From our observations and those of Kinchin (2001) teachers may know about concept mapping but they do not seem to use it as a consistent, effective strategy. We argue that the concept mapping may be better understood by using an expanded definition of traditional literacy, listening, speaking, reading and writing; to include visualizing, visual representation, and technological literacy Sinatra (1986). This ethnographic case study examines the use of concept mapping and collaborative learning strategies in the content area of marine ecology in high school science classrooms. To support students’ understanding of science concept and the improvement of writing students began with a field trip to study inter-coastal zones and follow-up laboratory activities, use of digital image analysis, and collaborative group work. Key vocabulary were identified to begin concept maps, and more vocabulary was added to support multiple revisions of concept maps with concept map software, and culminated with students’ writing. Concept mapping integrated with collaborative learning was used to engage students to construct and re-construct their understanding of a complex scientific concept, the energy cycle. The results showed that students benefited from the combination of collaborative learning and concept maps to focus their writing on key ideas, to organize their ideas, and include specific details. However, the interpretation and integration of quantitative data and laboratory results was not as consistent. Most importantly, initial concept maps and revisions provided the teacher with evidence of student learning in the form of formative assessment products, to guide teachers’ focused feedback and clarify specific ideas for re-teaching, as well as students’ self-assessment. We provide examples of concept maps and graphic organizers as formative assessment of students’ knowledge, what Novak (1998) calls heuristic or “facilitative tools,” and as visual representations and structures to provide flexible ways supporting learners’ meaningful learning through speaking, writing and in visual forms (Sinatra, 2000; Mintzes, Wandersee, and Novak, 2004).

Our aim is to describe the value of concept mapping and graphic organizers for learning in the context of literacy (reading, speaking, and writing, as well as visual representation and technological literacy), and the importance of understanding visual learning strategies as formative assessment. In this paper we discuss 1) the concept of literacy and visual literacy, and visual representation in particular (Sinatra, 1986), and the connection with 2) the role of formative assessment in learning (Black and Wiliam, 1998a). Research reviews on the impact of knowledge and concept mapping (Novak, 1998; Nesbit and Adesope, 2006) indicate moderate to large, positive effects, as does meta-analysis of research on formative assessment (Black and Wiliam, 1998a; Black and Wiliam, 1998b). In order for concept mapping to produce the promised effects on students it must be viewed as formative assessment of students’ knowledge, what Novak (1998) calls heuristic or “facilitative tools,”
and “learning how to learn” (Novak and Gowin, 1984; Black, McCormick, James, and Pedder, 2006). Effective use of visual representations and structures provide flexible ways to support both teachers’ and learners’ quest to answer three key, instructional questions to support formative assessment: 1) Where do I want to go in my teaching and learning? 2) Where am I now? And 3) What do I need to do to get there? (Black and Wiliam, 1998a; Stiggins, Arter, Chappuis, and Chappuis, 2004) Concept maps are concrete, formative assessment products that promote dialogue and focused feedback among students, and between teacher and students (Sinatra, 2000; Mintzes, Wandersee, and Novak, 2004). Concept mapping and collaborative learning are strategies that can be “thoughtful, reflective, and focused to evoke and explore understanding” (Black and Wiliam, 1998a).

According to the meta-analysis of research by Nesbit and Adesope (2006) which included fifty-five (55), well-designed experimental studies the average effect size estimates for concept mapping were positive, and greatest for collaborative mapping strategies with mixed ability students, for students with lower verbal ability and weak domain-specific background such as sciences like biology or chemistry. In a previous meta-analysis Horton, McConney, Gallo, Woods, Senn and Hamlin (1993) estimated the effects of concept mapping to improve knowledge is 0.42, and the impact on students’ attitudes and engagement is 1.57. Effect sizes are quantitative estimates of the impact on specific outcomes like achievement or attitudes, and these estimates help to summarize findings across multiple research studies. The effect size of 0.42 means that on average, experimental groups scored higher than control groups by 0.42 standard deviations. Or an effect size of 0.4 would mean that the average pupil involved in an innovation would record the same achievement as a pupil in the top 35% of those not so involved (Black and Wiliam, 1998a). Positive effect sizes of strategies such collaborative learning (effect size = 0.73), nonlinguistic representation like concept mapping (effect size = 0.75), and reinforcement and feedback (effect size = 0.80) are identified by Marzano (2003) as teacher-level factors representing effective, research-based instructional strategies. In Marzano’s meta-analysis What Works in Schools: Translating Research into Action, nonlinguistic representations include concept maps and visual representations, the use of images and metaphors, and art forms like the use of drama, constructing models. In addition, concept mapping and visual representations can be used to support other effective strategies like identifying similarities and differences, summarizing and note-taking, and the use of advance organizers.

Several other teaching and learning models provide strong support and suggestions for the use of concept mapping and visual representation, including Trowbridge and Wandersee’s model of theory-driven graphic organizers (2005), Hyerle’s toolbox of visual learning tools, and the Universal Design for Learning (2002). There are three major principles in the Universal Design for Learning (UDL) framework, 1) to support recognition learning, provide multiple, flexible ways of presenting and teaching new knowledge, 2) to support strategic learning, provide multiple, flexible methods of expression and practice, and 3) to support affective learning, provide multiple, flexible options for engagement. Our approach incorporates flexible learning strategies that reflect all three of these principles, especially the use of concept mapping software for knowledge construction and organization, and the use of collaborative and individual learning to support student engagement.

Several suggestions by Trowbridge and Wandersee were relevant for this study; our procedure for concept map construction closely follows their model (2005) of a progressive
The procedure by Trowbridge and Wandersee for constructing a concept maps focuses on individual students. A critical difference is that we suggest the use of collaborative learning as the initial step for map construction. Our interviews with students indicated strong support for the collaborative learning step. Also, Trowbridge and Wandersee suggest that expert maps be used only after students had struggled with map construction, another very helpful, useful recommendation with which we agree. Finally, we believe that for most learning goals concept maps be used as formative assessment products, and not graded or scored, a matter of specifying the purpose of the assessment. The issue in any case is that students actively construct the knowledge essential to their learning, and not depend on rote memorization (Novak and Gowin, 1984; Trowbridge and Wandersee, 2005).

In a comprehensive review Hyerle (1996) identified three types of visual learning tools: brainstorming webs, task-specific organizers, and thinking-process maps. He maintains that visual learning tools are important for designing learning that is linear and nonlinear, student-centered, developmental, interactive, and linked with technology – a constructivist environment. Hyerle explains how visual learning tools support the integration of teaching, learning and assessment, inclusive classrooms, and reflection (1996). He also pointed out that students’ skills at creating and using maps develop over time, when these skills are used deliberately across the curriculum.

Our study concentrates on concept maps as formative assessment products, created and used intentionally to blur the lines that separate teaching, learning and assessment. Just as important they are developed and used in a combination of group and individual learning settings, providing multiple opportunities to benefit students’ emerging understanding and teachers’ need to know students’ current conceptions and misconceptions of complex science concepts. The outcomes for this study are measured by students’ written responses on their lab reports.

We situate our case study in a high school biology classroom with a lesson on the energy cycle. Technology components of this study consisted of both commercial software for concept mapping, Inspiration, and new software provided by a National Aeronautics and Space Administration (NASA) grant, Measuring Vegetation Health (http://mvh.sr.unh.edu) emphasizing the use of digital images for environmental monitoring. The classroom work envisioned by this grant combines field-work and outdoor experiences with analysis of remote sensing imagery (aerial and satellite images) and digital photographs to support spatial, spectral and temporal investigations of plants, trees and living things in our environment. Concept mapping and formative assessment were strategies introduced with this grant for teachers and learners to improve comprehension of complex topics and to animate thinking processes of analysis, synthesis, and creativity (Ornstein and Sinatra, 2006, p. 27).

As we highlight the potential impact of concept mapping and visual representation we have a concern for classroom teachers echoing Kinchin’s (2001) observations. Concept mapping is a strategy that is familiar to many, if not most teachers, however in practice it may be used on a limited basis, or not well enough to produce positive effects on students’ learning. As Novak (1998) remarked, even though concept mapping is well known, and software tools like CMAP and Inspiration are readily available, the use of concept mapping remains inconsistent, at best. During a series of five workshops for the NASA science grant,
Measuring Vegetation Health (http://mvh.sr.unh.edu), we surveyed fifty-six teachers about their understanding and use of concept mapping in science. In self-reported responses teachers indicated that, even though they know about concept mapping, it is not a regular part of instruction (Beaudry, 2005). Kinchin pointed out that the two major barriers may be teachers’ own beliefs about teaching and the underlying philosophy of the curriculum (2001). We believe that consideration of literacy and formative assessment with concept mapping and visual representation may provide a stronger rationale for re-conceptualizing teaching and learning. In this respect our views are akin to what Kinchin calls an “ecological” perspective of teaching, one in which well-prepared teachers and active, motivated students work together to create and sustain conditions in which they “communicate effectively as partners within a learning community” (2001, p. 1267)

**Literature Review**

**Background: Measuring Vegetation Health**

The research and development for this paper is connected primarily with Measuring Vegetation Health (http://mvh.sr.un.edu), a NASA grant focused on development and initial testing of technological tools and resources for using light and color to investigate the health of plants and trees, and the promotion of spatial learning. Sources of digital information include remote sensing imagery (aerial and satellite) and handheld digital cameras. Digital images are analyzed using new, open-source image analysis software designed and improved by this grant, including Color Basics, Image Basics, and Image Analysis software packages.

One of the purposes of the Measuring Vegetation Health grant is to support inquiry in science classrooms with technological tools and resources. Our approach is to integrate the use of science tools and resources for inquiry with the literacy development tools like concept mapping and collaborative learning. The use of such tools relates to another new literacy, spatial literacy. According to the National Academy of Sciences (2006) “Spatially literate students who have developed appropriate levels of spatial knowledge and skills in spatial ways of thinking and acting together with sets of spatial capabilities, have the following characteristics:

1. They have the habit of mind of thinking spatially
2. They practice spatial thinking in an informed way
3. They adopt a critical stance to spatial thinking – they can evaluate the quality of spatial data and can evaluate the validity of arguments based on spatial information. (p. 4)

This perspective fits with our view of visual literacy, and we have begun to do research on student learning with this definition as the intended outcome. For our work in the future we will try to relate spatial thinking more directly to the literacy strategies, since it has a clear connection with the expanded literacy framework (See Figure 1) and visual literacy model (See Figure 2) elaborated by Sinatra (1986) in which learners’ understand how to plan, produce and evaluate visual representations.
Expanded Definition of Literacy: Reading, Writing, Listening, Speaking, Visualizing, and Visual Representation. Traditional forms of literacy include reading, writing, speaking, and listening, and Sinatra (1986) suggested expanding the model to include viewing (observing and experiencing), visual representation, and media technology (See Figure 1). Sinatra (1986) presented a model of literacy development that included four interactive phases: phase 1 - visual literacy, phase 2 - oral literacy, phase 3 - written literacy, and phase 4 - visual representation and communication (See Figure 2). Technological literacy is a rapidly evolving mode of learning involving interaction with computer hardware, software, and new information technologies. In order to “reinforce the learning of new concepts, understanding and vocabulary words” the integration of the reading, mapping and writing process is critical (Ornstein and Sinatra, 2003, p. 260; Sinatra, Beaudry, Pizzo, and Geisert, 1994). In his article, “Teaching Learners to Think, Read, and Write More Effectively in Content Subjects” Sinatra (2000) focused on three aspects of the teaching-learning construct: 1) text structure for expository writing, 2) concept mapping to clarify conceptual understanding and to represent text structure, and 3) the teaching-style shift from teacher-centered classrooms to more student participation. The review of research in the meta-analysis by Nesbit and Adesope (2006) suggests that concept mapping is a highly engaging and effective literacy development strategy, especially when students are involved directly in the construction and revision of their own visual products. Adding technology and new media environments to this model is relevant for this study because we explore a variety of software for concept mapping and spatial and spectral measurements, as well as digital cameras and images. In their framework for “technological pedagogical content knowledge” Mishra and Koehler (2006) point out that teachers need to have a deep
understanding of the interaction of content, pedagogy, and technology. Teachers must have “knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face; knowledge of students’ prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones” (pp. 1028-1029). For our study literacy and technological pedagogical content knowledge (TPCK) make important contributions. Literacy elaborates ways of knowing or epistemologies, especially viewing and visual representation, and TCPK offers a framework for planning and designing learning, teaching, and assessment with technology tools.

Figure 2: Visual Literacy and Relationship with Verbal and Nonverbal Literacies  
(Sinatra, 1986, p. 29)

Our perspective combines and extends the current recommendations for practice found in the USA’s national reports on literacy by the National Reading Panel and Writing Next. First, the National Reading Panel Report (2000) emphasizes the use of concept mapping to improve comprehension by using graphic organizers and concept maps. (See Figure 3) Second, the recommendations to improve writing in Writing Next (2006) emphasize writing in the content areas, use of summarization, pre-writing, the study of models, and specific
product goals. (See Figure 4) The elements of writing are arranged according to the magnitude of the effect size, which are the results of the meta-analysis in the Writing Next report. Effect sizes represent a summary statistic of the impact of a strategy or element on specified, quantitative outcome. The largest effect size is the use of multiple strategies with an effect size of 0.82, the use of summarization with an effect size of 0.82, collaboration with an effect size of 0.75 and students understanding specific product goals in advance of the assignment with an effect size of 0.70.

Concept mapping and related visual learning approaches engage students “in discovery, in creation, and in acts of synthesis” which are essential to learning relationships among words and concepts (Sinatra, 1986, p. 27). What is striking about the two models of literacy is that concept mapping is cited explicitly as a strategy for reading comprehension, but it is not specifically cited as a strategy for creating successful writers. Also, do not overlook the presence of collaborative group work in both reading and writing, and we suggest to concept mapping.

The use of mapping as an organizing framework for student-writers fits with pre-writing strategies, and according to Sinatra (2000) applying and practicing the use of organizational, concept maps “works for students at all grade levels and may benefit at-risk, low-achieving students to a high degree” (p. 272). Our suggestion to teachers would be to infuse visual literacy strategies like concept mapping to the list of literacy strategies explicitly across content and from early childhood to adolescent years and beyond. Concept mapping must be in the repertoire of teaching and learning strategies for strengthening students’ reading comprehension, and as a means for scaffolding students’ writing so that they can make the connection between reading and writing when they encounter new, complex ideas and difficult text. “Concept maps are to informational, expository text what story maps are to narrative literature,” as they are used to generate and organize concepts (Ornstein and Sinatra, 2003, p. 369). In addition, concept maps and graphic organizers are products that facilitate interactions of multiple forms of literacy, bringing thinking, writing, visualizing together with listening and speaking.

Finally, our approach embeds the expanded model of literacy in the strands of scientific proficiency identified by the National Research Council (2007) in Taking Science to School. In this framework for science there are four broad learning goals, “1) know, use and interpret scientific explanations of the natural world, 2) generate and evaluate scientific evidence and explanations, 3) understand the nature and development of scientific knowledge, and 4) participate productively in scientific practices and discourse” (Duschl, Schweingruber, and Shouse, 2007, p. 36). The field study of inter-coastal tidal zones is a key instructional strategy in our study because it provides a concrete experience in a complex, natural setting for all students to view and explore. Furthermore, it is an image and point of reference for the teacher and students to support classroom investigations, interpretation of data, and expression in speaking, visual representation and writing. All of the strategies contribute to the development of yet another form of literacy, science literacy.
Figure 3: The National Reading Panel (2000) Summary of Essential Elements
Formative Assessment Links Learning with Final Products. The purpose of this study is to investigate the role of formative assessment to focus learners’ attention on three questions: 1) Where am I now? 2) Where do I want to go? and, 3) What do I need to get there? In an age of accountability we struggle to find the balance between accountability through summative assessment like standardized testing and grading, and formative assessment, the need to support the learning of students and teachers. There are seven strategies associated with formative assessment suggested by Stiggins et al, (2007).

Where am I going?
1. Provide a clear and understandable version of the learning target.
2. Use examples and models of strong and weak work.

Where am I now?
3. Offer regular, descriptive feedback.
4. Teach students to self-assess and set goals.

What do I need to do to get there? How can I close the gap?
5. Design lessons to focus on one aspect of the quality at a time.
6. Teach students focused revision.
7. Engage students in self-reflection, and let them keep track of and share their learning. (p. 42)

One of the key findings in the research review by Black and Wiliam (1998a) is that the quality of feedback from teachers and/or other students can be a very positive component
to student learning. Comments in writing and orally carry specific guidance and messages to support students’ growth, whereas grades and marks tend to interrupt learning. Dweck observed that the shift caused by grading which emphasizes the fixed mindset, only ability counts, and de-emphasizes the growth mindset, I can do this if I keep trying, is most pronounced for students struggling with basic comprehension, understanding and performance (2005). The purpose of formative assessment is to keep students focused on self-efficacy and learning, especially through peer- and self-assessment, and that frequent self-assessment of specific learning strategies and processes produces more positive effects than instruction focusing on grading or performance.

The primary purpose of formative assessment is the promotion of student learning. “That is, the first priority in its design and practice is to serve the purpose of promoting students’ learning. This distinguishes it from any assessment designed primarily to serve the purpose of determining accountability, ranking, or competence” (Black and Wiliam, 2004, p. 21). Formative assessment has some lasting effects on classroom roles and responsibilities by: 1) developing the capacity for a variety of feedback sources (teacher-to-student, and student-to-student and student-to-teacher), 2) active involvement of students in their own learning, 3) adjustment of teaching to account for the results of assessment, 4) understanding of the impact of assessment on students’ motivation and self-esteem, and 5) by being explicit about self-assessment and how to improve learning (Black and Wiliam, 2004, pp. 4-5). Effective feedback, from teacher to students, and student to student, and students to teacher, is vital for effective formative assessment. Concept maps are flexible tools for allowing students to reveal the active construction of new understanding by generating and answering their own questions, to make novice errors, to support students’ collaborative dialogue, and to focus teacher-expert feedback on students’ individual formative assessment products. Misconceptions can be revealed to the teacher in an efficient and precise manner, with a quick look. During this process students learn how to make focused revision, and teachers gain another source of data for students to triangulate with other sources like interviews, students’ writing, other performance skills, and tests and quizzes.

Formative assessment is not a trendy term meant to circumvent grades or tests. Novak and Gowin’s initial work focused on cognitive development of students, but also incorporated the concept of formative assessment within Ausubel’s model of “meaningful learning.” Rather it is a key attribute of effective teaching and learning, as he/she learns how to use productive, cognitive and meta-cognitive strategies. Emphasizing formative assessment allows for more purposeful and sustained interactions between teacher-experts and student-novices to learn new ideas and to consolidate understanding of prior knowledge. Examples of cognitive strategies are concept mapping, summarizing, de-coding and self-questioning. Meta-cognition, the student’s own regulation of cognition, might include a learner’s identification of areas of misunderstanding, detecting errors, and re-writing sentences to improve sentence variety.
Purpose of the Research

Our purpose was to explore how a high school science teacher and her students used concept maps to develop understanding of the inter-tidal system, a progressively complex science concept. We conducted an ethnographic case study, from two perspectives, that of a teacher researcher and a university-based participant observer. The study focused on concept mapping, formative assessment and scientific inquiry in high school science in one science classroom in a medium-size high school with approximately 1,200 students in a city in northern New England.

High school science courses introduce difficult subject matter to students who may or may not have sufficient prior knowledge for successful assimilation of the content. The problem begins in middle school, where typical science textbooks present the same complex and abstract concepts that are later taught in high school. The result is that high school students often profess to know concepts that in reality they understand incorrectly if at all. The problem is exacerbated by the fact that many science concepts are encased in totally unfamiliar language or in language that is used in a new way.

Typically, students learn concepts through direct vocabulary-based instruction and are assessed with selected response tests. This use of summative assessments like grades does little to help students integrate new knowledge or to provide opportunity to clear up prior misconceptions (Novak and Canas, 2006). Even in science classes that are rich in inquiry studies, hands on activities, and constructivist pedagogy, students cannot engage in meaningful learning if they are building on partial understandings or misconceptions. Concept maps are useful tools to help students construct, describe and revise their basic understanding of concepts. In constructing maps, students can correctly link new information to what they already know and expand learning while teachers can quickly and easily see what their students know and adjust their teaching accordingly.

We have found that in high school science classes, students struggle to comprehend the interconnectedness and cyclical patterns central to biological and ecological concepts. As the literature review demonstrates, concept mapping strategies go well beyond memorization because they engage students in thinking about hierarchies and specific connections. However, while concept mapping is a powerful strategy it must be taught and learned. We have noticed that when asked to map their understanding of a topic, students tend to create images that are linear. They typically draw one concept that leads to another like an arrow passing through several targets lined up one behind each other. Another commonly drawn map shows concepts that radiate from a central idea, where each concept stands alone in its connection to the center. We view these visual representations as evidence of the naïve and underdeveloped concepts and lack of exposure that characterize novice learners as they reveal their understanding of complex concepts with the instructional strategy of concept mapping.

Setting for the Research

As indicated, the research occurred in one high school science class and was collaboratively conducted by a teacher researcher from inside her own classroom and a university researcher who functioned as a participant observer. We chose to focus on the use of concept maps in the study of matter and energy moving through ecosystems. Earlier classes had identified
this topic as being most problematic. This evaluation was substantiated by the teacher researcher who noted that student work and assessments reflected consistent misunderstandings. Energy moving through ecosystems is a complicated topic that relies on basic understanding of the difference between energy and matter and the biological processes of photosynthesis, cellular respiration and decomposition. It also incorporates knowledge of the elements important to building the basic molecules of organic matter. In an ecosystem, matter is cycled from inorganic reservoirs to organic reservoirs and energy is transferred from one form to another eventually dissipating in less usable forms of energy such as heat. Students often are confused by the difference between energy and matter and puzzled by the fact that the same matter held in the tissues of living things can be found in the air or water. Although these concepts are represented in familiar ecological food webs, the science behind them is abstract and difficult to grasp. The study began with the research question: could individually mapping these concepts using a software program and formative assessment strategies improve understanding of the complex concepts comprising ecosystems?

We wanted to move students beyond the typical rudimentary visual representations of prior classes. Typically, concept mapping is introduced as a collaborative learning experience in a strategy we called “glue, paper, scissors.” of “GPS.” Groups of students worked together with a list of 10 to 12 vocabulary words from a selected topic. They cut out and arranged the words together to describe and build their understanding of the topic. Each team described its map in a brief presentation to the teacher, who provided opportunities for students to ask questions and to expand and rethink their maps. When maps represented the ideas correctly, or close to accurately, students glued the words into place and posted the maps for whole class discussion. The teacher listened in on lively, focused conversations as the students worked out their ideas together. All groups completed their first map, an indicator that students were engaged. The maps and conversations offered an informative peek into the cognitive journey on which students had embarked; each was engaged in building his/her own understanding of complex scientific concepts and processes.

For the purpose of this study, we refined the GPS activity and also introduced the innovation of concept mapping software to follow the GPS activity with the hope these modifications would yield new and more sophisticated student products, visual representations, and writing. The strategies combining literacy, concept mapping, and collaborative learning are summarized in the Technology and Teaching Progression (See Appendix C). A complete narrative of the implementation of the innovation and its outcomes is presented in the Results Achieved section of this chapter.

**Research Methodology**

The research relied on qualitative methods of sampling, data collection and data analysis. Both authors implemented all phases of this study as a collaborative research team, one as the teacher researcher and the other as the participant observer. The multiplicity of roles is characteristic of an ethnographic design, one in which the immersion of the researcher in the setting is both empowering and transformative as well as conflicted and ambiguous (Smith, 1979; Harklau and Norwood, 2005). The ethnographic design provided triangulation of data including 1) long-term participant-observation, 2) collection of artifacts, i.e., concept maps and written laboratory assignments, and 3) interviews, both informal and formal.
**Sampling**

The classroom of middle- to low-achieving students was a purposive sample; it was selected because we wanted to work with students struggling to understand science concepts and who were challenged in communicating their understanding of science concepts in writing. There were a total of eighteen (18) students in the classroom. All of the students were observed over the course of the semester; for the in-depth interviewing at the end of the semester six students, four females and two males were selected as a focal group to represent a range of accomplishment on the written conclusion. For a focal group to study we deliberately selected students who represented the entire range of writing achievement, two high-, two medium, and two low-achievers.

**Data Collection**

The study was conducted as an ethnographic study that took place over a 12-month period and culminated with intensive data collection in the final three months of the study. Over the period of a year, we worked as a collaborative team, one as teacher-researcher and the other as a participant-observer. This approach allowed us to combine “emic” and “etic” perspectives, as pioneered by Smith (1979). There were at least six classroom observations, beginning with the field trip to collect specimens and make observations at the inter-coastal tidal zone. Field notes were made after each visit, which constituted “thick description” of the classroom interactions. The participant-observer provided technical assistance in taking digital photographs and assisting students with the basics of concept mapping software.

Interviews were a key source of information throughout the study. We met as a collaborative research team before and after each lesson. We talked about each lesson to determine specific roles for each person, and conducted a de-briefing interview after each lesson. The most intensive interviewing took place at the end of the semester with a group of six students. After the six students completed their writing assignment each of them was interviewed. A semi-structured interview approach was used with the following questions and prompts:

- What is your background in biology and marine ecology? Have you taken biology already?
- What is your prior experience with concept mapping? Have you used this strategy in prior courses?
- Describe the value of the collaborative mapping activity as a starter for the concept mapping.
- How did the concept mapping software help or hinder your understanding of the energy cycle? Were there any problems using the concept mapping software?
- How did you use the concept map for your writing assignment? How did you use your own map and the expert map produced by the teacher?

Each of the students was interviewed with his or her concept map in front of them to assist the interview as recommended by Novak and Gowin (1984). Interviews were designed to last 10-15 minutes to accommodate student schedules.

Document analysis was used to accomplish the ultimate goal of the study, examination of the concept maps and evaluation of the written communication of the students. The concept
maps were collected and used as the basis for interviews after the lessons. The students’ written summaries were scored with a rubric by the teacher-researcher. In addition, the teacher-researcher wrote numerous reflections during the study. For example, teacher reflections were written about the instructional sequence, and the use of the concept mapping software.

Finally, as another check for data credibility, an expert science educator, with prior experience as a teacher, a curriculum designer, and a researcher, conducted a final, debriefing interview at the end of the semester with the teacher-researcher and the participant-observer. The purpose of the interview was to validate the classroom observations of the participant-observer. The results of these interviews verified that the classroom activities focused on development of science literacy, and students used image analysis and concept mapping software as part of the investigation and the write-up of the investigation.

Data Analysis
Data analysis for the study relied on a constant comparative approach, which considered all of the data sources: written field notes, samples of student maps and written essays, student interviews, reflective teacher journal. Tools of analysis included coding of data, member checks, analytic memos, and checks for reliability by an outside reader.

Results Achieved
This section provides a narrative of the implementation of the refined version of the GPS activity and the incorporation of the innovation of computer based concept mapping. The narrative describes and reflects on the sequence of instruction and results attained in terms of student products, teacher reflections, and student interview data.

Sequence of Instruction and Results. The sequence of presenting concepts began as students were introduced to the topic of matter and energy movement in ecosystems through primary production and nutrient cycles. The lab component involved growing populations of fresh water algae in various solutions of nutrients and collecting data on growth, pH (carbon dioxide in the water) and dissolved oxygen. The summative assessment goal was for students to articulate in a written lab conclusion, their understanding of how matter was cycled from the nutrient solutions in the water into the bodies of the algae and back into the water as oxygen or carbon dioxide. While the algae were growing (or not) students were asked to describe their knowledge by manipulating 22 terms or words into the familiar cooperative paper maps. At the point where the instructions previously ended, students continued their work in the computer lab where each pair transferred their ideas to the concept mapping program.

The software was new to most students, but everyone picked up the basics in five minutes or less. Constructing a map in collaborative groups with paper cut-outs was a critical first step, a step we named “glue-paper-scissors” or “GPS.” This provided continuity from instruction and separated the construction of the initial map from learning the Inspiration software. It was surprising to see that students did not quickly reproduce their paper maps and declared they were finished. Instead, they puzzled over connections, considering how they could represent their ideas more clearly and discovering components of the software that make the
maps more visually interesting. Hands were popping up to ask for work to be checked and for feedback. At the end of the block, every student had a his/her own, unique formative assessment product, which could be the basis for feedback and improvement. Upon careful review the maps still needed work to clearly and correctly represent the concepts. A few changes to a rubric for concept maps (See Appendix B) and it was posted online and introduced during the next class. Students used the rubric to evaluate and comment on the maps created the previous day then the students found their original mapping partner and returned to the lab to act on the comments. The resulting maps and written comments from students pointed to increased understanding of how matter is cycled in ecosystems. The answers to one question on a post-mapping survey were troubling. When asked if their map described a cycle or a chain of events, the most common answer was yes. Teacher evaluation of the maps revealed a distinct difference; the information was organized, but usually not as a cycle.

The next step asked students to expand their understanding by relating specific details of marine ecosystems to the mapped concepts. We began with assignment criteria and a rubric but skipped the introductory paper maps. Students were not presented with a list of words or concepts, just an outline of information they needed to include. Confusion resulted. In order to begin the work, the terms to be used in the maps had to be identified and categorized. Students did not know where to begin. They needed to consider how the variety of pieces of information might be grouped into organizational categories in order to understand where to begin. After clarification and briefly modeling the process, everyone worked individually and again the level of engagement was surprising. The students were engrossed in solving puzzles with a tool that made it easy to fix, revise and act on feedback. As they worked with the concept mapping strategy their level of comfort with the software also evolved. Soon many were embellishing their work by incorporating images and arranging concept categories with similar shapes and colors. The maps were varied, but the software had a leveling effect on the finished, written products. More students produced higher quality written products than previous science investigations. In particular students whose work is often messy and less finished than the work of their peers, created equally polished products. Most importantly, more immediate and focused feedback was given to the based on how each student described their knowledge and that feedback could be instantly acted upon to improve the map. After class, more teacher review, more comments on the maps and the next day, students made final revisions to their work. Each student printed two copies, one to hand in and one to use as a guide when articulating their knowledge in the lab conclusions. The concept maps became tools for an even more challenging assignment, writing about science content.
Teacher Researcher’s Pedagogical Reflection. A progression of knowledge is evident when results of the two mapping exercises are compared (See Figure 5 and Appendix C). Although some connecting lines may need an arrow reversed, most of the maps grew less confusing and more clear and concise even though information was added. Circular patterns were evident and concepts were organized more coherently. Students could apply and articulate the larger concepts from their maps in a lab conclusion. As a summative assessment, the algae lab, started at the beginning of the unit, required students to explain their knowledge of how primary producers, and the biological processes they engage in, contribute to the cycling of matter in an ecosystem. The writing assignment, the lab conclusion consists of three parts, 1) a restating of the purpose of the lab, 2) a paragraph describing the students’ knowledge of the ecological concepts demonstrated in the lab and 3) a paragraph in which specific data and results from the investigation are cited to support and provide examples of the concepts at work. These three criteria were used to score students’ essays. Students were able to demonstrate an understanding of the concepts with more accuracy and authority than students in the past classes that did not work with concept mapping software. However, students still did not connect the lab data and results with their writing. They were unable to show how the data from the lab investigations is used to support and explain the concepts of energy.

Students’ Interview Data. We followed up the writings with semi-structured interviews with a focal group of selected students. After the lesson was completed six students
representing the range of achievement from high to low were interviewed. There were two boys and four girls; one of the boys speaks English as a second language, now referred to in Maine public education as an English Language Learner (ELL). Each student had his/her concept map during the interview as a reference resource as recommended by Novak and Gowin (1984). The results of the interviews were analyzed according to the interview questions: background in biology and marine ecology, familiarity with concept mapping as an instructional strategy, value of collaborative, group work, ease of use of concept mapping software to understand key concepts, and use of concept map for writing. The results are presented below.

All students had taken other high school science courses, and four out of six had taken a general biology course with Ms. Wilson. That meant that four out of six were familiar with her teaching approaches including concept mapping, and using Inspiration software to create a concept map to acquire and consolidate understanding, and use it to scaffold his/her writing. Students responded to questions in the following areas: initial collaborative learning, going from collaborative to individual maps, writing from maps, and transfer of mapping strategies to other courses and content areas.

All of the students in the Marine Ecology course strongly underscored the importance of initiating concept maps in a collaborative, group setting. The students were accustomed to group work, which made the challenge of constructing maps possible. As one girl stated, “the groups gave me the chance to see if I was wrong, and if I was questioning something.” Another talked about group work as a supportive setting for argumentation, “Agreement was good, but controversy was good. I could remember the arguments over the maps and the resolution.” Group work also allowed students to express their frustration with the content and the mapping activity, as they struggled to create a clear map. Working as a group to start the mapping activity gave students a chance to offer feedback as peers, in a learning community permitting academic and emotional learning to be shared with peers, too. The ELL student spoke about the importance of his vocabulary development; when he worked collaboratively he found out that algae were living organisms and not “dirt”, as he had believed. Other themes from the interviews were consistent but did not match the clear message, the benefits of collaborative work for the initial steps in concept mapping.

As students went from the paper “cut outs” in the “GPS” activity to the software, Inspiration, all but one student completed the assignment to construct his/her own map of the cycles. The student who continued to struggle had difficulties because she wanted to make a hierarchical map, and not a cycle. A key struggle for students was making too many connections, a common problem with map construction (Heinze-Fry, 1992). Some students used the visual-graphic tools like shape, color and line weight to improve and to differentiate concepts. Only one student mentioned that using connecting or linking words was important to improving his understanding. The lack of linking words indicates an area for improvement in the instruction of map making.

Did concept mapping help students write in the content area? All of the students agreed that the mapping positively affected their writing about cycles, and was a very engaging strategy for learning. In essence, the mapping served as a pre-writing activity, and as a means to summarize the science inquiry activities. In addition, for the ELL student the vocabulary was defined and organized into a structure. Another student noticed the
similarity between her map and an outline, “but,” she said, “with my map I could experiment with ideas.” Overall, students demonstrated sustained effort in thinking about and communicating ideas orally in writing about the topic with their concept maps.

Do students incorporate mapping as a strategy for other purposes? Several students experienced using concept mapping with other teachers, however, none had used mapping software. None of them mentioned the use of concept mapping for pre-writing or to plan the organization of his/her writing for other courses or assignments. However, the ELL student described how he used mapping to take notes and improve his understanding of events and people in his modern history course.

Finally, we asked about how to improve the concept mapping activity in Marine Ecology. Students realized that they did not have enough experience with concept mapping to design and produce a map of the cycles in one lesson, a skill that was missing or undeveloped in previous grades. The concept maps provided students with a reasoning tool to understand the difference between a hierarchical and a cycle map. Finally, they wanted to understand how to manage the links between concepts more meaningfully. “I wanted to draw lines, but there were too many lines and connections,” a comment made out of frustration by many of those interviewed. Overall, students suggested that the total number of concepts in the concept mapping activity be trimmed because the map became too complicated; with more concepts came the propensity for adding unnecessary links.

**Future Trends**

The biggest trend for the future is the continued use and investigation of concept mapping, collaborative learning, and formative assessment by the teacher researcher in her classroom. Collaboratively, we continue to refine the process, both the GPS activity and the computer-based concept mapping. The GPS activity now begins with fewer words at the start. It is more carefully monitored to show how a hierarchy of concepts is visually represented and linking words are a requirement, as recommended by Novak and Gowin (1984) and Novak and Canas (2006).

We will continue to explore the use of concept mapping software. Concept mapping software tools are not so different from hand-drawn maps, but the transfer to computer software allows for more flexibility in the re-drawing of maps, more tools for the development of multi-layered concept maps, the sharing of maps electronically, and the creation of concept maps for group presentations. There is more capacity to make complex links, and to use of shapes and colors to represent similarities and differences of concepts. Other concept mapping software such as CMAP tools represent new means of collaboration, also opportunities for research.

Future research can use the instructional sequences we have identified for more controlled experimental research. In order to validate our ethnographic research findings other quantitative research designs can be with computer software concept mapping strategies as the educational treatment. For example, research by Stull and Meyer (2007) utilizes an experimental design to investigate the impact of learner-generated versus expert-generated graphic organizers on students’ reading comprehension of difficult text in a college biology course. Our approach would emphasize the comparison of concept mapping and collaborative learning with other strategies.
Under the broad concept of strategies for teaching and learning there are numerous questions concerning concept mapping and collaborative learning to investigate. For example, how should teachers use both their own expert concept maps and student-generated concept maps in different learning contexts? How much training do teachers need to become expert producers and users of concept maps? How does peer assessment affect the development of concept mapping skills in individual students? The Universal Design for Learning (UDL) framework suggests that teachers provide opportunities to learn that are differentiated to match the needs of learners. Are there preferences for different visual representations such as concept maps and outlines? How is learning, especially metacognition, affected by these preferences? How do the strategies of concept mapping and collaborative learning provide teachers with the necessary tools for a differentiated learning environment? By utilizing concept maps as formative assessment we provided students with the opportunity to produce different visual representations of their understanding, but did not investigate individual representations from the UDL. We see the future trends for concept mapping and collaborative learning as positive, generative and beneficial for teaching and learning.

Conclusions and Recommendations for Visual Literacy and Concept Mapping, Collaborative Learning and Formative Assessment

In this section we return to the framework of the seven strategies for formative assessment (Stiggins et al., 2004) as an organizing framework to summarize the connections with concept mapping and collaborative learning. We believe that meaningful learning means that teachers use a combination of formative assessment strategies to address the three major questions:

Where am I going?
1. Provide a clear and understandable version of the learning target.
2. Use examples and models of strong and weak work.

Where am I now?
3. Offer regular, descriptive feedback.
4. Teach students to self-assess and set goals.

What do I need to do to get there? How can I close the gap?
5. Design lessons to focus on one aspect of the quality at a time.
6. Teach students focused revision.
7. Engage students in self-reflection, and let them keep track of and share their learning. (p. 42)

Clear learning targets are essential to establish and hold steady for students to succeed, and for effective teaching and assessment. The teacher researcher provided oral and written descriptions of the writing assignment at multiple points in the lesson. The concept mapping activity is a strategy to clarify conceptual understanding. Collaborative learning groups provided students with the forum for peer assessment to clarify their understanding of the content, the energy cycle. As students said, using their own words created argumentation and emotional discourse, essential to correct misconceptions and sharpen definitions of key vocabulary as they co-constructed the initial maps in the GPS activity.
To provide the clear target for all students, and to share a high quality exemplar the teacher researcher drew her expert map as an exemplar to represent the arrangement of the key concepts, and used it for a lesson to summarize the topic. These strategies helped focus on the question “where am I going?”

The initial concept map drawn by students was a visual representation of their current understanding of the topic, energy flow in an ecosystem. It established the baseline for his/her understanding of “where am I now?” With challenging content it is difficult for students to get a picture that is a personal representation of “where am I now” but that is just what the concept map did. Each concept map was a depiction of a student’s private universe, a visual representation that showed each stage of understanding, and marked progress along the continuum from novice to accomplished novice and for some, to expert. The progression of learning assisted students to assimilate and reconstruct their understanding of the energy cycle in an ecosystem (Mintzes, Wandersee, and Novak, 2005). Concept maps were a new tool for self-assessment, as well as a tangible product for the teacher researcher to assess formatively and provide descriptive feedback. The teacher researcher collected and examined the concept maps with each step in construction, and used the concept maps to re-set the learning targets. The collaborative learning strategy promoted peer assessment in which students provided feedback to each other. Students continued to look at each other’s maps and ask questions. Students were provided with a rubric as a self-assessment guide to improve the construction of their concept map. The maps were not graded, a critical adjustment in students’ expectations of the role of feedback. In teaching this difficult concept the teacher had to monitor students’ struggle to comprehend, to persist in “meaningful learning” and prevent this from becoming a frustrating and dissatisfying learning experience.

There were several key strategies that provided the teacher and students with meaningful answers to the question “how do I get there?” One thing that was clear from the beginning the teacher researcher wanted students to become better writers. That decision helped students focus on specific aspects of quality writing. The drawing and re-drawing of the concept maps assisted each student in making focused revisions even before actual writing took place. As mentioned the drawing and re-drawing of the concept maps the benefited both the students and the teacher researcher. Revising and improving concept maps was effortful and intentional for students, and helped each student to struggle with the complexity of the big picture and multiple levels of detail. Finally, students appreciated the opportunities to talk about their ideas with their peers at the early stages of concept mapping, and throughout the lesson. The impact of collaboration and peer assessment led us to an alternative name for the GPS activity, “group-paper-scissors.” In addition, the computer software component is a powerful, flexible tool, but by itself technology is not a formative assessment strategy without the inclusion of collaborative, group process, and other strategies. This lesson represents a teacher involved in using her “technology pedagogical content knowledge” for the specific purpose of selecting appropriate technology tools to support students’ learning (Mishra and Koehler, 2006).

Based on our research we have a number of points for consideration. Collaborative learning, highlighted in both reading and writing research as an effective strategy, was found to be extremely important as a strategy used in combination with concept mapping for formative
assessments and communications for high school science students. From our interviews and sustained observations in the high school classroom we developed several themes:

- Immerse students in authentic learning experiences (field trips, labs, digital photography, image analysis) to support rich literacy and language development.
- Use as many of the seven formative assessment strategies as needed to support students’ learning.
- To improve the ecology of teaching from a literacy perspective, use multiple strategies to distribute the roles and responsibilities for teaching, learning and assessing between the teacher and students.
- Use concept maps and graphic organizers as formative assessment—no grades or numbers (i.e., the rubric was a formative assessment tool) only grades with specific feedback for improvement, if necessary.
- Use concept maps and graphic organizers as pre-writing and text structure organizers, as well as for comprehension.
- Begin concept maps as collaborative group work (formative assessment with peers), “group-paper-scissors” (GPS), and transition to individual map making.
- Use technology tools purposefully for concept mapping to facilitate teachers’ understanding of students’ current knowledge, to design feedback, assist in focused revision of concept maps, and provide a flexible medium for revision.
- Expert, teacher-made maps may help students struggling to construct his/her own map to clarify concepts.
- Reflect on teaching before, during and after lessons, and make changes and adjustments based on evidence and feedback, not just grades and test scores.

Numerous sources have underscored the essential role of concept mapping to support and differentiate learning to accommodate all preferences. Grapho-motor skills are a part of spatial learning skills that figure prominently in Levine’s neuro-developmental systems. In the Universal Design for Learning, concept mapping creates a more inclusive learning environment by insuring the opportunity for students to learn using alternative, but equivalent strategies like webs and outlines. Webs and concept maps that show cycles and ecosystems are challenging topics that benefit from nonlinguistic (visual) representation of important information (Marzano, 2001).

We believe that the neglect of concept mapping may begin with limited understanding of the vital role of visual representation in literacy development. Edward Tufte suggested, “Many believe that graphical displays should divert and entertain those in the audience who find the words in the text too difficult” (1983, p. 80). Are visuals to be dismissed as mere decoration and less rigorous than text? And, will our obsession with grades and scores on all student work create a dilemma for teachers to minimize formative assessment? To promote student success teachers must resolve the balance between summative and formative assessment. The connection of visual representational thinking to content areas like science has resulted in documents like Science Literacy by the American Association for the Advancement of Science (AAAS). While the atlas of concepts and standards provides excellent expert models for teachers, it may remove teachers who are not comfortable with or masters of visual-graphic representations from learning about and doing his/her own concept mapping. The point is, even as finished products these teacher-expert maps need continuous elaboration and adaptation to allow for the growth of knowledge and for teaching and learning.
In terms of literacy development, teachers and students are now concentrating on the need to strengthen students’ content-area reading, and, we would add, content-area writing and visual representation. The multiple meanings of literacy serves as a reminder of the complexity of choices facing teachers and learners, and the need for integrative, constructive approaches that empower us to “learn how to learn” (Novak, 1984; Black et al., 2006); or, as Kinchin pointed out, the ecology of teaching and learning (2001). In the literacy model we have discussed how peer and group learning are collaborative approaches embedded in a model of literacy promoting meaningful communications – teacher to student, student to student and student to teacher. A deep understanding of literacy as it pertains to reading, writing, speaking, visualizing, visual representation, and technology, and of formative assessment can support rigorous and engaging, productive and sustainable teaching, learning and assessment.
Appendix A: Key Definitions

Key terms for this paper are organized around three big ideas: 1) literacy, 2) concept mapping, and 3) formative assessment, and are defined below.

**Concept Mapping.** A strategy in which verbal and visual thinking are integrated and displayed in a way distinctive from but traditional writing. Concept maps are constructed by the individual learner, in collaboration with other learners, or created and shared by teacher-experts. Key concepts are arranged in space, not in a linear, grammatically structured form, and may be accompanied by icons and graphic images. Novak and Gowin definition of concept maps specified maps be constructed in a hierarchical format, in which big ideas are linked with verbs or key words to supporting concepts and details. The National Reading Panel (2000) issued a definition of literacy for reading in which concept mapping is included as a key strategy to assist learners in the comprehension of text.

**Formative assessment.** Formative assessment represents the use of evidence and data to inform teaching and learning. The seven strategies for formative assessment (Stiggins et al., 2004) aim to improve students’ self-assessment, and rely on teachers’ feedback and peer assessment and self-assessment. Three essential questions help to organize the concept: Where am I going? Where am I now? What do I need to do to get there? Formative assessment is another concept with multiple meanings, but can be understood as “encompassing all those activities undertaken by teachers, and/or by their students, which provide information to be used as feedback to modify teaching and learning activities in which they are engaged” (Black and Wiliam, 1998, p. 8). The important distinction here is between summative, grades or test scores, and formative assessment, evidence collected and used to modify instruction and learning.

**Literacy.** “Literacy is a normative statement of what members of a culture should know and be able to do with that knowledge. The Workforce Investment Act of 1998 (Public Law 105-220) stated that ‘...the term literacy means an individual’s ability to read, write, and speak in English, compute, and solve problems, at levels of proficiency necessary to function on the job, in the family of the individual, and in society’ (Title II, Section 203, Number 12) (Learning to Think Spatially, National Research Council, 2006, p. 4). The definition of literacy is extended to include visual literacy. (See Visual Literacy and Figures 1 - 4).

**Technological Literacy.** The newest phase of literacy development is technology, and the field of technology is evolving very quickly. Technology is cited as a major strategy for reading and writing literacy in national reports, and is the unifying theme of the model for designing instruction, technological pedagogical content knowledge (TCPK). The model includes computer hardware and software, and all types of digital equipment like digital cameras, recording devices, laboratory equipment, and multimedia. Technological literacy is an essential component supporting the accessibility of learners to information as described by the Universal Design for Learning.

**Universal design for learning.** Universal design for learning (UDL) is a framework for providing alternative learning strategies for learners. According to the Center for Applied
Special Technology (CAST) “requires 1) multiple means of representation, to give learners various ways of acquiring information and knowledge, 2) multiple means of expression, to provide learners alternatives for demonstrating what they know, and 3) multiple means of engagement, to tap into learners' interests, offer appropriate challenges, and increase motivation.”

**Visual Literacy.** The first stage of literacy development for learners with all five senses, visual literacy, is followed by language and then written literacy (Sinatra, 1986). (See Figure 1) Humans with sight actively view and seek information as hearing develops. It is the responsibility of educators to create learning environments for all learners to develop cognitive skills. “Language, then, becomes the natural extension of symbolic thought, and symbolic thoughts help form the mental schemata of a visually literate person” (Sinatra, 1986, p. 11).
## Appendix B: Rubric for Concept Maps - Inspiration Diagrams

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>Exemplary</th>
<th>Proficient</th>
<th>Developing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Content</strong></td>
<td>Reflects essential information; information is correct and logically arranged; concepts succinctly presented;</td>
<td>Reflects most of the essential information correctly; is generally logically arranged; concepts presented without too many excess words</td>
<td>Contains extraneous information, information is incorrect or is missing; is not logically arranged.</td>
</tr>
<tr>
<td><strong>Arrangement of Concepts</strong></td>
<td>Main concept easily identified; sub-concepts branch appropriately from main idea</td>
<td>Main concept easily identified; most sub-concepts branch from main idea.</td>
<td>Main concept not clearly identified; sub-concepts don’t consistently branch from main idea.</td>
</tr>
<tr>
<td><strong>Links and Linking Lines</strong></td>
<td>Linking lines connect related terms/point in correct direction; linking words accurately describe relationship between concepts.</td>
<td>Most linking lines connect properly; most linking words accurately describe the relationship between concepts.</td>
<td>Linking lines not always pointing in correct direction; linking words don’t clarify relationships.</td>
</tr>
<tr>
<td><strong>Graphics</strong></td>
<td>Graphics used appropriately; greatly enhance the topic and aid in comprehension; are clear, crisp and well situated on the page.</td>
<td>Graphics used appropriately most of the time; most graphics selected enhance the topic, are of good quality, and are situated in logical places on the page.</td>
<td>Graphics used inappropriately and excessively; graphics poorly selected and don’t enhance the topic; some graphics are blurry and ill-placed.</td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td>Clean design; high visual appeal; four or fewer symbol shapes and text fonts; fits page without a lot of scrolling; color used effectively for emphasis. Text easy to read.</td>
<td>Design is fairly clean, with a few exceptions; diagram has visual appeal; four or fewer symbol shapes and text fonts; fits page well; uses color effectively most of time. Text easy to read.</td>
<td>Cluttered design; too many shapes and fonts, low in visual appeal; requires a lot of scrolling to view entire diagram; choice of colors lacks visual appeal and impedes comprehension. Text difficult to read.</td>
</tr>
</tbody>
</table>
### Appendix C
Technology – Teaching Progression for Marine Ecology Unit

<table>
<thead>
<tr>
<th>Date</th>
<th>Teaching – Learning Activity</th>
<th>Technology Connection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug 21</td>
<td>Planning meeting PW JB for two independent studies</td>
<td>How can concept mapping and MVH software tools be used?</td>
</tr>
<tr>
<td>Sept 11</td>
<td>Planning meeting PW-JB to study macro-algae in marine ecology</td>
<td>Use MVH software tools</td>
</tr>
<tr>
<td>Oct 13</td>
<td>Visit to beach with two Marine Ecology classes</td>
<td>Data collection with digital cameras</td>
</tr>
<tr>
<td>Oct 19</td>
<td>Talked about light as energy and what makes up light. In-class digital photos of macro-algae for analysis with MVH software. Flash and available light. Trans-illumination lighting.</td>
<td>Data collection with digital cameras</td>
</tr>
<tr>
<td>Oct 25</td>
<td>In the computer lab to use image analysis software. Used Image Basics (Pixel View component) with group photo of the class. Played Color Basics (Color Matching) Games to understand the difference between color separation and color intensity, percent reflectance and absorption</td>
<td>Use MVH software tools for color analysis; experience color concepts</td>
</tr>
<tr>
<td>Oct 26</td>
<td>In the computer lab, use of MVH Image to analyze macro-algae color values of red, green and blue, and the absorption/percent reflectance</td>
<td>Use of MVH software tools for color analysis; collect color reflectance data</td>
</tr>
<tr>
<td>Oct 30</td>
<td>Adjusted plans for implementation, more concept mapping to assist comprehension of difficult concepts.</td>
<td></td>
</tr>
<tr>
<td>Oct 31</td>
<td>In-class experiment to grow phyto-plankton. Close-up digital photos of treatment and control test tubes. Lighting indirect with backlight.</td>
<td>Use of MVH software tools for color analysis; collect color reflectance data</td>
</tr>
<tr>
<td>Nov 2</td>
<td>Concept mapping activity. First step in drawing the system or cycle of events. Began activity with discussion of big ideas. Used a list of 12 words that characterized the marine eco-system, students cut out pieces of paper and arranged them into a map. Transferred the original paper map to Inspiration concept mapping software in the computer lab. Resulted in Concept Map #1</td>
<td>Group-paper-scissors (GPS) activity, followed by use of Inspiration concept mapping software</td>
</tr>
<tr>
<td>Nov 7</td>
<td>Concept Map #2 – create a “Matter Web”, with 12 organisms and processes. Students were asked to represent three levels of consumers, with producers and decomposers. Written reflection about concept mapping.</td>
<td>Individual students use Inspiration concept mapping software</td>
</tr>
<tr>
<td>Nov 9</td>
<td>Teacher-expert Map and Revision of Concept Map #2 – Based on the results of the reflective writing the teacher provides her own expert map and asks</td>
<td>Teacher constructs her own expert map with Inspiration and individual</td>
</tr>
</tbody>
</table>
students to identify components of her map, and asks students to revise their maps, in particular to include the energy cycle, not just the components.

<table>
<thead>
<tr>
<th>Date</th>
<th>Activity Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov 13</td>
<td>Students use MVH software to calculate color of digital photos of phyto-plankton at the conclusion of the experiment.</td>
<td>Use of MVH software tools for color analysis; collect color reflectance data</td>
</tr>
<tr>
<td>Nov 16</td>
<td>Students write an in-class assignment about the system including the energy cycle.</td>
<td>Students write essays in class by hand.</td>
</tr>
</tbody>
</table>
References


Kinchin, I. (2001). If concept mapping is so helpful to learning biology, why aren’t we all doing it? International Journal of Science Education. 23(12), pp. 1257-1269.


http://www.nichd.nih.gov/publications/nrp/smallbook.cfm


