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Concept Maps in the Science Classroom

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Science curriculums are often contain concepts and vocabulary that students are expected to memorize through reading and listening to lectures. Unfortunately rote learning is often short term without a complete understanding. Concept maps are designed to use a cognitive structure of hierarchical organization with more general concepts occupying higher levels and more specific concepts at lower levels. The map is a diagram that represents conceptual and verbal knowledge in graphical and visual forms. Prior studies have shown concept maps are a meaningful learning tool and an alternative to rote learning when students work cooperatively in small groups. The study investigated the effectiveness of using concept maps in the high school chemistry classroom. The students learned from each other while working in small groups and addressed any misconceptions. The concept map is an important tool for science teachers to use for effective understanding.

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Abstract

Science curriculums are often contain concepts and vocabulary that students are expected to memorize through reading and listening to lectures. Unfortunately rote learning is often short term without a complete understanding. Concept maps are designed to use a cognitive structure of hierarchical organization with more general concepts occupying higher levels and more specific concepts at lower levels. The map is a diagram that represents conceptual and verbal knowledge in graphical and visual forms. Prior studies have shown concept maps are a meaningful learning tool and an alternative to rote learning when students work cooperatively in small groups. The study investigated the effectiveness of using concept maps in the high school chemistry classroom. The students learned from each other while working in small groups and addressed any misconceptions. The concept map is an important tool for science teachers to use for effective understanding.

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Concepts Maps in the Science Classroom

Rote learning is often used in the science classroom as there are numerous terms and concepts in the curriculums to be learned. Students often use rote learning to succeed with standardized, multiple choice questions. Unfortunately, this verbatim method of memorized knowledge is often lost in a short time if not reviewed consistently. More meaningful learning happens when the student actively uses prior knowledge to relate to new knowledge and concepts.

Concept maps were originally developed in a Cornell University research program that attempted to understand the changes in a child's knowledge of science. The program was led by Novak (1998) and was based on the learning psychology of Ausubel (1963). The fundamental idea of Ausubel's cognitive development theory was that learning takes place by the assimilation of new concepts into prior knowledge of the learner. Ausubel believed cognitive structure is hierarchical organization with more general concepts occupying higher levels and more specific concepts at lower levels.

The concept map is a node-look diagram that expresses conceptual and verbal knowledge in graphical and visual forms. In comparison to Ausubel's (1968) cognitive structure, the concept map is represented with the most inclusive or most general concepts at the top of the map and the more specific, less general concepts arranged below. Concept maps have been found to be a meaningful learning tool when students work cooperatively in small groups to learn subject matter.

The study will investigate the effectiveness of using concept maps in the high school chemistry classroom. The study will research if concept maps are helpful for understanding chemistry concepts as opposed to not using maps and simply having the students use rote memorization. This will be investigated by having one class, with students working in heterogeneous groups, create concept maps of different topics and another class not creating the maps. The students will be surveyed and assessed for the usefulness of the maps. The study will research if the concept map, a representation of conceptual and verbal knowledge in visual form, is an important tool for science teachers to use for effective understanding.

Literature Review

Meaningful learning occurs when a student chooses to relate new knowledge to prior knowledge. Ausubel (1963) believed learning is meaningful when the relationships between concepts are precise and integrated. Students should be taught meta-cognitive learning tools that enable them to construct structural and organized representations of the knowledge in order to transition from rote learning to more meaningful learning.

Education researchers have developed different methods for constructing and assessing concept maps. The maps contain propositions and relationships to describe the concepts. The hierarchical structures can be constructed with pencil and paper or computer software. Some education researchers and science teachers believe when students work in small groups to cooperatively construct concept maps, it can be a powerful learning tool.

The literature review covers ideas from Ausubel (1964) and Novak (1984) on meaningful learning and concepts. The review will discuss the development and hierarchical structure of the concept map with propositions between concepts. Alternative methods for creating concept maps such as computer software including Inspiration and Cmap Tools will be reviewed. The literature review will cover assessment and benefits of using small groups for discussions while preparing concept maps.

Meaningful Learning and Concepts

Science curriculums are often filled with copious amounts of vocabulary and concepts. Students tend to use memorization as a way to quickly learn the required terms to succeed with multiple choice, standardized examinations. Unfortunately, memorization does not help a student understand scientific concepts and can often lead to misconceptions (Canas & Novak, 2006). Canas et al. stated “This is characteristic of students who sometimes learn by rote and sometimes at relatively low levels of meaningful learning” (p. 177). When students develop misconceptions it makes learning science difficult and may be a reason that teachers simply ask students to use rote learning and memorize concept definitions (Novak, 1991).

Rote learning happens when the student memorizes new information without relating it to prior knowledge (Novak, 1991). This type of learning is arbitrary, verbatim, and non-substantive incorporation into cognitive structure**.** Novak stated “information learned by rote usually forgotten in two to three weeks unless continually reinforced” (p. 47). The limiting factor of short term memory is that the brain holds two or three concepts (Novak, 2008). To structure large bodies of knowledge there must be a series of iterations between short term and long term memory as new knowledge is being received. Vocabulary is effectively learned by putting words into use and not by simply memorizing definitions (Daniels, 2004).

Research has illustrated the common problems students have in acquiring an understanding of science such as chemistry. The chemistry subject matter is largely conceptually opaque to students so they do not recognize the key concepts (Pendley, Bretz, & Novak, 1994). The instructors often fail to effectively present the key concepts, vocabulary, and relationships so the concepts are difficult to understand. A common problem students have in science class is that they are learning predominantly by rote rather than by actively seeking to construct their own meanings for subject matter.

Learners should be introduced to powerful meta-cognitive learning tools that enable them to construct structural representations of the knowledge in order to transition from rote learning to more meaningful learning (Van Zele & Wieme, 2004). Novak (1991) stated that implementation of concept maps in the science classroom could transform it to a place of meaningful learning and conceptual understanding.

In contrast to rote learning, Novak (1998) stated meaningful learning has three requirements. These include: the learner must have some prior knowledge relating to the new information to be learned; the knowledge to be learned must be relevant to other knowledge and must contain significant concepts; the student must deliberately choose to relate new knowledge to knowledge the student already knows. In order for successive learning to take place, a student must take active possession of what she or he already knows, find a relationship between the concepts being learned, and restructure the key concept with new relationships and terms (Brown, 2003).

Novak's (1984) ideas on meaningful learning progressed from Ausubel's theory on cognitive developmental. Ausubel (1963) viewed the development of new meanings to be based on prior relevant propositions and concepts. Ausubel regarded cognitive structure as hierarchical organization with more general concepts occupying higher levels and more specific concepts at lower levels. Ausubel believed learning is meaningful when relationships between concepts become more precise, explicit, and better integrated with other concepts.

In the 1960s Novak studied children in grades one to twelve for their understanding of the concepts of matter, energy, and living systems (Canas et al., 2006).

Novak used Ausubel's ideas on progressive differentiation and of integrative reconciliation to design lessons and lesson sequences. The idea of progressive differentiation involves students building upon their prior knowledge and elaborating concepts acquired in earlier lessons. Integrative reconciliation is the clarification of ideas that may have been initially confusing to a child or where meanings acquired may have been distorted. Learners often hold misconceptions that need to be modified and this process requires meaningful learning.

Development of Concept Map

In 1972, Novak interviewed first and second grade students for science concept understanding (Canas et al., 2006). There were 24 graduate students in Novak's research program at Cornell University that sought to learn children's abilities to acquire scientific concepts. The study used audio-tutorial lessons that were supplemented with video clips. The ideas for the lessons were based on ideas from the National Science Teachers Association report, *Importance of Conceptual Schemes for Science Teaching*, and the textbook series, *The World of Science,* by Novak, Meister, Knox, and Sullivan.

The study involved 191 first and second grade students who received 28 audio-tutorial lessons on basic science concepts and 48 children who did not receive the lessons (Marzano, 2001; Canas et al., 2006). The children were interviewed periodically as they moved through grades one to twelve to determine the extent of understanding the concepts of matter, energy, and living systems. The interview questions gave Novak's team answers to what concepts the children already had and gave feedback on what how the lesson was interpreted. Novak accumulated hundreds of interview tapes to observe proposition improvements in relevance, number, and quality, but it was difficult to determine how their cognitive structure changed with science lessons.

Novak followed Ausubel's ideas regarding cognitive development structure to translate the numerous interview transcripts into a hierarchical organization of concepts and relationships between concepts or propositions (Canas et al., 2006). The organized structure positioned the more general concepts at the higher levels and the least general concepts at the bottom (Novak, 1984; Novak, 2008; Quinn, Mintzes, & Laws, 2003). The organizational tool Novak used to summarize 239 student survey tapes was developed into the concept map (Brown, 2002; Novak, 1998; Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005).

Novak found a 15 to 20 page transcript could be summarized into a one page concept map without losing any essential concepts and proposition meanings expressed by the student (Daley, 2004; Novak, 1998). It was found that the concept maps the team created from interview transcripts revealed misconceptions the students acquired in past lessons. Novak studied concept maps and their benefits in different situations such as elementary to high school science classes, college level courses, and corporations (Canas et al., 2006). Novak realized the concept map is a powerful and concise knowledge representation tool to organize and understand interconnections, themes, and patterns.

A concept map is a representation of the meaningful relationships among terms and concepts that can enhance learning in all disciplines (Chiapetta, 2006; NISE, 2003; Vanides, Yin, Tomita, Ruiz-Primo, 2005). The technique helps students visually represent meaningful relationships between science concepts (Chiapetta, 2006; Novak, 1984).

Quinn (2003) stated “concept maps are two-dimensional, hierarchical, node-link diagrams that depict verbal, conceptual, or declarative knowledge in succinct visual or graphical forms” (p. 12). Concept maps reinforce learning and increase depth and breadth of understanding of the concepts and vocabulary as the students visually connect, organize, and express the relationships (Rogers, 1999; Vanides et al., 2005).

Concept maps are similar to graphic organizers as students must think about a concept word in a variety of ways, notice when and why the words are being used, and why they are important to know (Daniels, 2004). As students use the concept words, they became better at meaningful learning and potentially reduce the need for rote learning. The concept map is a valuable tool to represent the meaningful framework a person has for a group of concepts. Novak’s research on concept maps with children and adults found meaningful learning through maps was the most important factor in building powerful knowledge structures where learning by rote contributed little to building knowledge structure (Canas et al., 2006). Canas et al. (2006) and Novak (1991) found when students construct their own personal concept maps from topics they are studying, they find new meanings in the subject and new ways to reflect prior knowledge to the new subject they are learning.

The learner needs to think and explain how the different concepts are related (Novak, 1991). By discussing the relationships and meanings of the concepts, students can address and correct misconceptions. This is another problem with rote learning as it does not remediate misconceptions held by learners. The subject matter used in concept maps is not only a list of vocabulary to memorize but the structure and propositions are helpful to get the students thinking about the relationships. In the same way, concept maps are helpful to teachers when constructing a map as it usually leads to new insights on the subject matter.

Structure of Concept Map

To map is to construct a graphic representation that corresponds to a perceived reality (Wandersee & Novak, 1990). The science of map making, cartography, has a long history. The earliest known map was found on a bone artifact in the Soviet Republic that dates back to 10,000 BC. Humans have explored and mapped their travels and known geographies throughout history. Wandersee stated terra cognita means a region known to humankind. Maps have been used by humans to communicate meaning through graphic conventions. In the same manner, maps can be used in science class to represent concept meanings through an organized structure.

Concept maps display a one or two word label for one concept in a node or box with linking words to create a meaningful statement (Mintzes, 2001; Canas et al., 2006). Novak (1998) defined concepts as perceived regularities in events, objects, or records of events designated by a label. The hierarchical representation enables meaningful learning through subsumption which is to include within something larger or more comprehensive (Ausubel, 1968).

Vanides et al. (2005) studied maps by giving students eight to twelve key terms from the unit. The students were given free opportunities to draw, organize, and redraw the maps. The open ended construct-a-map style gave maximum insight into student understanding as the ideas came from the student not the teacher (Vanides et al., 2005).

Vanides et al. stated students were allowed to create their own phrases and map structure so they demonstrated their understandings or misunderstandings. Vanides et al. stated open-ended concept maps “accurately reflect the differences across students’ knowledge structures” (p. 31). Students worked in groups and branched out from the main concept while they discussed the subject matter. The groups brainstormed key words from the unit without the teacher’s help and identified related concepts on their own (Rogers, 1999).

Another style of map started the students with a partially completed concept map and asked the group to fill in the empty boxes or circles (Daniels, 2004). This is in contrast to the belief of Vanides et al. (2005) that the map structure should not be a pre-defined tool. The fill-in-the-blank map had the teacher select three to six challenging words from the curriculum material that the students have studied and the group added other related words to the map (Daniels, 2004). Then, as the unit progressed and the students expanded their knowledge, they added the linking words and propositions.

A focus question should be used to guide the teacher and students with 10 to 20 pertinent concepts and where to place the concepts in the hierarchy (Novak, 1998; Quinn et al., 2003). The focus question needs to address the problem, issues, or knowledge domain that the teacher wants to map. The focus question can be modified if necessary and the addition of concepts could be done at any time. The sub concepts should be selected and placed under the general concepts. Quinn et al. (2003) suggested adding as many subordinate concepts as necessary to display depth and breadth of knowledge of the topic. In contrast, Novak (1998) suggested avoiding placing more than four sub concepts for each general concept to avoid confusion. Novak (1998) stated an intermediate concept could be started if there are too many sub concepts placed under one general concept

The students should not construct sentences in the boxes or closed-in areas of the map (Chiappetta, 2006). If sentences were added to the boxes the map would be inundated with extra words that make reading the map more difficult. The boxes or closed-in areas should only contain one or two words that describe the concepts and sub concepts.

The concepts should be connected by colored lines with arrows for easy visualization (Novak, 1998; Rogers, 1999; Vanides et al., 2005). The arrows will help indicate the reading direction. One or several linking words can be used to label the lines so the connected terms can be clearly read as a sentence. The linking words will demonstrate the relationship between two concepts and the connection creates the meaning. The structure of meaning for a given subject domain will be seen when the student hierarchically links the related ideas together. Readers should be able to clearly understand the relationships and read the concept map from to top to bottom (Quinn et al., 2003).

Concept maps combine the nonlinguistic mode of organizing concepts with arrows and the linguistic mode with words and phrases (Marzano, 2001). The maps are a starting point for writing about science so there is integration between literacy and science as students devise vocabulary to be used with concepts (Vanides, et al., 2005). The linking words are the integration that students devise to create propositions with literacy and science.

Novak described propositions as words describing some event, object, or idea (Novak, 1998). Zak (2008) stated "each proposition consists of two concepts connected by a linking word or word on a labeled line identifying the relationship between the two concepts" (p.33). A proposition in a concept map is known as the sentence that includes two terms connected by an arrow and phrase. Vanides et al. (2005) explained the connected terms should be read as a sentence, such as "water has density" (p. 27). The more correct propositions the student uses, the more complex and meaningful the knowledge base the student has (Quinn et al., 2003). Concept meanings grow as concept labels are linked to other concepts to form the propositions.

Students might initially encounter problems when trying to formulate meaningful propositions (Wandersee et al., 1990). The students use the linking word, be, too often and the propositions are less powerful because of it. Wandersee (1990) stated students need to see examples that use other verbs, adjectives, and prepositions so the concept map reads like a graphic argument.

Vanides et al. (2005) provided an example with the scientific concepts, density and mass, and used the linking words, times volume equals, between the concepts density and mass. When looking at the map, this relationship would read volume times density equals mass. See figure 1 for a density and matter concept map. The terms matter, mass, density, and volume are the most fundamental words.

Relationships between concepts in two different areas are called cross links (Canas et al., 2006). Any cross links between different concepts should be looked for and the lines should be labeled. The density and matter concept map included links between

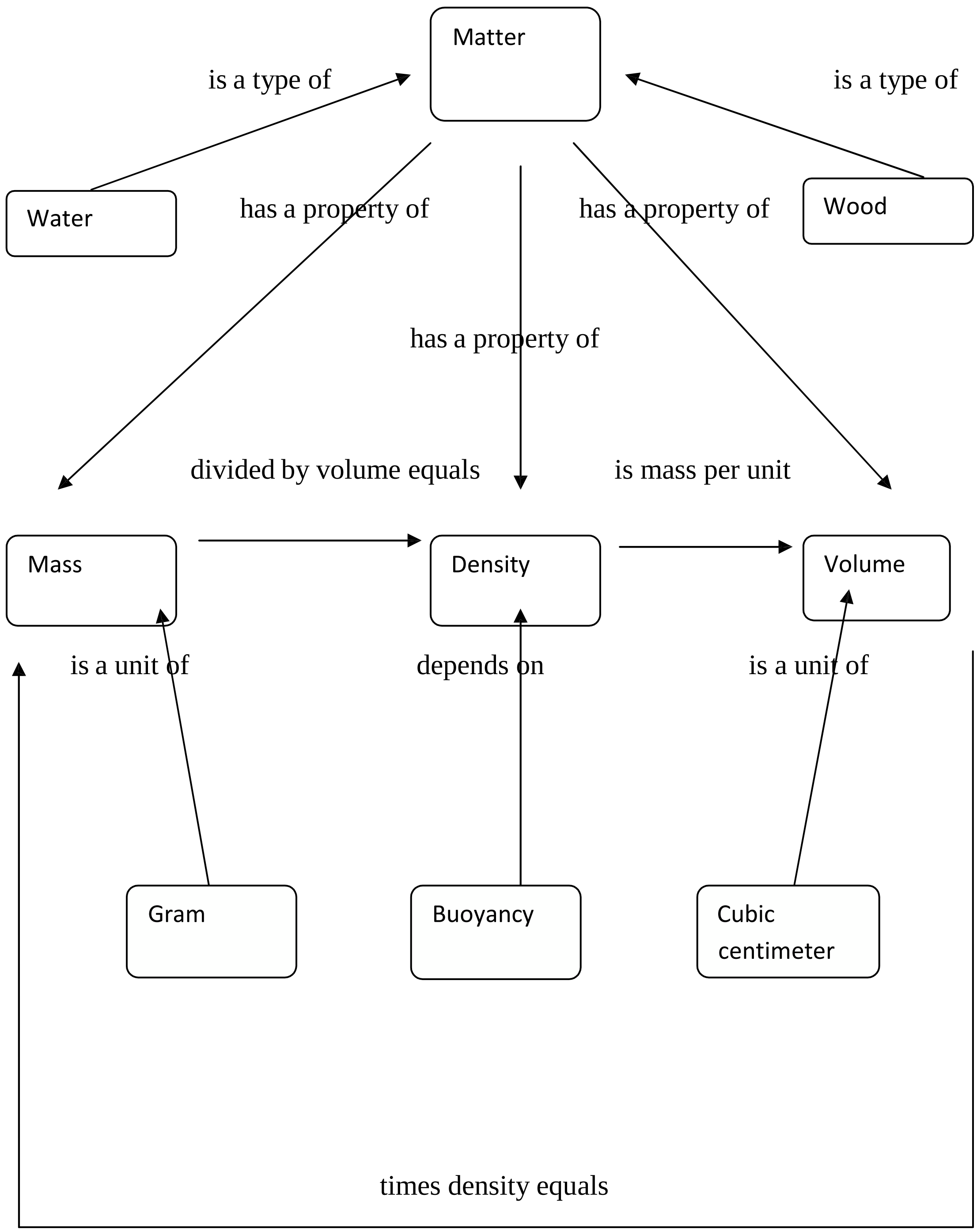

Figure 1, Concept map for density and matter unit (Vanides et al., 2005) mass and density, density and volume, and volume and mass. The number of cross links can show the degree of integration between concepts (Brown, 2003). The cross links help to visualize new relationships and connections between concepts in the domain. Experts and highly proficient students tend to create highly interconnected maps which show thorough understanding of the material (Vanides et al., 2005).

Students can construct a map at the beginning of an instructional sequence in order to determine the beginning knowledge level (Chiappetta, 2006). During the instructional sequence, the map structure can be reworked so more sub-concepts can be added, subtracted, or changed. This will allow the students to externalize their thinking and illustrate the conceptual change that is occurring during the lesson. The preparation of the concept map must include time for the students to revise and redraw the map structure (Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005).

The concept labels could be initially written on index cards or small sticky notes like Post-Its (Novak, 1998). After the students use index cards or Post-It notes on the rough draft, there should be discussions between the group members. When the students redraw the maps, they should be given the opportunity to discuss and reflect on the science terms. The reflection will provide new insight and additional details on the topic. By allowing the students to use sticky notes, the students can organize their thoughts by moving ideas around on a rough draft concept map (Vanides et al., 2005). At the end of the unit instruction, the reworked tool can be used as review material (Chiappetta, 2006).

Quinn et al. (2003) studied successive concept maps in college geology courses that could also be used in middle and high school. The study involved 56 college students, including 41 women and 15 men, which majored in kindergarten through eighth grade science education. The students were in the semester prior to student teaching. The objective of the study was to analyze concept map use during a semester to determine how participants organized, associated, and described relationships between geology concepts.

Quinn et al. (2003) initially showed the students exemplary concept maps on overhead transparencies to get the students used to the learning tool. The concept maps were similar to Novak's style using conceptual relationships with arrows and linking words. After the students were familiar with preparing concept maps, they created complete maps in a 50 minute class period. Concept maps were designed three times in the course to evaluate conceptual sophistication over the course of a semester. The team used steps for concept mapping that was very similar to Novak's suggestion for this tool.

Quinn et al. (2003) team used six steps for creating concept maps in the first year geology course:

> Step one: Review a topic for conceptual domain. Step two: Identify the major concepts. Step three: Arrange the concept on paper. Step four: Link and label connections among concept. Step five: Branch out. Step six: Make crosslinks. (p. 13)

The topic was reviewed by reading, viewing a video, listening to a lecture, or reflecting on prior knowledge on a topic. The students and teacher identified a topic by listing 10 to 15 important concepts on paper. The concepts were then organized from inclusive or super-ordinate to least inclusive or sub-ordinate. Readers of the map understood relationships and clearly read the complete map from top to bottom. Quinn et al. suggested adding as many subordinate concepts to the map as group can to display the breadth and depth of the knowledge. Finally, the connections were linked and labeled using arrows for indication of reading direction.

Concept Map Software

Computer software from Inspiration, Institute for Human and Machine Cognition / Cmap Tools, Knowledge Manager, or Smart Ideas can be helpful for creating and easily changing concept maps (Mintzes, 2001; Canas et al., 2006). By using computer software it is easy to add, delete, or move text with a click of the mouse. The technical design problems that some students associate with concept maps can be lessened through the use of concept map software (Chiappetta, 2006). As students use the software to construct and reorganize hierarchical outlines, they gain and retain a better understanding of concepts. Software, such as Inspiration, uses symbols, links, text and multimedia files to make it easy to express ideas, discover relationships, and develop new thoughts and perspectives (Inspiration Software, 2008).

Inspiration software is a useful tool that uses reflection and understanding of concepts with the benefit of hyperlinks to provide additional information. Inspiration software allows students to hyperlink online or local documents to concept boxes and proposition phrases that link the concepts (MacKinnon, 2006). Programs like Inspiration became popular as it allows children to easily place pictures and clipart with their concepts (Novak, 2006). This allows students to build meaningful graphic organization on one dimension while providing sources of understanding through hyperlinked information.

MacKinnon (2006) reported that students found Inspiration moderately simple to use as the drawing features were easy to learn and apply. MacKinnon's survey results reported the hyperlinking of online or local documents allowed other opportunities for adding related information. This feature offered extended organization of related ideas, which helped to keep the student stay on task and involved. The hyperlinks allowed students to represent their personal understanding patterns.

Inspiration software allows the student to represent thoughts and information with pictures, images, words and multimedia including QuickTime movies and MP3 files. The concept map program contains over 1,000 searchable symbols in the software or an online symbol collection tool containing more than one million illustrations and photographs. The student can show relationships among ideas with the link tool and explain relationships by adding text directly on the links. The user can differentiate among ideas and groups with colors, shapes, patterns and fonts.

MacKinnon (2006) surveyed 68 pre-service teachers about the use of Inspiration software to construct hyperlinked concept maps. The pre-service teachers reported the mapping allowed for a complete view of an entire unit of study as all the concepts were organized on paper. MacKinnon found that "reviewing for an exam was easier to relate all the information and make sense of over-arching themes" (p. 442). The pre-service teachers reported as teachers they would be planning units and a concept map would be a powerful tool for students as well as teachers. The map can help instructors ask good questions about relationships of topics they are trying to teach.

Cmap Tools provides concept map software that may be downloaded free of charge for nonprofit use (Mintzes, 2001; Canas et al., 2006). Users can share concept maps through a network of thousands of users in over 150 countries (Canas et al., 2006). This software integrates a wide range of learning tools such as readings, pictures, presentations, and research into a concept map. Cmap Tools and the world wide web make a powerful tool that has offered new meaning to visual representation of the concept map.

The Cmap Tools program empowers users to construct, navigate, share and discuss knowledge in the form of concept maps. Cmap users can construct their concept maps with their personal computers, share the maps on Cmap servers on the internet, create web pages of their concept maps, edit their maps at the same time with other users, and search the internet for information relevant to the concept map. The network servers enable the user to collaborate, share, browse, and search for information while creating a map. The Cmap website in figure 2 shows a Novak style concept map with linking words describing the software. The map describes how organized knowledge in concept maps is comprised of concepts and propositions with hierarchical organization in the cognitive structure.

Group Involvement When Constructing Concept Maps

Vanides et al. (2005) found when a class creates an initial map, without a solid introduction, it is time consuming and not engaging for every student. Therefore, if the

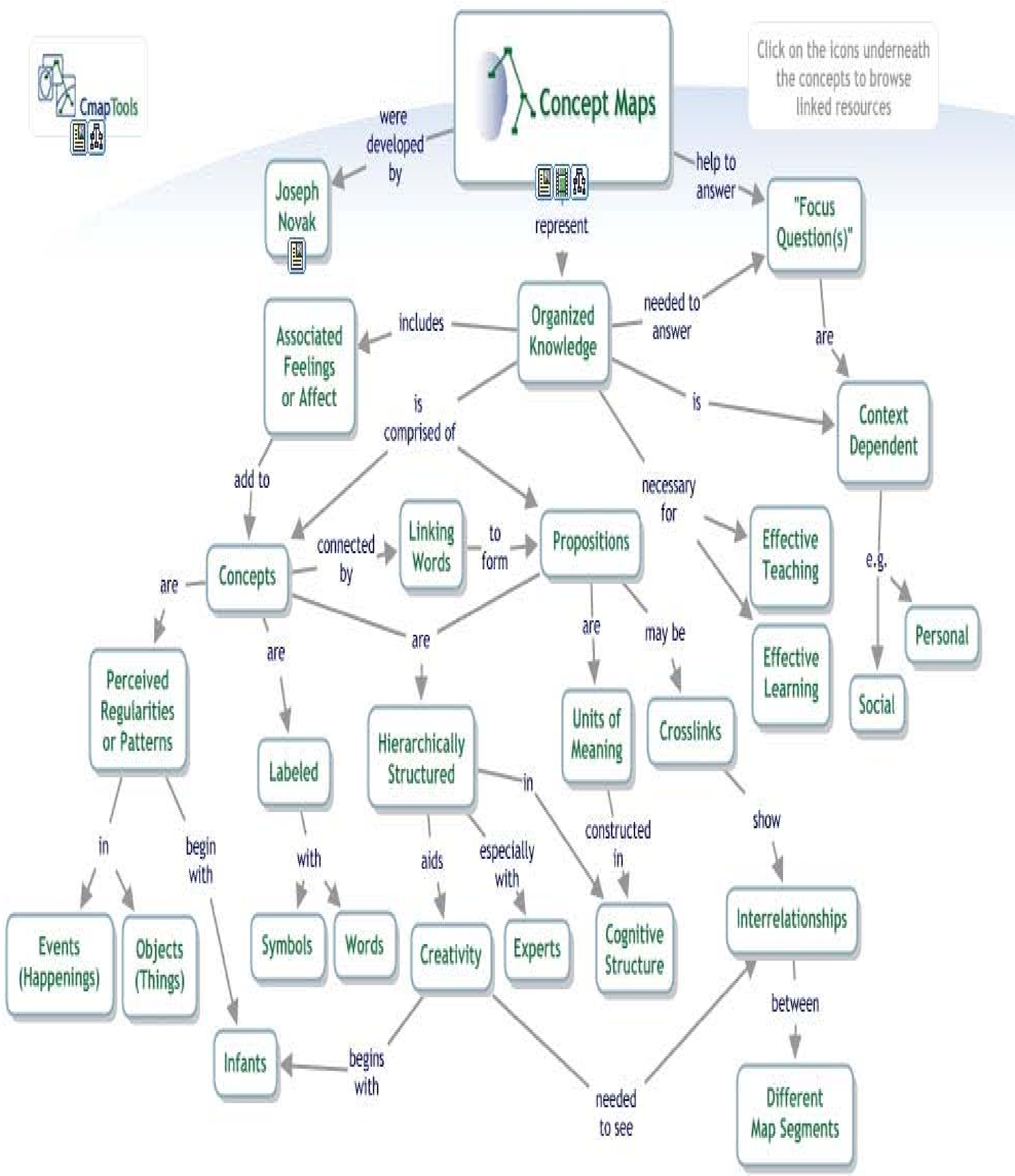

Figure 2, Concept Map from Cmap Website (Cmap Tools, 2008) students have never worked on a concept map they should be introduced with a simple and familiar subject such as bicycles or food. The students should be taught the process of making a concept map first before being expected to create a useful map.

After the individual maps are created the maps should be shared and discussed in small groups (Brown, 2002). When every student is familiar with the process of making a map, the concept maps can be prepared in groups of two to three students. Restructuring concepts while in small groups can greatly enhance the learning process with social interaction as the students discuss, organize, and think about the concepts.

The interns in MacKinnon's (2006) study found it purposeful to use group discussions to support their understandings of conceptual relationships. Students identified improvements in their abilities to formulate arguments, lead effective discussions, and substantiate their map frameworks when working with a group. According to MacKinnon's study, students found it useful to discuss how they logically connected their ideas. MacKinnon reported that one student stated "I would have normally just spoken my mind without thinking how to logically connect my ideas. Now when I think of making a contribution I am more careful of how I present the ideas" (p. 444). Students found the group involvement of concept maps to be effective in thinking about and discussing conceptual relationships.

Brown (2003) studied group concept mapping of biology concepts with 97 students in a Midwest suburban high school. The study involved two teachers that presented overhead notes and a video on photosynthesis and cellular respiration while the students recorded notes. The research involved an individual mapping class where each student created a map, a group mapping class where students worked in groups of two to three students, and a control group class where concept maps were not used. At the end of the unit, examinations were given and the students that created groups concept maps outperformed students that worked on their own maps and students who did not create maps at all.

In the modern world, students have access to the internet, cable television, computer programs, and reference materials so they arrive in class with so many experiences. Teachers can tap these resources and knowledge of the students by involving students in a group activity to teach the rest of the class (Brown, 2003). The peer collaboration allows students to influence and teach one another as students demonstrate what they know while listening, observing, modifying, and learning from one another. Brown found "students teach one another and learn from one another, all the result of a concept mapping assignment" (p. 193). Some high school teachers have found that using students to teach students not only helps one party to understand concepts but also helps the other party to understand and have their confidence strengthened.

The interaction takes place in class with discussions instead of students working alone on weekend homework activities (Brown, 2003). The in-class discussions lead to a greater depth of understanding as a result of the group assignment. So the new knowledge is constructed, not discovered, while working as a group and discussing the concepts. The more experience the student or group has with concept maps, the more the maps will change and the complexity in the maps will increase.

When working in groups the students can communicate and challenge their extended meanings when they bounce ideas off each other (Daniels, 2004). The exchange of ideas in small groups helps to correct faulty ideas and promotes meaningful learning (Brown, 2003; Canas et al., 2006). Once on paper, the members can observe, agree, and modify their explanations. One student in Brown's study explained:

> These group concept maps are kind of like a jigsaw puzzle. We can add pieces to make the final product. If we make a mistake, others can help out so we understand what we did wrong. (p. 197)

The groups promote active learning where each student must participate in the creation of the concept map (Chiappetta, 2006).

The small groups should be heterogeneous with students at different learning levels (Vanides et al., 2005). The heterogeneous groups can discuss similarities and differences and allow for students to learn from each other. Different propositions can be discussed but the focus should be on the ones that are most relevant to what the teacher wants the students to understanding. The teacher can steer the discussions if they get off track from the focus terms. The discussions allow for high end cognitive processes as the students explain their maps to each other.

Implementation of Concept Map in the Science Unit

Concept maps work best when fitted in with hands-on science activities (Vanides et al., 2005). The maps are based on important terms that make up the vocabulary in experiments. The preparation of the concept map will help the students understand the vocabulary necessary for the activities and discussions.

Concept maps can be fit into the unit when a sub-goal of the unit is achieved and there is knowledge to be assessed. Another key juncture is when a critical point of instruction is reached and it is important to know what the student understands before proceeding (Vanides et al., 2005). Vanides et al. suggested inserting a concept map when feedback to students is crucial to improve their understanding. For maximum insight the students should be provided with key terms and given the opportunity to freely create the concept map as they see fit (Yin et al., 2005).

Assessment

Vanides et al. (2005) stated concept maps represent how students organize, connect, and synthesize information. The concept map can be analyzed and characterized to assess the map's structure, content accuracy, and depth of content knowledge (Zak, 2008). Concept maps offer students opportunities to think about the connections between the science terms being learned. Students organize their thoughts and visualize the concepts in a systematic way, and reflect on their understanding (Vanides et al., 2005).

Graphical representation tools are a way for students to realize what concepts are important and allow them to expand their associations with a central concept (Brozo, 2003). The students think deeply about science as they understand and organize what they learn. The students can then store and retrieve information more efficiently. This organization tool is an alternative assessment that gives teachers the opportunity to gain a richer understanding of what the students are thinking and how they construct meaning (Chiappetta, 2006). Teachers can look for misunderstandings the students might have by quickly looking at the linking words and relationships in a concept map.

The concept map is a visual representation of the student's prior knowledge and concept understanding (Brown, 2003). Novak found that concept maps were beneficial for not only students but also teachers. Teachers gain insight into subject matter when they construct concept maps for lectures, laboratory experiments, or demonstrations (Novak, 1991). As the maps are organized, the concepts are linked and the relationships are identified. Concept maps are a good way for teachers to organize knowledge for instruction as well as for students to find the key concept and principles in lectures and readings.

Concept maps are useful to the teacher when doing curriculum planning. The maps use a highly concise manner to present the key concepts and principles that the teacher will instruct (Novak, 2008). The hierarchical structure helps the teacher with sequencing of instructional material. The teacher can start instruction with the more general concept and proceed to the more specific information. This sequencing encourages and enhances meaningful learning as the students use prior knowledge to relate to new information. The complete curriculum map will give global view of all the content from the curriculum.

Concept maps are a teaching and learning tool that is especially suited for science courses (MacNeil, 2008). Concept mapping encourages the students to self-evaluate their concept relationships and recognize the hierarchical structure of scientific knowledge and the priority scientists place on some knowledge over other knowledge (Quinn, et al. 2003). Concept mapping is an easy way to determine the knowledge that has been developed from the student's work. The tool can be also used throughout a course to evaluate what the students know prior to instruction and after the lessons.

Research has been done to determine how beneficial concept maps are to student understanding. MacNeil (2008) studied 45 students in a health and wellness course to determine the effectiveness of concept maps. Pendley et al. (1994) used graduate students from Cornell University's chemistry program to draw conclusions on the values of concept mapping over rote memorization in chemistry class. Both professors provided a general overview of concept maps and a list of important concept terms before lecture on the topics. The pre-lecture concept maps were circular diagrams that were nonspecific and lacked detail. The post-lecture maps showed more detail which reflected the knowledge gained by the students.

The research by MacNeil (2008) and Pendley et al. (1994) stated the most common diagram drawn was a box arrangement in a hierarchical structure with supporting concepts at various levels of importance. The post-lecture results showed significant improvements in relationships among the terms. MacNeil reported the concept maps detailed what information was important to the students. The maps were excellent teaching and learning aids and were effective in determining if the students had understood the concepts and facilitated meaningful learning.

Novak (1998) stated concept maps are the most powerful evaluation tool for educators. Concept maps offer user-friendly methods of evaluating understanding and are alternatives to multiple choice tests (Quinn, et al., 2003). It is difficult to use multiple choice questions to evaluate how much the student understands. With multiple choice tests, all knowledge is assumed to be of equal value such as one point. Multiple choice questions do not give the student an opportunity to organize their concepts and knowledge as the concept map does.

Standardized testing has been widely accepted as a means of assessment but it is now clear that these tests are of little value to teachers who encourage conceptual understanding (Mintzes, 2001). The understanding assessed from standardized tests is not meaningfully revealed through normalized comparisons. Conceptual change is not represented by a single score on the test.

Pendley et al. (1994) determined that answering multiple choice, numerical questions in examinations does not represent conceptual understanding of the material. The researchers extended the problem-solving questions to include questions requiring general, qualitative explanations. Pendley et al. (1994) found most of the students' answers were indicative of rote memorization which rapidly becomes retrieval from short term memory. When the answers indicated meaningful learning and restructuring of concepts, the memory can be retrievable for months or years. Students took an active role in learning when using concept maps rather than ineffectively learning by rote. Pendley et al. (1994) reported concept maps were useful for illustrating change or lack of change in the student's conceptual understanding.

Vanides et al. (2005) stated concept maps can be effective as both instructional and assessment tools with the following recommendations. The teacher should scan the curriculum unit and decide on the most important and critical terms related to the key concepts. The teacher should use the selected terms and construct propositions that reflect what students should know and be able to express at the conclusion of the unit.

The students are empowered with their concept representations as well as the teachers are empowered with better instructional structure. The teachers can assess the sophistication of the concept maps to determine understanding of the topic (Vanides et al., 2005). Highly sophisticated maps show highly integrated knowledge structures expressing knowledge of the concepts. The teacher can assess the propositions and cross links between concepts for levels of understanding. An absence of a link between two closely related items shows a lack of understanding. If there is a link between items that are not closely related, this reveals alternative or naïve conceptions. The teacher can use concept maps to assess for understanding or misunderstanding and re-teach when necessary.

Teachers can use concept maps on repeated occasions to see if the student's understandings improve over a period of time. If sophistication increases over the time of a unit for example, this reveals understanding has developed. If there are gaps in learning the teacher can modify lessons plans based on the student's concept maps (Vanides et al., 2005). By using the teacher selected terms the concept maps can be quickly scanned to give the teacher an idea on what the students understood. The propositions can also be read to see if they are valid.

Brown (2002) used a rubric in biology classes to let the students know what the teacher expects from the concept map activity. From the rubric, students learned how their concept maps would be evaluated based on a number of topics. The biology teacher would assess the map on creativity, number of concepts, number of links, quality of links, cross links, hierarchy, and scientifically, accurate material. Brown (2002) stated the creative category on the rubric helped students develop a positive attitude toward the visual representation activity. Students were then given a topic and after ample instruction were encouraged to use the scoring rubric as a format for their concept maps.

Brown (2002) suggested using quantitative requirements including a minimum of 10 concepts, at least three cross links, and each concept needed a corresponding linking word. The linking words had to make sense and be scientifically accurate. Brown's (2002) rubric required a hierarchy with at least three distinct levels for full credit.

Other researchers showed there are a variety of ways to quickly score concept maps. Scoring systems can be categorized as quantitative, such as counting counts of concepts and cross links, or qualitative methods, such as describing the content and quality of the map (Van Zele et al., 2004). Van Zale et al. (2004) researched 170 engineering students with their understanding of the atom in a concept map. The students were instructed the nature of concept maps during a 45 minute period to familiarize the students with the method. The students were given over 20 terms related to atoms that could be chosen or not chosen for use in the concept maps.

A quantitative analysis of the maps included the number of concepts added, number of certain concepts used, number of links and cross links, and the number of hierarchical levels used in the maps (Kinchin, 2000; Van Zele et al., 2004). Each of these descriptors were analyzed qualitatively also. For example, links were scored by the number of wrong links, no text links, weak links, moderate links, excellent links, and missing links. The Van Zele et al. (2004) study reported sample scoring guides showing the number of particular descriptors and the detailed parts of the descriptor that were important. Qualitative analysis of concept maps provides an informative and complete picture of student understanding.

Concept maps represent hierarchical nature of scientific knowledge and the priority scientists put on some concepts over other concepts (Quinn et al., 2003). Teachers can let the students know when grading the concept maps the importance of hierarchical nature of knowledge and the importance in engagement of learning rather than rote memorization. The teacher can specify the most important, general terms and the less general, relatable terms. It is important to have hierarchical structure on the rubric to let students know the importance of organization of concepts.

Quinn et al. (2003) stated the concept map can be scored for complexity and content validity. To score for content validity the teacher can identify all scientifically valid concepts and propositions and pool them to create conceptual descriptors on a frequency basis. Students are awarded points based on the basis of the occurrence of advanced concepts. The purpose is to characterize changes in conceptual sophistication over a time period and award the students with advanced maps.

Vanides et al. (2005) stated the teacher should evaluate the complexity of the map as highly proficient students tend to create highly interconnected maps. Concept maps draw attention to the structural complexity of the student's knowledge of the concepts (Quinn et al., 2003). The novice tends to create simple structures such as linear, circular, a hub with spokes, or a tree with a few branches. The teacher should look for the important propositions on the student's maps. If the student does not have the important propositions, the student may not understand the relationships among key concepts (Vanides et al., 2005).

The propositions indicate whether the student knows there are relationships between the concepts. An individual's understanding is revealed in the linking words used to describe the relationship between two concepts (Zak, 2008). Vanides et al. (2005) stated a rubric can be made to determine if the relationships are scientifically meaningful. A four level rubric can be used to examine the quality of student proposition. Vanides et al. provided an example of a four level rubric for a mass – matter map:

0 - Mass is an object equal to matter (wrong or scientific irrelevant)

1 - Mass is related to matter (partially incorrect)

2 - Mass measures matter (correct but scientifically thin)

3 – Mass is the amount of stuff in matter (scientifically correct). (p. 31)

Vanides et al. stated to save time when assessing a similar concept map, a three level scoring rubric can be used instead of the four level rubric:

0 –wrong;

1- partially correct or correct but scientifically thin;

2 – scientifically correct. (p. 31)

The individual propositions can be scored and summed to obtain a final score.

Vanides et al. (2005) suggested color coding the propositions with highlighter pens to match the scores in the rubric. For example, green equals three points, blue equals two points, yellow equals one point, and no color equals zero points. The color coding grading system gives the students a quick impression on how they are doing with their concept maps. To simplify the color coding system the teacher can use a green pen to highlight only the correct and key propositions that students create on their concept maps.

Quinn et al. (2003) suggested an alternative way to score student group concept map. The method the Quinn et al. team used for scoring complexity and content validity was giving students one point for each of the following.

> Concepts: Total number of non-redundant concepts. Relationships: Total number of scientifically acceptable and non-redundant propositions. Hierarchy: Maximum number of hierarchical levels containing at least one branch. Branching: Total number of super ordinate to subordinate branches. Cross links: Total number of scientifically acceptable and non-redundant branches. (2003, p. 13)

In order to fairly assess the complexity of the student's maps, the teacher would have to determine and communicate to the students the number of required concepts and branches. Quinn's (2003) team scored the inductive method as students were awarded points on the basis of the occurrence of advanced concepts or acceptable propositions. The evaluators prepared a list of conceptual descriptors and the frequency of the descriptor in the maps was recorded.

The most important propositions describe relationships that reflect the key ideas in the science unit. The propositions are the important ideas that the students understand and know after the unit ends. These are the connections that a teacher expects to see on the concept map. An example of a unit on density and buoyancy should include a concept map with written propositions to show the connections among mass, volume, and density.

Any misconceptions within propositions on the student's map can be identified for further discussion with the students or as a class. A benefit to assessing concept maps is that misconceptions may be the focus of a clarification in a follow-up lesson.

Advantages and Disadvantages of Concept Maps

There are advantages and disadvantages of using concept maps and assessment with these organized classroom tools. In comparison to multiple choice or fill in the blank tests, concept maps take more time to evaluate. A scan tron multiple choice test is automatically graded while a concept map takes time to evaluate propositions and look for misunderstandings. With more experience and the use of rubrics, the teacher can assess the maps in 10 minutes or less (Quinn et al., 2003).

Another disadvantage is that students become good at rote memorization so a new strategy such as a concept map might have some resistance. The more students use memorization to remember terms and definitions to successfully pass multiple choice examinations, the more difficult it becomes to break the routine. For this reason, Quinn et al. (2003) suggested not assessing the maps until the students have experience with the learning tool. As the students become familiar with the procedures and are allowed to be creative with their maps, the more enjoyable concept maps will be.

The advantages of using concept maps outweigh the disadvantages (Quinn et al., 2003). Zak (2008) stated "Concept maps show how individuals remember, organize, interpret, and understand in a particular subject area" (p. 32). Concept maps give a big picture on conceptual understanding rather than piecemeal depiction of memorized facts. Using maps as an assessment tool tells the students that teachers value conceptual understanding over rote memorization (Quinn et al., 2003). Concept maps emphasize quality of knowledge through understanding of conceptual relationships rather than the map's quantity. Finally, students benefit from sharing and discussing ideas as they work in collaboration within groups to show how their knowledge can be organized in different ways.

Textbook manufacturers are starting to include concept maps in science textbooks as a way to summarize understandings acquired by students after they complete a chapter. Novak (2008) stated concept maps in school instruction will increase substantially in the next decade or two. Novak stated national examinations may one day utilize concept mapping as a powerful evaluation tool. This will give teachers the incentive to use concept mapping in the science classroom. It is a chicken and the egg problems as either the teachers or the standardized examinations have to start using this tool. Once students are given opportunities to use concept mapping as an organization tool to visually represent their conceptual understanding, the powerful learning tool will be implemented nationally.

Summary

Concepts maps have been studied to show they can be a useful tool to help students organize and express their knowledge and understanding of a particular topic. Concept maps are an alternative to simply memorizing terms and definitions. The students can work in small groups and discuss and interpret relationships and meanings of the concepts. The group discussions and reworking of the concept maps can help the students learn from each other and determine if there are any misunderstandings. The visual representation of the concepts can enhance learning in science as well as in other disciplines.

Methodology

Concept maps are visual representations of student understanding. The hierarchical structure of a concept map contains a more general concept at the top to less general concepts at the bottom of the page. The propositions and relationships describe the concepts in the map. Through the use of discussions in small groups the students can determine if there any misunderstandings that need to be addressed. The use of concept maps in science classrooms has been studied to learn the effectiveness of this learning tool. The following methodology will determine if students in two high school chemistry classes believe the use of concept maps in small groups is helpful and effective in concept understanding.

Participants

The concept map was implemented in three chemistry classes at a small, rural high school in western New York. Four chemistry classes were researched in the study including classes one, two, and three which used concept maps to represent the concepts and vocabulary from different units and a fourth group, class four, which did not use concept maps in the chemistry classroom. Class one consisted of 24 students including eight males and 16 females. Class two consisted of 23 students with eight males and 15 females. Class three consisted of 21 students with 10 males and 11 females. Class four consisted of 22 students with 11 males and 11 females. Each class was surveyed and assessed for understanding of the curriculum. Classes one, two, and three were surveyed to determine whether the students believed concept maps were helpful in understanding chemistry and if the maps were useful in determining misconceptions. The unit examinations were compared to determine if concept mapping made a difference in student understanding of the material.

Materials

Concept maps can be simply prepared with pens, pencils, markers, and paper. The paper used in this study included poster paper that measured 24 inches by 36 inches. The students used pencils and Post-It notes during the initial creation of their maps. The students used colored markers for the final concept maps.

Design and Procedure

Density was chosen as the subject to introduce concept maps because the students were familiar with the topic. The teacher used a smartboard to show the students the steps involved in the creation of a concept map. The steps to concept mapping included asking a focus question, reviewing the topic with group discussions, identifying the concepts, arranging the concepts in a hierarchical structure, linking and labeling the relationships, and drawing any cross links between the concepts.

Class one was taught by one teacher and classes two, three, and four were taught by another teacher. The teachers reviewed density with a whole class discussion with the three participating classes. The teachers asked the students a focus question on buoyancy to get the students thinking about the topic. The teachers allowed the students to work in groups of three to brainstorm the concept for ten minutes. The groups then explained to the whole class ideas such as the density of a material is defined as the massper unit volume. The students discussed how different materials can have different densities due to buoyancy.

After the topic was reviewed with the participating classes, the teachers and students identified the important concepts of density including density, mass, volume, buoyancy, and the units associated with the main concept. The key concepts were written on the smartboard as the student groups wrote the terms on poster paper in front of them. The students were taught to construct the hierarchical structure with the broadest and most inclusive concept at the top of the map and the least inclusive concepts at the bottom. The groups organized their concepts on 24 by 36inch paper with the main concept, density, on top and the other concepts written below the super-ordinate term.

The student groups were given additional time to discuss the less inclusive concepts and the relationships between the main concept. The teachers used the smartboard to show the students how to draw colored arrows to connect the relationships between the key terms. The teachers explained how the arrows indicate reading direction and using color helps visualization of the propositions. The students were instructed to use a few linking words at each arrow to describe the relationships. The teachers stressed using only a few words to maintain clarity of the map so it is not difficult to read. The students were asked if there were any additional cross link relationships between sub-ordinate concepts. If the groups determined there were cross links, the relationships were also drawn with arrows and linking words.

The students were instructed when constructing concept maps Post-It notes could be initially used to write concepts and linking words on the maps. The teachers told the students the maps could be reorganized by simply removing a Post-It note and adding another note. After the students have had time to discuss the structure of the maps the groups were given time to reorganize the Post-It notes if necessary.

The teachers walked around the room to view each group working on their maps and asked questions about the concepts. If the teachers or students revealed any misconceptions, the students corrected the maps by simply adding new notes. When the students were satisfied with their introductory map, the students removed the Post-It notes and permanently wrote the concepts, linking words, and cross links on the maps. Each group was given a few minutes to present their initial maps to the whole class to make sure they were comfortable with the creation of concept maps as a way to portray the relationships and propositions of scientific concepts.

The teachers used the concept map creation steps during different chemistry units including atomic structure, chemical bonding, and moles. As with the introductory density map, the teachers started each class with a focus question to address the issue or knowledge domain that the teacher wanted the students to map. The concept map classes broke into groups of three students and discussed the focus question and topic. The groups selected at least ten terms from the unit to be displayed on the maps. The students worked in heterogeneous groups with students of different learning abilities, genders, and grade levels. This group structure provided the opportunity for the students to learn from each other through the discussions of the concepts.

The participating classes were allowed to draw open ended concept maps to allow the students to freely create their own maps. The students were given opportunities to draw, organize, discuss, and redraw the maps throughout the unit. The groups were allowed to create their own propositions and phrases to demonstrate their knowledge and misunderstandings. The teachers only intervened if misconceptions were revealed. If any misconceptions were determined, the teachers addressed and discussed the misunderstanding with the class in a future lesson.

Data Collection

The concept map was a visual representation of student knowledge and concept understanding in two chemistry classes. The teachers looked for sophistication and complexity of the maps, understanding of the topic, and evaluated the propositions and cross links. The propositions indicated if the students understood the relationships between concepts. An absence of links between concepts revealed a lack of understanding.

The teachers used a rubric to determine the quality of propositions between concepts and if the relationships in the concept maps were scientifically meaningful. The rubric evaluated if each proposition was correct, partially correct but scientifically thin, or incorrect with a score of two, one, and zero points respectively. The rubric included points for using all the concepts that the students and teachers determined to be important after discussing the focus question. The rubric included points for cross links between the concepts (see Appendix A).

Class four was taught with the same lesson plans as the participating classes including lecture, note taking, videos, worksheets, and textbook reading. The difference was class four did not participate in concept mapping during the units. At the end of the units, all classes were given the same examinations to assess for understanding. The examination results from class four were evaluated and compared to the participating class examination results to determine if concept mapping made a difference with understanding chemistry concepts.

The participating classes were surveyed with several questions on the concept map experience (see Appendix B). The assessment determined if the students believed group concept mapping was helpful in understanding of the chemistry concepts and if the maps were useful to organize and represent knowledge in a visual form.

Results

Four classes taught by two teachers were researched to determine if concept maps were helpful in understanding three chemistry units. The class period was 41 minutes. The students were both males and females in grades nine to 12. Classes one, two, and three prepared concept maps during the atomic structure and bonding units while only classes one and two prepared maps for the mole unit. Class four did not participate in preparing any concept maps.

Class one contained eight boys and 16 girls. There were three ninth graders, 10 tenth graders, nine eleventh graders, and two twelfth graders in class one. Class one contained eight boys and 15 girls. There were eight ninth graders, 15 tenth graders, six eleventh graders, and ten twelfth graders in class two. Class three contained 10 boys and 11 girls with three ninth graders, 11 tenth graders, and seven eleventh graders. Class four contained 11 boys and 11 girls. There were three ninth graders, 12 tenth graders, and seven eleventh graders in class four. A description of the classes can be found in Table 1.

The teachers introduced concept map preparation with a familiar topic, density, to the three participating classes during one class period. Once the students were comfortable with the small group discussions and creation of a density concept map, classes one, two, and three prepared concept maps at the conclusion of the atomic structure unit. This activity confirmed the students were comfortable with the group work and preparation of concept maps. The atomic structure map was used to make sure the students were familiar with concept map preparation so the examination scores were not compared with this unit. The students were asked “Did you find the creation of the

Table 1

Description of classes

	Class one	Class two	Class three	Class four
Boys	8	8	10	11
Girls	16	15	11	11
Ninth grade	3	6	3	3
Tenth grade	10	10	11	12
Eleventh grade	9	4	7	7
Twelfth grade	2	3	0	0
Total students	24	23	21	22

concept map helpful in your understanding of atomic structure as learned in chapter four?" Selected responses included "Creating the map was useful for my understanding chapter four. Writing concepts in one place helped to solidify things in my memory," "yes, the concept map made a clearer thought because I learn better when its hands-on learning instead of not taking," "yes, it made it easier to understand and remember. I learn better when we do activities with a lesson, it helps me practice and understand it," "yes because you see how things are related instead of trying to memorize all the words," and "yes it was, physically drawing it and visually seeing everything helped."

Several units after the atomic structure unit, the concept map activity was used for review on the unit of ionic and covalent bonding. The three classes were given a rubric for the bonding concept map that explained the points that could be obtained for correct, partially correct but scientifically thin, and incorrect propositions (see Appendix A).

The concept map activity implemented in classes one, two, and three was used to review important concepts before the unit examination. To get students thinking about the topic, both teachers asked the classes the following focus question, "What is the difference between ionic and covalent bonding?" The teachers allowed heterogeneous groups consisting of three students to discuss the question and write down thoughts in their notebooks. The groups contained students of different genders, grade levels, and learning abilities. The initial discussions lasted ten minutes as the teachers moved around the room to listen to the students.

The groups were initially given poster paper that measured 24 by 36 inches, pencils, and Post It notes. The students wrote their key concepts and created a hierarchical structure with the broadest and most inclusive concepts at the top, such as ionic and covalent bonds, and the least inclusive concepts at the bottom of the poster. The students wrote the least inclusive concepts on Post It notes. The groups then drew arrows to indicate reading direction and wrote propositions with linking words on Post It notes between the concepts. If the students found cross links they connected the concepts with arrows and linking words on Post It notes.

If the groups believed the maps needed to be reorganized the students moved the Post It notes to new locations that made the map easier to follow and read. If the linking words need to be modified the students simply added a new Post It note with the correction. The students were told to discuss the map at the end of the period and were told at the beginning of the next class period, they could reorganize the map. The teachers walked around the room to listen to the group discussions and to determine if there were any misunderstandings or questions. The teachers helped address any misunderstandings with the whole class as closure at the end of the period.

At the start of the next period the students corrected any misconceptions on bonding. The Post It notes were simply changed or rearranged on the maps. When the groups were satisfied with the maps the students removed the Post It notes and used markers to permanently write the concepts, linking words, and cross links. The groups used the next period to present their maps to the whole class as a final review before the examination the following day.

The examinations scores for the covalent and ionic bonding unit were evaluated for the three concept map classes and for the non participating class. The examination scores revealed the three concept map classes scored slightly higher than non-participating class. The average examination score from class one was 89 percent. The median score was 90 percent and the range of scores was from 58 to 100 percent. The average examination score from classes two was 79 percent. The median for class two was 82 percent and the range was 60 to 98 percent. The average examination score from classes three was 79 percent. The median for class three was 78 percent and the range was 59 to 96 percent. The average examination score for class four, which was not involved in the concept map activity, was 76 percent. The median for class four was 79 percent and the range was 53 to 94 percent.

After the examination the students in classes one, two, and three were surveyed with five questions to determine if concept maps with small groups were helpful for understanding bonding concepts (see Appendix B). Twenty out of 24 students from class one, 21 out of 23 students from class two, and 18 out of 21 students from class three thought concept maps were useful for organization and representing knowledge in a visual form. The majority of students from the three map classes believed the concept maps helped the students clearly understand the topics and working in groups was helpful. Selected responses for the group work question included "it was helpful because they could clarify questions you had while writing," "helpful because more people to brainstorm ideas," and "I think it was helpful because we can learn new things through different people's knowledge." The majority of students also found the maps useful as misunderstandings were found while working in groups.

Several units after the bonding unit the regents classes finished the unit on chemical moles. The mole unit is a difficult and abstract topic for high school students to grasp. The same procedures implemented in the atomic structure and bonding units were used to prepare concept maps for the chemical mole unit. As with the atomic structure and bonding units, class four did not participate with the concept map activity. During the mole unit, only classes one and two were assigned to construct concept maps. No changes or procedure modifications were made with the mole concept map.

The examinations scores for the mole unit were evaluated for two concept map classes and for the non participating class. The examination scores revealed the concept map classes scored higher than class four. The average examination score from class one was 89 percent. The median score was 92 percent and the range of scores was from 61 to 100 percent. The average examination score from class two was 89 percent. The median score for class two was 90 percent and the range was 73 to 98 percent. The average examination score for the non-participating group, class four, was 82 percent. The median for class four was 83 percent and the range was 66 to 96 percent.

After the mole examination the students in classes one and two were surveyed with five questions to determine if creating concept maps in small groups was helpful for understanding chemical mole concepts (see Appendix A). As with the bonding survey the majority of students believed concept maps were useful for organization and representing knowledge in a visual form. The majority also believed the concept maps helped the students clearly understand the topics and working in groups was helpful. The majority of students found the maps useful for finding misunderstandings while working in groups.

Discussion & Conclusion

A solid introduction to preparing concept maps is important as to avoid a time consuming and confusing activity. As Vanides et al. (2005) stated the students should be taught the process before being expected to create a useful map. The introduction map during this study involved a familiar topic, density. The topic was chosen as the students were knowledgeable about the concept and could be engaged while discussing the concepts with their classmates.

The teachers taught the steps that Quinn et al. (2003) suggested for preparation of a concept map. These steps include reviewing the topic with a focus question and discussions, identifying the major concepts, arranging the concepts on paper in a hierarchical structure, linking the concepts with arrows for reading direction, labeling the concepts with a few words, and identifying any cross-link relationships. The teachers emphasized the readers of the map should understood relationships and be able to clearly read the map from top to bottom. After the students had finished the density map, the students seemed to find constructing concept maps an enjoyable and beneficial activity for reviewing science topics.

When the students were comfortable preparing the density concept map, the students created concept maps on atomic structure, chemical bonding, and the chemical mole. The introduction to each concept map activity started with a focus question to guide the students and teachers with pertinent concepts. The introduction with a focus question was suggested by Novak (1998) and Quinn et al. (2003). Novak and Quinn et al.

believed the focus question should address the knowledge domain that the teachers wanted to map.

The focus questions in this study helped start the activity to get the students thinking about the topics that were learned in the units. The discussions from the focus questions helped the Bloomfield teachers and students select at least 10 concepts that could be used in the maps. Concept map researchers such as Novak (1998), Quinn et al. (2003), and Vanides et al. (2005) suggested using eight to 20 key terms from the unit.

The students in this study were placed in heterogeneous groups to work on the concept maps. The groups discussed the pertinent concepts and searched for information in their text books and note books. Vanides et al. (2005) stated the small groups should be at different learning levels so the students can discuss the concepts and learn from each other. This study used groups of different grade levels, gender, and higher and lower ability students. The responses to the fifth survey question, "Explain why you believe or do not believe working in groups is helpful" showed the students believed working in groups was helpful to learning. Representative quotes from students on working in groups were "it is helpful to talk to other people and see what their ideas are and hear someone explain things in a different way" and "you can learn other people's perspectives and have them explain what you do not understand".

An open ended concept map was used in this study to assess the student understanding as Vanides et al. (2005) stated the map should not be a predefined tool. The open ended construct-a-map style gave maximum insight into student understanding as the ideas came from the student not the teacher. The students were given the opportunity to discuss, visualize and place the concepts where they saw fit so long as they stayed with the discussed structure of the map. The teachers only intervened if the student groups were showing misunderstandings or not focused on the chemistry topic.

The structure of the concept maps used in this study positioned the more general concepts at higher levels and the least general concepts at the bottom as suggested by Novak (1984, 2008) and Quinn et al. (2003). As Chiappetta (2006) suggested, the students should not construct full sentences in the concept boxes. The students were told too many words would make the map difficult to read with the extra words. The maps contained boxes with only one or two words to describe the concepts.

The concepts were connected by colored arrows for easy visualization as suggested by Novak (1998), Rogers (1999), and Vanides et al. (2005). The arrows indicated the reading direction and the colored writing helped with visualization. The students wrote a few linking words between concepts to demonstrate the relationships and helped the students create connections between terms. The survey questions clearly demonstrated the chemistry students found the activity to create concept maps was extremely useful to understanding. The majority of the students believed concept maps were useful to organize and represent knowledge in a visual form and the concept map activity helped the students clearly understand the topics. Selected responses of student opinions on the concept map visualization and aid for understanding included “concept maps are useful as all the information is in one place,” “concept maps help visualize the chapter,” “yes, it is easy to access and organize all the information,” “yes, the maps are a good visual model of the unit,” and “yes, it helped me understand the relationships”. The student responses portray how the students understood the relationships and chemistry concepts with the creation of the visual concept map.

Novak (1998) and Brown (2002) stated that by allowing the students to use concept maps while working in small groups, the students can organize their thoughts, move ideas, and correct misunderstandings on the rough draft. Many student responses to the survey questions indicated the students believed it was helpful to discuss the ideas and correct misconceptions when working in small groups. Survey responses such as "the group work on the maps helps us to discuss the topic and correct misunderstandings" and "if you do not understand a concept, the group can help you understand it" indicate discussions in small groups help determine misunderstandings.

The activity is necessary in the classroom to reveal misconceptions before examination time. The majority of the students found misunderstandings during the creation of the concept map. The social interaction enhanced the learning process as the students discussed, organized, and thought about the concepts. The peer collaboration allowed the students to teach each other and help everyone understand the concepts.

Vanides et al. (2005), Quinn et al. (2003), and Zak (2008) suggested the concept map is useful to the teachers as it allows for assessment of understanding while the students are working on the map. The assessment can be done as the teacher moves around the room and watches the students working. The teachers in this study assessed the linking words to reveal the understanding or misunderstanding. If there were any misunderstandings the teachers would address it with the group. The students then had the opportunity to discuss the error, review notes or the textbook, and correct the misunderstanding on their map. By allowing time to correct misunderstandings, the Post It notes proved to be useful for easy manipulation of the maps.

The final maps were evaluated for content validity. The concept maps in this study were graded with a similar rubric as the Vanides. et al. (2005) rubric. As Quinn et al. (2003) and Zak (2008) stated the teacher can assess the final maps and determine whether the propositions between concepts are scientifically valid top receive full credit. The propositions indicated if the student groups understood the relationships between concepts.

The results from the bonding examinations after the concept map activity proved the map was useful for understanding. The average scores for the bonding examination were 89, 79, and 79 percent for the map classes one, two, and three respectively. The non participating class averaged 76 percent for the bonding examination. The concept map classes also scored higher than the non-participating class with the mole examination. The concept map classes averaged 91 and 89 percent versus 82 percent for the non-participating class. The data from this study is similar to the biology concept map study by Brown (2003). Brown stated "students who created concept maps in small groups outperformed students working on their own" (p. 196).

The study determined students find concept maps to be useful visual representations of the chemistry units. The hierarchical structure of concept maps, propositions, and relationships describe the concepts in the map. Propositions between concepts help students easily read the meanings and relationships of the concepts. The majority of the students believed concept maps are a useful tool to organize and represent knowledge in a visual form.

The students stated the concept map activity helped them clearly understand the topics. By assigning the student to work in heterogeneous groups, the students felt the other group members helped teach the concepts that others might not correctly understand. The teachers also found the maps to be helpful in assessing student knowledge and determining any misunderstandings. This study used student surveys and examinations to show the use of concept maps in science classrooms is an effective learning tool for conceptual understanding.

Future concept map studies could involve using computer software instead of markers and paper. The software would avoid the use of Post it notes as the keyboard could simply delete and change the map when necessary. The concept maps on the computer would definitely be excellent visual representations of the key topics. As students enjoy using computers and visual engagement, the software would be interesting to implement in the science classroom. A future study would need to investigate the costs of installing software such as Inspiration and Cmap Tools on classroom computers.

Another study could be to introduce concept maps to middle school science students. The procedures from this study could be repeated with younger students and the examination scores could be compared to non-participating middle school students that are taught the same lessons. The objective would be to determine if younger students also believe concept maps are helpful for understanding science topics.

Science teachers could use this study to help teach abstract subjects such as chemistry. The concept map can be used to help learn topics and vocabulary without trying to have students simply use memorization of terms that is quickly forgotten. Concept maps can be used in the science classroom to help students visualize the meanings and relationships of pertinent topics in the curriculum.

Teachers can use the methods from this study, including focus questions and discussion time, to address important topics. Teachers could use this study to realize the benefits of assigning heterogeneous groups while working with concept maps. By using groups with students of different learning abilities, the students can help teach each other and learn difficult concepts. The groups are effective when there is discussion time to address misconceptions and questions. Science teachers can use the rubric in this study to effectively assess if there are any misunderstandings and score if the concept propositions are scientifically valid. The concept map can be a meaningful learning tool for science teachers to use to help students understand topics such as chemistry.

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Appendix A

Rubric for concept map classrooms

	Three points	Two points	One point	Zero points
Concepts	Team used 100% of concepts	Team used 80 - 90% of concepts	Team less 70 - 80% of concepts	Team used less than 70% of concepts
Proposition # one	Correct	Partially correct but scientifically thin	Incorrect	
Proposition # two	Correct	Partially correct but scientifically thin	Incorrect	
Proposition # three	Correct	Partially correct but scientifically thin	Incorrect	
Proposition # four	Correct	Partially correct but scientifically thin	Incorrect	
Proposition # five	Correct	Partially correct but scientifically thin	Incorrect	
Proposition # six	Correct	Partially correct but scientifically thin	Incorrect	
Proposition # seven	Correct	Partially correct but scientifically thin	Incorrect	
Proposition # eight	Correct	Partially correct but scientifically thin	Incorrect	
Proposition # nine	Correct	Partially correct but scientifically thin	Incorrect	
Proposition # 10	Correct	Partially correct but scientifically thin	Incorrect	
Cross Link # 11	Correct	Partially correct but scientifically thin	Incorrect	
Cross Link # 12	Correct	Partially correct but scientifically thin	Incorrect	
Cross Link # 13	Correct	Partially correct but scientifically thin	Incorrect	

Total allowed points ______________________

Score _______________________________________

Appendix B

Survey questions for classes one, two, and three

Were concept maps useful to organize and represent knowledge in a visual form?

Do you believe the concept map activity helped you clearly understand the topics?

Did your group find any misunderstandings during the creation of the concept map?

Do you feel working in groups of three students was helpful?

Explain why you believe or do not believe working in groups is helpful?