 457–475). Mahwah NJ: Lawrence Erlbaum Associates for AERA.

Stahl, G., Koschmann, T., & Suthers, D. D. (2006). Computer-supported collaborative learning. In R. Sawyer, K (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp. 409–426). New York, NY: Cambridge University Press.

Stegmann, K., Wecker, C., Weinberger, A., & Fischer, F. (2011). Collaborative argumentation and cognitive elaboration in a computer-supported collaborative learning environment. *Instructional Science*, *40*(2), 297–323. doi:10.1007/s11251-011-9174-5

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.

Stratford, S. J., Krajcik, J., & Soloway, E. (1998). Secondary students' dynamic modeling processes : Analyzing, reasoning about, synthesizing, and testing models of stream ecosystems. *Journal of Science Education and Technology*, *7*(3), 215–234. doi:10.1023/A:1021840407112

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. doi:10.1177/0011000006290983

Tal, R. T., & Hochberg, N. (2003). Reasoning, problem-solving and reflections: Participating in WISE project in Israel. *Science Education International*, *14*, 3–19.

Tal, R. T., Kali, Y., Magid, S., & Madhok, J. J. (2011). Socio-scientific issues in the classroom, In T.D. Sadler (ed.), Socio-scientific issues in the classroom: Teaching,learning and research, contemporary trends and issues in science education 39, 11–38. doi:10.1007/978-94-007-1159-4

Tal, R. T., & Kedmi, Y. (2006). Teaching socioscientific issues: classroom culture and students' performances. *Cultural Studies of Science Education*, *1*(4), 615–644. doi:10.1007/s11422-006-9026-9

Tashakkori, A., & Teddlie, C. (1998). *Mixed methodology:Combining qualitative and quantitative approaches*. Thousand Oaks, CA: Sage.

Teddlie, C., & Tashakkori, A. (2003). Major issues and controversies in the use of mixed methods in the social and behavioral sciences. In C. Teddlie & A. Tashakkori (Eds.), *Handbook of mixed methods in social and behavioral research* (pp. 3–50). Thousand Oaks, CA: Sage.

Teddlie, C., & Yu, F. (2007). Mixed methods sampling: A typology with examples. *Journal of Mixed Methods Research*, *1*(1), 77–100. doi:10.1177/2345678906292430

Toulmin, S. (1958). *The uses of argument*. Cambridge, UK: Cambridge University Press.

Toulmin, S., Reike, R. D., & Janik, A. (1979). *In introduction to reasoning*. New York: Macmillan.

Tsui C-Y (2003) Teaching and learning genetics with multiple representations. Unpublished Doctoral Dissertation. Curtin Uni- versity of Technology, Perth, Australia

Tsui, C., & Treagust, D. F. (2003). Genetics reasoning with multiple external representations. *Research in Science Education*, *33*, 111–135.

Van der Meij, J., & de Jong, T. (2006). Supporting students' learning with multiple representations in a dynamic simulation-based learning environment. *Learning and Instruction*, *16*(3), 199–212. doi:10.1016/j.learninstruc.2006.03.007

Van Eemeren, F. H. (1995). A world of difference : The rich state of argumentation theory. *Informal Logic*, *17*(2), 144–158.

Van Eemeren, F. H., & Grootendorst, R. (1992). *Argumentation, communication, and fallacies: A pragma-dialectical perspectice* (p. 236). Hillsdale, NJ: Lawrence Erlbaum Associates.

Van Eemeren, F. H., & Grootendorst, R. (1999). Developments in argumentation theory. In J. Andriessen & P. Coirier (Eds.), *Foundations of argumentative text processing* (pp. 43–57). Amsterdam: Amsterdam University Press.

Van Eemeren, F. H., & Grootendorst, R. (2004). *A systematic theory of argumentation. The pragma-dialectical approach* (p. 216). Cambridge, UK: Cambridge University Press.

Van Eemeren, F. H., Grootendorst, R., & Henkemans, F. S. (1996). *Fundamentals of argumentation theory: A handbook of historical backgrounds and contemporary developments* (p. 424). Mahwah NJ: Lawrence Erlbaum Associates.

Van Eemeren, F. H., & Houtlosser, P. (1999). Strategic manoeuvring in argumentative discourse. *Discourse Studies*, *1*(4), 479–497. doi:10.1177/1461445699001004005

Vanides, J., Yin, Y., Tomita, M., & Ruiz-Primo, M. A. (2005). Using concept maps in the science classroom. *Science Scope*, *28*(8), 27–31.

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

Waldrip, B., Prain, V., & Carolan, J. (2006). Learning Junior Secondary Science through Multi-Modal Representations, *11*(1).

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

Walker, P. J., Sampson, V., Grooms, J., Anderson, B., & Zimmerman, C. O. (2012). Argument-Driven Inquiry in Undergraduate Chemistry Labs: The Impact on Students' Conceptual Understanding, Argument Skills, and Attitudes Toward Science. *Journal of College Science Teaching*, *41*(4), 74–81.

Walton, D. (1998). *The new dialectic. Conversational contexts of argument* (p. 304). Toronto: Buffalo: London: University of Toronto Press.

Walton, D. (2007). *Dialog theory for critical discussion* (p. 307). Amsterdam/Philadelphia: John Benjamins.

Weber, R. P. (1990). (1990). *Basic content analysis*. Beverly Hills, CA: Sage.

White, B. Y., & Frederiksen, J. R. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction*, *16*(1), 3–118. doi:10.1207/s1532690xci1601_2

Wong, D., Poo, S. P., Hock, N. E., & Kang, W. L. (2011). Learning with multiple representations : an example of a, *178*.

Wu, H.-K. (2010). Modelling a complex system: Using novice-expert analysis for developing an effective technology-enhanced learning environment. *International Journal of Science Education*, *32*(2), 195–219. doi:10.1080/09500690802478077

Wu, H.-K., & Krajcik, J. S. (2006). Inscriptional practices in two inquiry-based classrooms: A case study of seventh graders' use of data tables and graphs. *Journal of Research in Science Teaching*, *43*(1), 63–95. doi:10.1002/tea.20092

Wu, H.-K., & Puntambekar, S. (2012). Pedagogical affordances of multiple external representations in scientific processes. *Journal of Science Education and Technology*, 754–767. doi:10.1007/s10956-011-9363-7

Yoon, J., & Brice, L. (2011). Water project : Computer-supported collaborative e-learning model for integrating science and social studies. *Contemporary Educational Technology*, *2*(3), 250–263.

Yoon, S. A. (2011). Using social network graphs as visualization tools to influence peer selection decision-making strategies to access information about complex socioscientific issues. *Journal of the Learning Sciences*, *20*(4), 549–588.

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., Osborne, J., Erduran, S., Simon, S., & Monk, M. (2006). The role of argument during discourse about socioscientific issues. In D. L. Zeidler (Ed.), *The role of moral reasoning on socioscientific issues and discourse in science education* (pp. 97–116). Dordrecht: Springer.

Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research-based framework for socioscientific issues education. *Science Education*, *89*(3), 357–377. doi:10.1002/sce.20048

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. doi:10.1002/sce.10025

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching, 39*(1), 35–62. doi:10.1002/tea.10008

APPENDIX A

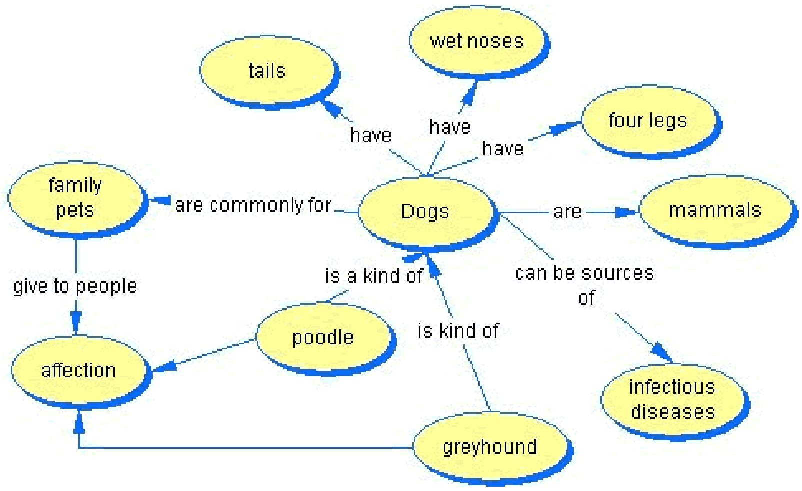
NUCLEAR ENERGY UNIT LESSON PLANS

Day 1 (55 Minutes)

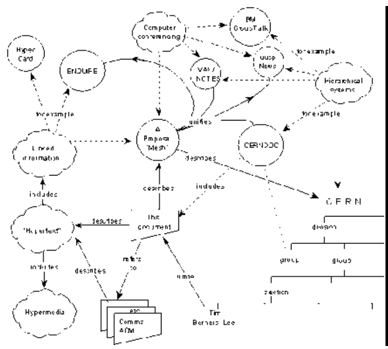
1) Consent forms (5 minutes)
2) Argumentation Essentials (5 Minutes)
   a. What is argumentation? The place of argumentation in the new framework
3) Components of Arguments (10 Minutes)
   a. Students will watch a YouTube video http://www.youtube.com/watch?v=DlB1PcgkYLU). Here I will ask them the following guiding questions in three aspects:
      - Claim/Explanation (What is he arguing for?)
      - Evidence (How does he support his argument?)
      - Reasoning (How does his evidence support his claim?)
4) Activity: Build your own argument (10 minutes)
   a. Please answer the following question:______________________

Question:		
Claim/Explanation (Provide an answer to the question)	**Evidence (Measurements/Observations)**	**Reasoning (How your evidence support your claim/explanation and why the evidence should count as support)**

5) Conclusion (5 minutes)
   a. Why is it important? How should you integrate it in your own classrooms?
6) Concept Map (15 minutes)
   a. What is a concept map?
   b. Example



c. Why do we use concept maps?
d. What are the purposes of using a concept map?
e. Components of a concept map?
f. Identify the better concept map.



g. Thinking about the argumentation structure that we talked about previously
    i. Answer the following question: Which of the concept map on the screen is a better concept map?

Possible answer should look like the following

Claim: The concept map on the right is a better concept map

Evidence: It includes proper/ accurate propositions to connect nodes.

Reasoning: The one on the right is a more accurate one because a concept map should include links and propositions when connecting the ideas presented in the concept map.

7) Some concept mapping tools you can use in your own classroom (3 Minutes)
    i. Webspiration/Inspiration (link)
    ii. CMap (link)
    iii. iKOS
8) Create a concept map of energy (10 minutes): Students work together in their table to create a concept map regarding energy topics that they have learned through the course.

HOMEWORK

1) Creating accounts
    a. Create students accounts
    b. Log into NEU class Password is:

DAY 2. INTRODUCTION TO iKOS (60 Minutes)

2) Create entries (40 minutes)
    a. I will show students how to create and submit entries (15 minutes: i—iii, 10 min; iv, 5min)
        i. Event, emphasizing the following criteria
            1. Understand how to upload a (multiple) background picture (s)
            2. Emphasize the event is more useful for showing processes or multiple components
            3. Students can point out the resource/link of the image in the box below the event window
        ii. Wiki, emphasizing the following criteria
            1. Do not make a wiki entry too long (breaking long entry into several smaller ones)
            2. Enter keywords
            3. Use one's own words
            4. Communicate the meaning at the level your classmates can understand
            5. Point out citation/resources/links
        iii. Concept Map, emphasizing the following criteria
            1. Words or short phrase in the bubbles, not sentences
            2. Include linking phrases

            3. At least 5 nodes
        iv. Submitting entries to open to the class (5 minutes)
            1. Importance of keywords
            2. Co-edit, Comment, Rate
    b. Students will create entries on nuclear energy
        i. Directions: Create one entry on each mode on nuclear energy
        ii. Have at least 5 keywords for wiki entry, at least 5 nodes for event and concept map entries ; double check the linking phrase

HOMEWORK:

1) Assign students to read an article on nuclear power plant building; thinking of the following questions
    a. How far should we depend on nuclear energy as an energy source?
    b. Is it OK to build nuclear power plants in our state?

2) Before coming to the next class, students should create at least 1 entry on each mode to understand the underpinnings of the nuclear energy issue.
3) Students should make sure NOT to copy and paste information from other sources in WIKI mode. They should construct their wiki entry on their own words. Students should include at least five key words and tags in their wiki and event entries. Concept map entries should include at least 5-10 nodes.

DAY 3. COLLABORATIVE LEARNING

1) Students log in to their accounts (5 minutes)
2) Show students two brief YouTube videos focusing on nuclear energy (5 minutes)
    a.
3) In their groups students should discuss the following questions (15 minutes)
    a. Based on their knowledge organization entries that they created as their homework and the videos that they watched students will be asked to answer the following questions
        i. How far should we depend on nuclear energy as an energy source?
        ii. Is it OK to build nuclear power plants in our state?

NOTE: While arguing on each question, ask students to provide their claim/explanation, evidence, and reasoning.

4) Collaborative Knowledge Organization (60-80 minutes)
    a. Acknowledging the complexity of nuclear energy (rationale for the following activity)

b. As a group, ask students to focus on one science aspect of the nuclear energy (i.e., radiation, how nuclear power plants operate, nuclear waste and bio magnification etc.).
c. Ask students what aspect they decide to focus on. Make sure that all groups focus on different scientific aspect.
d. Remind students that they will present their knowledge entries to the classroom.
e. A group should work on one computer, but making sure they utilize all members' input/entries

DAY 4. COLLECTIVE LEARNING ABOUT THE SCIENCE BEHIND NUCLEAR ENERGY

1) Group presentation (15 minutes for each group) (4 groups/5-6 students in each group)
    a. Groups will have 10 minutes to present their entries
    b. At the beginning of the presentation ask them if they reached a consensus about the nuclear energy dependency and nuclear energy as a reliable energy source.
        i. Ask them to state their claim, evidence, and reasoning
    c. After 10 minute group presentation, let the audience ask questions for 5 minutes

APPENDIX B

R CODES FOR KEYACTOR ANALYSIS

#Spring 2013 Data Key Actor Analysis

```
"D:\\Dropbox\\Dr. Shen & Baha_Meeting Folder\\Spring Data Analysis\\Network
Connections.csv"

dta <- read.csv("c:\\users\\msgc\\dropbox\\baja.csv", header = TRUE, sep = ",", skip =
0,row.names = NULL)
rownames(dta)<-dta[,1]
dta2<-dta[,-1]
dim(dta2)
library(igraph)
G<-graph.adjacency(dta2, mode=c("undirected"))
cent<-data.frame(bet=betweenness(G),eig=evcent(G)$vector)
cent

rownames(cent)<-rownames(dta)
rownames(cent)<-rownames(dta)

res<-lm(eig~bet,data=cent)$residuals
cent<-transform(cent,res=res)

install.packages("ggplot2")
library(ggplot2)
p<-ggplot(cent,aes(x=bet,y=eig, label=rownames(cent),colour=res,
size=abs(res)))+xlab("Betweenness Centrality")+ylab("Eigenvector Centrality")
p+geom_point()+labs(title="Key Actor Analysis for iKOS Entries")
p+geom_text()+labs(title="Key Actor Analysis for iKOS Entries")
p + geom_point() + geom_text(hjust=2, vjust=2)+labs(title="Key Actor Analysis ")
coeffs<-as.data.frame(coef(lm(eig~bet,data=cent)))
#To add the regression line that depicts the best possible distributioon we compute the linear
regression
p + geom_point() + geom_text(hjust=2, vjust=2)+labs(title="Key Actor Analysis") +
geom_abline(intercept = coeffs[1,], slope = coeffs[2,],colour = "red", size = 2,alpha=.25)
p + geom_point() + geom_text(hjust=2, vjust=2)+labs(title="Key Actor Analysis for iKOS
Entries") + geom_abline(intercept = coeffs[1,], slope = coeffs[2,],colour = "red", size =
2,alpha=.25) + theme(legend.position = "none")

# Top 25% of eigenvectors shown
```

```
library(igraph)
G<-graph.adjacency(dta2, mode=c("undirected"))
cent<-data.frame(bet=betweenness(G),eig=evcent(G)$vector)
rownames(cent)<-rownames(dta) #Ids in this case
res<-lm(eig~bet,data=cent)$residuals
cent<-transform(cent,res=res)
set.seed(12)
G<-simplify(G)
l<-layout.fruchterman.reingold(G, niter=100)
V(G)$name<-rownames(dta)
V(G)$size<-abs((cent$bet)/max(cent$bet))*10 #The divisor is the highest betweenness
V(G)$color<-NA
V(G)$color[1:17]<-"red"
V(G)$color[18:40]<-"green"
V(G)$color[41:60]<-"yellow"
V(G)$edge.color<-NA
V(G)$label.cex<-.5
labCol<-rgb(33, 33, 33,255/2,max=255)
labCol2<-rgb(199, 199, 199,255/3,max=255)
nodes<-V(G)$name # Setting a variable to manipulte names, nodes contains the IDs of the
participants
x<-summary(cent$eig)
nodes[which(abs(cent$eig)<(x[5]))]<-NA # this gives the top 25%
# nodes[which(abs(cent$eig)>(x[2]))]<-NA  # this gives the bottom 25%
plot(G,layout=l,vertex.label=nodes, vertex.label.dist=0.0025,
vertex.label.color="red",edge.width=0.1)
pdf("actor_plot.pdf", 15, 15)
plot(G,layout=l,vertex.label=nodes, vertex.label.dist=0.0,
vertex.label.color=labCol,edge.width=.01, edge.color=labCol2, vertex.frame.color=NA)
title(main="Key Actor Analysis for iKOS Entries", sub="Key actors weigthed by eigenvector
and betweenness centrality", col.main="black", col.sub="black",
cex.sub=1.2,cex.main=2,font.sub=2)
dev.off()

# All names shown
library(igraph)
G<-graph.adjacency(dta2, mode=c("undirected"))
cent<-data.frame(bet=betweenness(G),eig=evcent(G)$vector)
rownames(cent)<-rownames(dta) #Ids in this case
res<-lm(eig~bet,data=cent)$residuals
cent<-transform(cent,res=res)
set.seed(12)
G<-simplify(G)
l<-layout.fruchterman.reingold(G, niter=100)
V(G)$name<-rownames(dta)
V(G)$size<-abs((cent$bet)/max(cent$bet))*10 #The divisor is the highest betweenness
```

```
V(G)$color<-NA
V(G)$color[1:17]<-"red"
V(G)$color[18:40]<-"green"
V(G)$color[41:60]<-"yellow"
V(G)$edge.color<-NA
V(G)$label.cex<-.5
labCol<-rgb(33, 33, 33,255/2,max=255)
labCol2<-rgb(199, 199, 199,255/3,max=255)
nodes<-V(G)$name # Setting a variable to manipulte names, nodes contains the IDs of the
participants
# x<-summary(cent$eig)
# nodes[which(abs(cent$eig)<(x[5]))]<-NA # this gives the top 25%
# nodes[which(abs(cent$eig)>(x[2]))]<-NA  # this gives the bottom 25%
plot(G,layout=l,vertex.label=nodes, vertex.label.dist=0.0025,
vertex.label.color="red",edge.width=0.1)
pdf("actor_plot_All.pdf", 15, 15)
plot(G,layout=l,vertex.label=nodes, vertex.label.dist=0.0,
vertex.label.color=labCol,edge.width=.01, edge.color=labCol2, vertex.frame.color=NA)
title(main="Key Actor Analysis for iKOS Entries", sub="Key actors weigthed by eigenvector
and betweenness centrality", col.main="black", col.sub="black",
cex.sub=1.2,cex.main=2,font.sub=2)
dev.off()
```

APPENDIX C

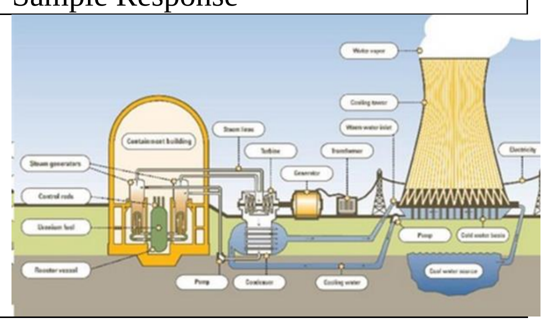
KNOWLEDGE ORGANIZATION SCORING RUBRICS

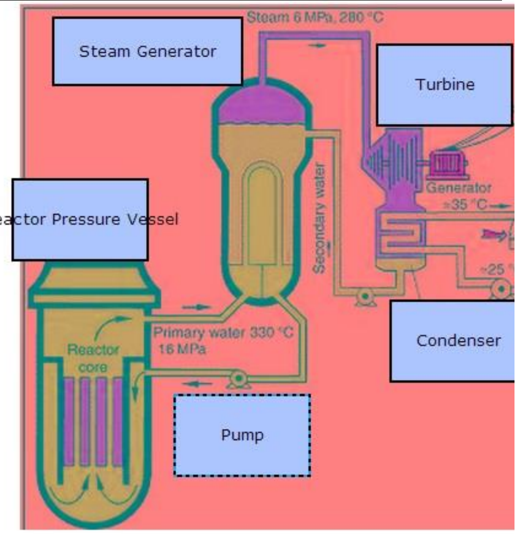
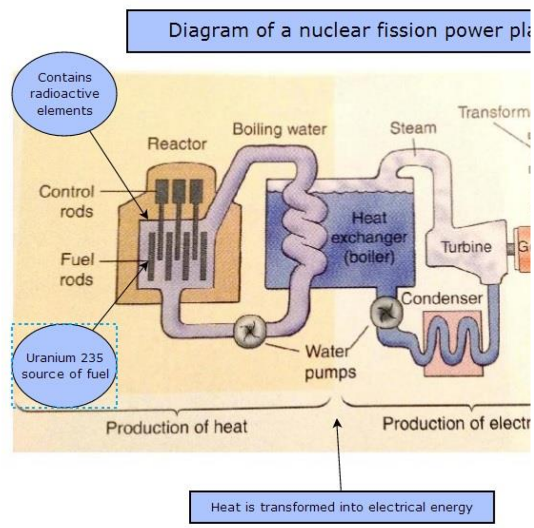
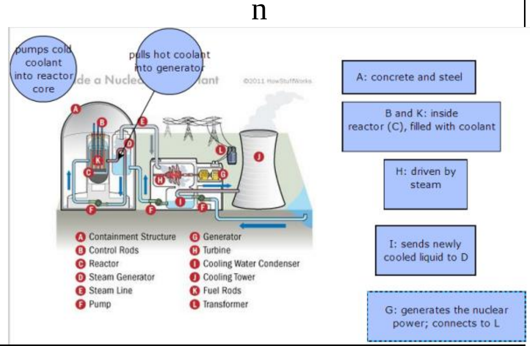
Wiki Conceptual Quality Scoring Rubric

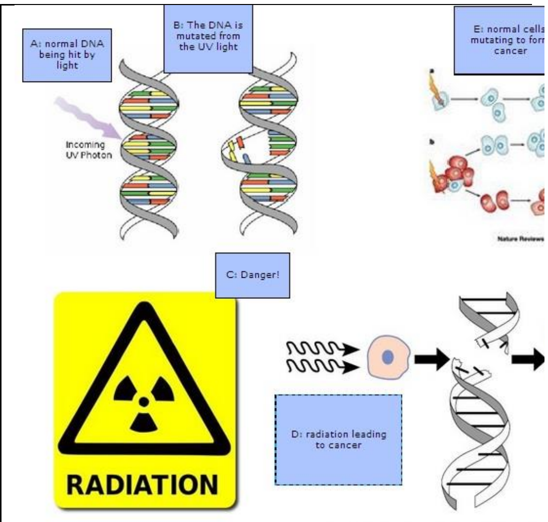
Score	KI Level	Description (Wiki entry includes)	Sample Response
1	Off-task	No answer or off task	"I have nothing to say"
2	No Link	Non Normative or scientifically invalid links/ideas	"When a roller coaster is rolling, energy is what is causing it to move! It goes around flips and turns all because of this energy. When a roller coaster is sitting still it has all this potential energy. While sitting still at the bottom, 100% of its energy is potential energy. While the coaster is going up the energy is being transferred from potential to kinetic. So then when it is on the top of the hill it is 100% kinetic energy. Then energy always adds up to be the same amount it is just being transferred to something different, the law of conservation of energy!"
3	Partial Link	Normative ideas without scientifically valid connections between ideas Includes one full link but also normative ideas without providing any connections.	"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."
4	Full Link	One scientifically valid and	"Process of nuclear fission begins by shooting a single neutron into Uranium 235. The uranium then becomes Uranium 236, which is highly unstable. It then splits into

		elaborated link between normative and relevant nuclear energy ideas	Barium and Krypton along with a release of heat and energy. Atoms continue splitting as neutrons continue being released.”
5	Complex Link	Two or more scientifically valid and elaborated links between normative and relevant nuclear energy ideas	“Radiation is sending out energy from a source. There are multiple types of radiation, but the two most common types that cause cancer are: 1. x-rays 2. Radiation from nuclear reactors (man-made radiation). The radiation that comes from nuclear reactors is ionizing radiation. Ionizing radiation = high-frequency radiation that removes electrons from atoms or molecules (ionization). 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. 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. picture 2 Types of ionizing radiation: 1. Radioactive materials such as alpha particles and protons are types of ionizing radiation; they have different energy levels, and penetrate cells to different extents, but can all cause cancer

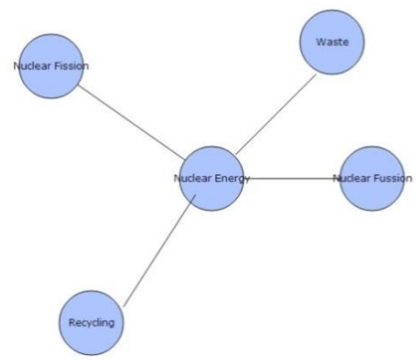
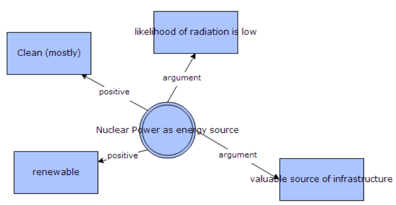
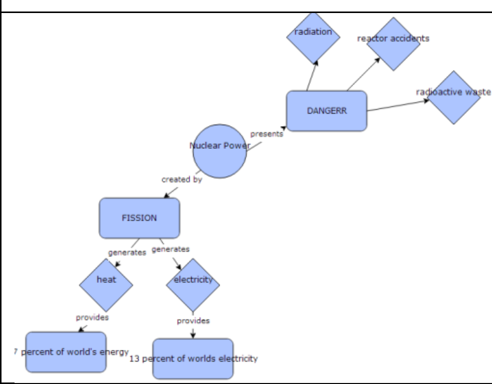
Event Conceptual Quality Scoring Rubric

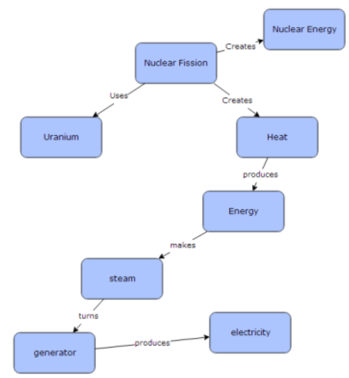
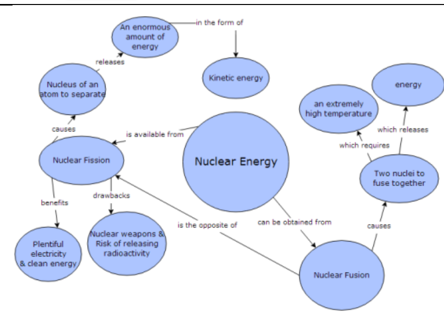
Score	KI Level	Description	Sample Response
1	Irrelevant/No information	Off task (No tags included to explain/elaborate on the scientific phenomena/principle depicted in the event. Although the picture includes existing tags, does not reflect student’s own understanding)	

2	Incomplete	Non Normative or scientifically invalid links/ideas • (Tags include non normative ideas or • does not serve to the purpose of linking (socio)scientific ideas or • tags are used in inappropriate places or scientific information is not correct)	
3	Partial	Normative ideas without scientifically valid connections between ideas (Event includes a)appropriately placed tags and b)partially correct scientific ideas)	“ 
4	Full	One scientifically valid and elaborated link between normative and relevant nuclear energy ideas (Event includes a) appropriately placed tags and b)tags include completely correct scientific ideas/principles/ explanations)	n 

5	Complex	Two or more scientifically valid and elaborated links between normative and relevant nuclear ideas connected in one or multiple visuals (Event includes a) at least two different scientific principle depicted either in one visual or multiple visuals and one of the following either b) appropriately placed tags or c) fully correct scientific definitions/explanations/phrases in the tags)	

Concept map Knowledge Organization Scoring Rubric

Score	KI Level	Description	Sample Response
1	No information	Concept map only includes nodes but no linking words or links in between nodes (concepts) Or concept map does not include any (socio)scientific ideas	
2	Incomplete	Non Normative or scientifically invalid links/ideas or concept map does not have any hierarchy or concept map includes scientifically inaccurate information	
3	Partial	Normative ideas without scientifically valid connections between ideas (Concept maps include normative/ (socio)scientific ideas without scientifically valid connections between ideas or	

		Concept maps include normative ideas but also includes some invalid scientific ideas Concept maps includes normative ideas but does not elaborate on the scientific ideas completely	
4	Full	One scientifically valid and elaborated link between normative and relevant nuclear energy ideas or socioscientific ideas	
5	Complex	Concept map includes two or more scientifically valid and elaborated links between normative and relevant nuclear energy ideas	

Technical Quality Scoring Rubric

Description	Score 1	Score 2	Score 3
Number of keywords used	0-1	2-3	3-5
In Event: Number of keywords accurately placed	None	Some	Most
In Wiki : Key words are related to content	None	Some	Most
In Concept Map: Prepositions are accurate	Less than half	More than half	Most