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# A UNIQUE USE OF CONCEPT MAPS AS THE PRIMARY ORGANIZING STRUCTURE IN TWO UPPER-LEVEL UNDERGRADUATE BIOLOGY COURSES: RESULTS FROM THE FIRST IMPLEMENTATION

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**Abstract.** Constructing Concept Maps (CMaps) allows students opportunities to: (i) create "meaning" (Novak 1998) about a concept; (ii) invest in their own personalized knowledge of a topic or reading, and (iii) develop team-building skills when working collaboratively (as they do in my classes). When these opportunities are provided in an iterative manner, students are exposed to an empowering learning experience. The objectives of this paper are two-fold: (i) to describe my two learner-centered upper-level undergraduate biology courses in which CMaps are the primary organizing structure of the courses, and (ii) to assess the efficacy of my CMaps courses using three different assessment tools (thereby providing triangulation of assessment). In my two CMaps courses, students collaboratively construct a CMap, an accompanying written summary page, and a reference page for each major theme covered in the course based on readings from the textbook and scientific literature. I serve as a facilitator of learning by providing guided inquiry in these innovative courses that do not have traditional lectures or traditional assessments (exams). An analysis of the change in structure from the first "What is Ecology?" CMap to the final "What is Ecology?" CMap reveals that students gained a knowledge base in Ecology and improved their CMap building skills over the course of the semester. An analysis of students' perceptions of my CMaps courses reveals that students perceived that construction of CMaps facilitated their overall understanding of course material, yet the students' perception of the usefulness of this learning tool was context-dependent. Students responded that my CMaps format was better than the Traditional Lecture (TL) format for learning scientific literature, but ranked CMaps and TL formats equally useful for learning textbook material. Despite the context-dependence perception, most students responded that CMaps format: (i) was superior than TL format in helping them develop thinking skills; (ii) envisioned constructing CMaps for other courses or scientific literature readings (showing transference by students); and (iii) preferred these courses continue in the CMaps format. An analysis of students' comparison of my CMaps courses to TL courses using Novak's (1998) "5 Elements of Teaching" CMap, reveals that students perceive both course formats emphasize the concept "knowledge". Students perceive TL courses also emphasize "teacher" and "disempowering". Students perceive my CMaps courses emphasize "empowering", "learner", and "interact" (in addition to "knowledge"). I conclude that my collaborative CMaps courses provide students with deep, meaningful, and empowering learning opportunities.

## 1 Introduction

Learner-centered practices place the responsibility and rewards of learning on the student, with the teacher guiding the learning process, fostering a conducive learning environment, and providing examples or explanations of relevant experiences (Weimer, 2002; Blumberg, 2004 & 2008). Social interactions between students (as peer collaborators) and the teacher (as a facilitator) are central to this pedagogy. In this environment, the teacher reflects on and designs meaningful exercises that focus on the: (i) context of learning; (ii) content of what is to be learned; (iii) retention of material; (iv) application and transference of knowledge; and (v) relevance of this knowledge for the students' future (Weimer, 2002).

Concept Map (CMap) construction provides a creative cognitive tool for organizing knowledge about concepts in a hierarchically structured, non-linear, visual format in which concepts are connected with lines and accompanying linking words to form propositions (Novak & Gowin, 1984; Novak, 1998; Novak & Cañas, 2008). This learning tool is based in social constructivist learning theory, in which learning is a self-regulated building of concepts upon a scaffold of previous knowledge (von Glaserfeld, 1995; Biggs, 1999; Bransford et al., 2000). Constructivist teaching and learning requires reflection about the concept, abstraction of knowledge into one's own meaning, and acceptance of personal value of this meaning and process (von Glaserfeld, 1995; Biggs, 1999; Bransford et al., 2000; Novak & Cañas, 2008). When students work collaboratively "knowledge is socially produced by consensus among knowledgeable peers" (Barkley et al., 2005, p. 6). Therefore, collaborative construction of CMaps by students should promote "deep, meaningful" (Biggs, 1999; Bransford et al., 2000; Barkley et al., 2005; Novak & Cañas, 2008) and "significant" (Fink, 2003) learning opportunities, and provide empowering learning experiences for the students (Preszler, 2004; Morse & Jutras, 2008).

## 2 Description of my CMaps Courses

The two upper-level undergraduate CMaps courses I implemented in the 2006-2007 academic year were Animal Behavior (for which 3 students were enrolled) and Ecology (for which 13 students were enrolled). The entire semester of Animal Behavior was a CMaps format, and first ½ semester of Ecology was a CMaps format. The second ½ semester of Ecology (taught by another professor) was a Traditional Lecture (TL) format. In my CMaps courses students work collaboratively in teams of 2-3 to create a CMap (with a congruent written summary page and reference page) for each major theme addressed. Adding a written summary page: (i) encourages students to carefully examine and modify their CMap in order allow congruence between the CMap and summary page; (ii) allows students to convert their non-linear knowledge from their CMap to linear knowledge; (iii) clarifies the CMap for readers who are not familiar with their structure; and (iv) develops students' writing skills. Cognitive learning theory suggests that linking verbal and visual mental activity improves retrieval for both (Nesbit & Adesope 2006). The textbook and both primary and secondary scientific literature are used as source materials. Students construct CMaps electronically using CmapTools™ (http://cmap.ihmc.us) and/or Microsoft™ PowerPoint software tools.

For both Animal Behavior and Ecology, the topics covered are the same as those covered in previous non-CMaps iterations of the course. A topic takes approximately four 1-hour class meetings to complete, which is the same time needed for a topic in previous course formats. Students are required to bring an individual CMap (based on an assigned reading) to the first hour class meeting relating to a topic. During that class meeting students compare and discuss these individual CMaps in their small groups to reach a consensus CMap. In the second hour students revise the consensus CMap and start writing a summary page and reference page. In the third hour teams revise their CMap and summary to allow congruence between the two. In the fourth hour students complete their CMap and summary, evaluate themselves and their team members, and orally present their group's CMap. Team revision of CMaps facilitates learning (Morse & Jutras, 2008) and presentation of group CMaps to the class facilitates awareness of different perspectives and receptivity to new ideas (Angelo & Cross, 1993). As instructor, I oversee the teams' interactions and progress, congruence of each group's CMap to its group's summary page, and address confusions that arise.

In order to align assessment (Biggs, 1999; Fink, 2003) with the constructivist CMaps learning format, I score each group's CMap based on (i) complexity (relating to concepts, hierarchy levels, and propositions / linkages); (ii) congruence between the CMap and written summary; and (iii) completeness of the reference page. Additionally, students receive participation scores from me, their peers, and themselves. I never lecture in these courses; therefore, I never use exams to assess learning. Students in Ecology do receive an exam on material presented in the second half of the semester which is conducted in the TL format and which is taught by another professor. These courses each have weekly 3-5 hour field/lab experiences associated with them and grades relating to these are incorporated into each student's final grade.

## 3 Assessment of the Efficacy of my CMaps Courses

### *3.1 Triangulation of Assessment of my CMaps Courses*

I collected data on the efficacy of my CMaps courses (compared to TL courses) by using three (one knowledge and two attitudinal) assessments. I collected data in the Spring 2007 Ecology (but not Fall 2006 Animal Behavior) course that allowed me to assess students' knowledge progression and CMap building skills over the semester. The first CMap that was assigned (after a CMap modeling session) was "What is Ecology?" for which the source material was the first chapter in the textbook. At the end of the semester, the students revisited this CMap and modified it to reflect what they had learned over the ½ semester of the CMaps course. The second assessment was an attitudinal survey students completed at the end of the semester for Animal Behavior (or ½ semester for Ecology). For the third assessment, I asked students to construct two CMaps (with a written summary page and reference to Novak 1998) that compared my CMaps course with TL courses. Students were required to use Novak's (1998) "5 Elements of Teaching" CMap as a template and asked to show emphasis of concepts by either enlarging and/or changing the color of the concept boxes, or by changing font characteristics of the concept words. Students were not restricted in the number of concepts they could emphasize; therefore, they were free to emphasize as many (or few) concepts as they wished. This attitudinal assessment was also completed at the end of the semester for Animal Behavior (or ½ semester for Ecology). Conclusions regarding the efficacy of my CMaps courses are robust due to the triangulation of assessment.

### *3.2 Assessment #1: The Development of a Knowledge Base and CMap Building Skills*

#### 3.2.1 Specific Methods of Data Collection and Analysis

The data that address the development of a knowledge base and CMap building skills were generated by comparing 5 Ecology groups' final (end of semester) "What is Ecology?" CMap with their first (beginning of semester) "What is Ecology?" CMap. These were assessed using Novak's & Gowin's (1984) criteria and Cañas *et al*. (2006b) taxonomy. No statistical analysis was conducted on these data.

### 3.3 *Hypothesis and Results*

Hypothesis: Student groups will show marked improvement in their final "What is Ecology?" CMap as compared to their first "What is Ecology?" CMap. This improvement will occur in the number of valid hierarchical levels and propositions that link concepts. Improvement may not occur in the valid number of cross linkages between concepts in different areas of the CMap because I did not emphasize this element when modeling CMap construction.

Results: All five groups' final CMap was more complex than their first CMap when scored using Novak's & Gowin's (1984) criteria. The mean increase in the total score was 48.30 (s.d. 47.28). The mean (and s.d.) increase in number of valid: (i) hierarchy levels was 2.50 (2.06); (ii) propositions was 23.80 (25.56); and (iii) cross linkages was 1.20 (+/- 1.30). The mean total score (and s.d.) for the final "What is Ecology?" CMap was 123.30 (50.37). The mean (and s.d.) of the other variables in this final CMap was: 8.30 (3.03) (hierarchy levels); 49.80 (25.47) (propositions); and 3.20 (2.59) (cross linkages). Using the Cañas et al. (2006) taxonomy with six topological levels of increasing complexity, two of the five groups' final CMap was at a higher taxonomic level than their first CMap. Three groups' first and final CMaps were at the same level, with one group's at each of the following three Levels: 4, 5, and 6 (the highest level, and therefore could not improve). The mean (and s.d.) increase of all five groups' CMaps was 0.40 (0.55) levels, from a mean (and s.d.) level of 5.00 (0.71; range: 4-6) to a mean (and s.d.) level of 5.40 (0.89; range: 4-6). The large variability in the data was due to the different creative structures of the CMaps; some were organized as classic top-down hierarchies, but others were organized as "wagon wheels" with radial spokes emerging from a central node. One groups' first map was so detailed and had seven cross linkages; therefore, it was difficult to improve upon. The CMaps generated by a group using CmapTools™ were consistently more complex than most other groups' maps generated using Microsoft™ PowerPoint. It is impossible to determine whether the effect is due to group membership, the software tool, or an interaction of these variables.

#### 3.3.1 Discussion

It would be unusual for students to delete concepts from their first "What is Ecology?" map when generating their final "What is Ecology?" map; therefore, it is not surprising that the final concept map is more complex than the first. Nonetheless, the magnitude of increase in the mean (Novak & Gowin, 1984) CMap score, number of hierarchy levels, and number of propositions in the final CMap shows an increase in knowledge and an improved ability to construct CMaps over the ½ semester. These results are consistent with other CMap studies (see CMC 2004 & 2006 proceedings archived at http://cmc.ihmc.us Cañas *et al.*, 2004, Cañas & Novak 2006a; Preszler, 2004; Nesbit & Adesope, 2006). It would be disappointing if, after seven weeks of constructing CMaps, students did not improve their ability to construct CMaps.

### 3.4 *Assessment #2: Students' Perceptions of My CMaps Course Compared to TL Courses Based on an Attitudinal Survey*

#### 3.4.1 Specific Methods of Data Collection and Analysis

These data were generated from the responses of the 16 students to an attitudinal survey completed at the end of the semester for Animal Behavior (or ½ semester for Ecology). The response to survey questions for which five response categories exist could not be statistically analyzed due to the small sample size (N = 16). The minimum sample size to analyze these questions is 25 (due to a minimum expected frequency = 5 for all categories). The response to other survey questions could be statistically analyzed because either fewer response categories were offered, or I was able to combine similar response categories to allow fewer than five categories. I determined the expected frequency of the combined categories based on the frequency that these categories were offered in the original survey. These data were statistically analyzed using chi-square ($X^2$) one-sample test for goodness of fit (Ambrose et al., 2007).

#### 3.4.2 Hypotheses and Results

Hypothesis 1: Students will perceive that construction of CMaps facilitates their understanding of course material.

Results: All 16 students responded that CMaps were either "very helpful" or "helpful". While this result is unequivocal, these data cannot be statistically analyzed using chi-squared ($X^2$) one-sample test for goodness of fit test until 25 students are surveyed because five response categories were offered in the original survey (see minimum expected value = 5 criterion for chi-squared test; Ambrose et al., 2007).

Hypothesis 2: Students will perceive that construction of CMaps allows them to learn more material from the textbook and scientific literature than traditional classroom techniques (lecture and class discussion, respectively).

Results: The trend of the data differ according to context. Students responded that construction of CMaps was superior to traditional classroom techniques for learning scientific literature but not for learning textbook material. When asked about learning from the textbook, 7 of the 16 students stated CMaps and TL format were equal to each other. Another 7 students found construction of CMaps to be superior to TL, and only 2 found CMaps to be inferior to TL. Therefore, there was not a majority of students who perceived construction of CMaps to be superior to TL when learning textbook material. However, a majority (13 students) responded that construction of CMaps allowed them to learn much more (N = 8) or more (N = 5) than a guided class discussion of scientific literature. Only one student responded that CMaps and discussion provided an equal learning experience, and 2 students responded that construction of CMaps allowed less learning than a class discussion. The sample size (N = 16) was too small to permit statistical analysis.

Hypothesis 3: Students will perceive that construction of CMaps allows them to develop thinking skills more than traditional classroom techniques (lecture and class discussion).

Results: The trend of the data support this hypothesis. Twelve students responded that construction of CMaps developed their thinking skills much more (N = 6) or more (N = 6) than traditional classroom techniques. Four students responded that the two formats allowed for similar development. The sample size (N = 16) was too small to permit statistical analysis.

Hypothesis 4: Students will prefer the course be structured in the CMaps format over either a hybrid CMaps & lecture format or a lecture only format.

Results: The students showed a statistically significant preference for exclusive CMaps format over either other format. Twelve students preferred exclusive CMaps format, and four preferred a hybrid CMaps/Lecture format. The original survey offered 3 categories, therefore statistical analysis could be conducted with an N = 16 ($p < 0.001$; chi-squared ($X^2$) one-sample test for goodness of fit; expected value for each category = 5.33).

Hypothesis 5: Students will envision transferring their ability to construct CMaps to other courses or environments.

Results: A statistically significant number of students (14) responded that they envisioned constructing CMaps for other courses or readings, while only 2 students responded that they did not envision constructing CMaps ($p < 0.05$; chi-squared, $X^2$, one-sample test for goodness of fit; two categories: “transference” vs. “no transference”; transference expected value = 9.6 because three response categories were collapsed; no transference expected value = 6.4 because two response categories were collapsed). The two Ecology students who did not envision using CMaps in the future responded that they did see their value. In reviewing these students’ responses to other survey questions, one student responded that CMaps and TL allow equal learning of the textbook, but that CMaps allowed much more learning than class discussions of scientific literature, and the two formats (CMaps vs TL and class discussion) allow equal development of thinking skills. The second student consistently responded with the most favorable CMaps response category for all questions except the transference question. Both students responded that they preferred the course continue as exclusively CMaps.

### 3.4.3 Discussion

#### 3.4.3.1 Context-Dependence of the Perceived Usefulness of CMaps

While it is encouraging that students recognize that construction of CMaps is helpful in understanding material, results of the survey suggest there is a context-dependence to the perceived usefulness of CMaps. Students perceived CMaps as a better learning tool than class discussions of scientific literature, but only an equally useful learning tool as a TL for understanding textbook material. Below I propose two hypotheses (that are not mutually exclusive) to explain this context-dependent view.

Hypothesis 1: “Discomfort with Constructing CMaps in Perceived Unequivocal Contexts”

Students may view the textbook as a source of material that provides answers, and should not be questioned, challenged, or open to multiple interpretations. Therefore, students are uncomfortable when asked to construct their own knowledge from this source material, because they view that the knowledge has already been constructed for them, and they need only assimilate it. In this manner students are neophobic; they are afraid of their new role in which they are expected to question the authority of the textbook and synthesize their own understanding from it. Students may view scientific literature as material for which construction of CMaps is appropriate because scientific data and literature, by nature, are open to multiple interpretations. Students provided no written comments to either support or refute this hypothesis. In order to overcome students’ discomfort with CMaps in perceived unequivocal contexts, students need to be convinced that textbooks are not unequivocal sources of knowledge. It is imperative that students be exposed to teachers who remind them that: (i) scientific textbooks are equivocal sources; (ii) most of the information provided within them is a result of the scientific method and is a basic summary of scientific literature; and (iii) this information will be outdated within a decade of publication. Therefore, students need to realize that textbooks should be open to inquiry and multiple interpretations in a manner similar to scientific literature. Students need to be exposed to this perspective from multiple teachers vertically throughout their educational progression. If students are not reminded of the equivocal nature of textbooks they will continue to believe that these sources provide information that should not be questioned and will continue to be resistant to active learning / guided inquiry methods of learning from textbooks.

Hypothesis 2: "More is Better"

Students may also perceive that a large volume of class notes is better than high quality class notes. Upon leaving a TL class meeting, and by extension a TL course, students have many pages of notes that they may perceive as being equivalent to lots of knowledge. Upon leaving my CMaps class meeting, student groups leave with 1-3 pages of dense (often confusing) material which is not fully clarified until the final CMap for the topic is completed. At the end of the semester, students have a portfolio of their groups' CMaps, but possess relatively few pages to show for their work. Students may be conditioned to believe "more is better", and may perceive that a CMaps course has short-changed their learning because an expert teacher has not lectured and provided them with a notebook of information. Written comments (collected from both attitudinal surveys) provided by four students support this hypothesis. In order to overcome the perception that "more is better", students need to be exposed to teaching pedagogies that embrace the philosophy that "less is more" (see Brooks & Brooks, 1999, p. 49-50).

#### 3.4.3.2 A Discussion of Other Encouraging Results from the Attitudinal Survey

It was encouraging that: (i) most students recognized the value of constructing CMaps in developing their thinking skills; (ii) a majority of students expect to transfer this learning skill to new environments; and (iii) most students preferred that I maintain CMaps as the organizing structure of these upper-level undergraduate courses. These results show that students are willing to adapt to novel learner-centered approaches and are open to the pedagogical advantages of these environments, despite their context-dependent view of the usefulness of CMaps. Bonwell and Eison (1991) summarize that: (i) students prefer active learning over lectures; (ii) active learning strategies promote learning equally well as lectures; and (iii) active learning develops students' thinking and writing skills better than traditional lectures. Barkley et al. (2005) provide a literature review that strongly supports collaborative learning environments. One of the many conclusions they present is that students who work collaboratively in small groups have more favorable attitudes towards learning than students working alone in traditional classrooms. The results I found are congruent with those summarized by Bonwell and Eison (1991) and Barkley et al. (2005). Additionally, one of the key philosophies provided by Novak & Gowin (1984) and reiterated by Novak (1998) is that a positive learning experience is a key element to empowering learners.

## *3.5 Assessment #3: Students' Perception about My CMaps Courses Compared to TL Courses (based on using Novak's "5 Elements of Teaching" CMap to compare elements emphasized in each of the two course formats).*

### 3.5.1 Specific Methods of Data Collection and Analysis

These data were generated from the response of 13 of the 16 students. Three students did not complete this survey. The 13 students who completed the survey individually constructed two "5 Elements of Teaching" CMaps that compared the two course formats (CMaps vs. TL). I generated a composite CMap for each of the two formats in which I tallied the number of students who emphasized each of 10 concepts Novak (1998) presents in his "5 Elements of Teaching" CMap. I did not include Novak's concept with the phrase "5 elements of teaching" because each of the five elements ("teacher"; "learner"; "knowledge": "evaluate"; "context") is illustrated as its own concept. Also, no student emphasized the "5 Elements of Teaching" concept when summarizing either of the two course formats. The additional 5 concepts represented in Novak's "5 Elements of Teaching" CMap that summarize the education process are: "educating"; "interact"; "the meaning of experience"; "disempowering"; and "empowering". The two composite CMaps (summarizing students' perceptions of the CMaps course format vs. TL course format) were compared statistically using chi-square ($X^2$) test of independence between two samples (Ambrose et al., 2007) to determine if different concepts / elements were emphasized in these two course formats. Additionally, each composite CMap depicting each of the two formats was statistically analyzed to determine if the 10 concepts / elements were represented equally or unequally (chi-squared , $X^2$, one-sample test for goodness of fit; Ambrose et al., 2007).

### 3.5.2 Hypothesis and Results

Hypothesis: Students will perceive that the two course formats emphasize different suites of concepts, with an uneven distribution of these for both CMaps and TL course formats. Students will perceive that CMaps courses are empowering and provide an opportunity to interact; therefore, these concepts will be over-represented in the composite map. Concepts that will be under-represented will be “evaluate” and “disempowering”. Students will perceive that TL courses emphasize the teacher and may be disempowering; therefore, these two concepts will be over-represented in the composite map. Concepts that will be under-represented will be “interact” and “empowering”.

Results: The distribution of the concepts emphasized in the comparative (CMaps vs. TL course format) CMaps was statistically significantly different from each other ($p < 0.001$; d.f. = 9; chi-square, $X^2$, test of independence between two samples; Ambrose et al., 2007). Students’ perceptions of both types of course formats also showed an unequal distribution of emphasized concepts ($p < 0.001$; d.f. = 9; chi-square, $X^2$, one-sample test for goodness of fit; Ambrose et al., 2007). The total number of concepts emphasized by each student in their CMaps versus TL course format maps was not statistically different (sign test; Ambrose et al., 2007; TL range: 2-7 concepts / student; mean = 5.00; s.d. = 1.35; CMap range: 2-7 concepts / students; mean = 5.15; s.d. = 1.41).

Concepts that students emphasized most strongly regarding my CMaps courses were (in descending order): “learner”, “empowering”, “interact”, and “knowledge”. Each of these concepts was strongly over-represented in the composite map; 12 (of the 13) students emphasized “learner”, 11 “empowering”, 10 “interact”, and 9 “knowledge”. Concepts that students chose least often to summarize my CMaps courses were (in ascending order): “disempowering”; “meaning of experience”; “teacher” and “evaluate”. For example, only one student emphasized “disempowering” (and this student also selected “empowering”, yet provided no written clarification regarding the ambiguity).

Concepts that students most strongly emphasized when summarizing TL courses were (in descending order): “teacher”, “knowledge”, and “disempowering”. Each of these concepts was strongly over-represented in the composite map. For example, “teacher” was emphasized by 12 (of the 13) students, “knowledge” by 11 students, and “disempowering” by 10 students. Concepts that students chose least often to summarize TL courses were (in ascending order) were: “interact” and “meaning of experience”, “learner” and “empowering”. Only two of the 13 students emphasized “interact” and “meaning of experience”, and only four emphasized “learner” and “empowering”.

### 3.5.3 Discussion

My hypothesis regarding students’ perceptions to my CMaps course and TL course formats was supported; students perceive courses conducted in these to formats as being very different from each other. Students clearly view my CMaps courses as empowering experiences for learners, allowing them opportunities to gain knowledge and interact with peers and the teacher. Students perceive TL courses as ones in which the teacher dominates and provides knowledge, but which can be disempowering (partly due to the lack of interaction). Both formats showed under-representation of the element “the meaning of the experience”. This concept within Novak’s “5 Elements of Teaching” CMap leads directly to “empowering” and “disempowering”. Students probably selected the concepts “empowering” and/or “disempowering” over “the meaning of experience” because of the strong emotions associated with “empowering” and “disempowering”.

## 4 Elevating Construction of Concept Maps to a Higher Level

A CMap that includes cross linkages shows that students are thinking deeply about relationships between concept clusters. These students are rewarded when their CMap is scored according to Novak’s and Gowin’s (1984) technique and Cañas *et al.* (2006) taxonomy. Additional components that could be added to concept maps to elevate students’ cognitive processing include: (i) a written summary (with references); (ii) qualitative emphasis of components; and/or (iii) quantitative emphasis of components. I have described how I incorporate a written summary (with references) earlier in this paper. I have also described the manner in which I used a qualitative manipulation of Novak’s “5 Elements of Teaching” to provide an assessment of my CMap courses. In a similar manner, students could alter components of their CMaps to emphasize specific concepts, linkages, or cross linkages that are particularly important. If the differences can be quantified, the numeric or probability value associated with the component could be placed within the concept enclosure or with the proposition (Porter 2008, personal communication, unreferenced). The qualitative and/or quantitative manipulation of the CMap may be relevant to some of the concept clusters but not to other clusters; therefore, this additional manipulation of the CMap need not be applied to the entire CMap. Scores for CMaps that include these added levels of complexity should reflect the deep thinking associated with these components. These enrichments of a CMap could be used as an additional challenge and motivator to students already proficient with the basic CMapping skills (possibly as a capstone CMap), or could be used when students work collaboratively on a CMap to promote deep and meaningful discussions of a topic / question about which students already perceive themselves as knowledgeable.

## 5 Summary

In this paper I describe the implementation of CMaps as the organizing structure in two upper-level undergraduate biology courses and demonstrate the efficacy of these CMaps courses using three (one knowledge and two attitudinal) assessments. Students constructed more complex CMaps as the semester progressed, and perceived my CMaps courses to be learner-centered empowering experiences that provided interaction as well as knowledge acquisition. Generally students favored my CMaps format over TL format, although there was a context-dependence to the perceived usefulness of CMaps. Students perceived constructing CMaps of scientific literature to be more useful than a class discussion, but perceived constructing CMaps to be only equally as useful as (but not superior to) a lecture for textbook material. Within this paper I propose two hypotheses to explain this context-dependence perception. Below I provide a summary CMap.

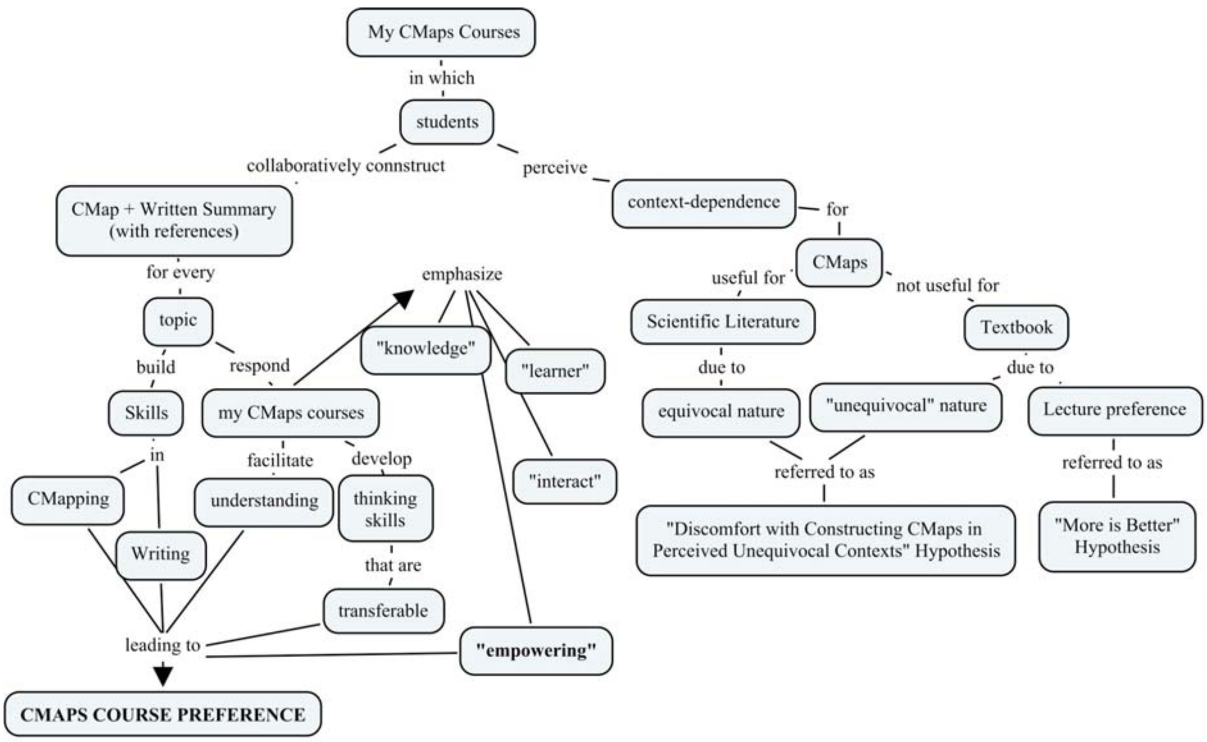


Figure 1. Summary concept map: CMaps as the organizing structure in my two upper-level undergraduate biology courses.

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