To What Extent can Concept Mapping Motivate Students to Take a More Meaningful Approach to Learning Biology?

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Abstract

Concept mapping was investigated as a learning strategy to motivate 82 high-ability, 10th-grade students to take a more meaningful approach to learning biology. The study employed a quasi-experimental, pre-post mixed methodology design to assess the relationship between concept-mapping proficiency and changes in motivational and learning strategies use profiles using the Motivated Strategies For Learning Questionnaire (MSLQ). The qualitative and quantitative findings suggest a mixed motivational response by learners in taking a more meaningful approach to learning biology using concept mapping. Specifically, the findings revealed that concept mapping may play a supportive role in contributing to a more meaningful approach to learning biology, as indicated by positive and statistically significant effects on students' test performance, as well as adaptive and statistically significant fall-to-spring changes in motivational and learning strategy use profiles in direct relation to the level of mapping proficiency. This dichotomous relationship appears to be a consequence of whether learners' perceive that concept mapping can provide them with a more effective learning strategy than those utilized in the past and, more importantly, upon their willingness to put in the requisite time and effort to develop proficiency in using mapping to take a more self-regulated and meaningful approach to their learning. Thus, it behooves the educator interested in using concept mapping to consider students' receptiveness to using concept mapping and encourage them to perceive the value of becoming sufficiently proficient in its use.

Introduction

Concept Mapping as Formative to Meaningful Learning

Can meaningful learning be fostered and visualized? Novak and his colleagues at Cornell University developed the concept map as a tool to represent the knowledge structures that emerged during interviews of science students during their 12-year longitudinal study (Novak & Musonda, 1991). Concept mapping is founded on Ausubel's (1968) assimilation theory of cognitive learning, which is predicated on the assumption that learning involves understanding concepts, as well as the patterns of relationships that link them together. Effective learning, according to Ausubel, involves constructing conceptual understanding in a meaningful way. Ausubel suggested "meaningful learning takes place if the learning task can be related in a non-arbitrary, substantive (nonverbatim) fashion to what the learner already knows" (Ausubel, 1968, p. 24). Meaningful learning also requires a deliberate effort on the part of the learner to link new knowledge to prior constructs. Ausubel referred to this deliberate activity as a *meaningful learning set*. Novak's learning theory proposes that one's cognitive framework is organized in a hierarchical manner with concepts linked propositionally from more general and inclusive to more specific and less inclusive (Novak, 1977, 1990).

Most importantly, the real utility of concept mapping as a metacognitive learning tool lies in the fact that it offers learners opportunities to reflect on their conceptual understanding and reconceptualize it through elaboration and refining of the propositional relationships between concepts, as well as anchor those relationships by constructing crosslinks between different branches of their maps in an attempt to construct more meaningful conceptual schemata, all of which are prerequisite to meaningful learning (Jonassen, Reeves, Hong, Harvey, & Peters, 1997).

Concept mapping not only applies Ausubelian constructivist theory (Ausubel, 1968), but also incorporates many of the principles underlying the stages of developing meaningful learning described by Shuell (1990), Alexander (1997), and Rumelhart and Norman (1981).

Cognitive and Metacognitive Learning Strategies and the Self-Regulated Learner

During the last 2 decades, a plethora of literature has emerged urging for a science pedagogy that not only provides students with opportunities to construct concepts as to how the world works, but also to foster students' ability to self-regulate their learning processes. This new thinking calls for providing students with opportunities to discover and construct concepts, as well as internalize them as a consequence of dialogue between themselves and others. Self-regulation refers to the processes whereby students create and sustain thoughts and actions that are intentionally oriented toward goal attainment (Schunk, 1994). Zimmerman (1989a, 1990) further defined self-regulated learning behavior by the degree to which students are "metacognitively, motivationally, and behaviorally active participants in their own learning process" (1989a, p. 329). Self-regulated behavior is also characterized by the use of specific cognitive learning strategies designed to increase encoding, understanding, retention of learning, or academic goals, as well as regulatory strategies that provide learners a means to self-monitor and control their own learning (Corno, 1989; Sternberg, 1988; Weinstein & Mayer, 1986; Zimmerman, 1989b; Zimmerman & Martinez-Pons, 1986).

One of the most important goals of education is to foster students in becoming learners who possess the cognitive learning strategies to acquire a conceptual understanding of the subject matter. Learning strategies serve to aid the learner in encoding information and thus affect learning outcome and performance. While various classifications of learning strategies are found in the literature (Dansereau, Brooks, Holley, & Collins, 1983; Pintrich & Garcia, 1991; Weinstein & MacDonald, 1986; Weinstein & Mayer, 1986), they basically can be collapsed into two categories; cognitive and metacognitive. Cognitive learning strategies generally consist of activities that serve to aid the learner in processing, organizing, and retrieving information. Metacognitive learning strategies are mostly involved with helping learners regulate and perform cognitive learning processes. Planning, monitoring, and regulating serve to help learners execute their learning processes and hence are called metacognitive strategies (Gall, Gall, Jacobsen, & Bullock, 1990; Pintrich, 1988). Concept maps help learners to take a meaningful approach to learning by developing metacognitive thinking patterns through planning how to organize concepts in such a way as to reflect the patterns of relationships between them and monitoring the progression of their conceptual understanding, as well as self-regulating their learning as they strive to construct logical and valid propositional statements relating concepts in a hierarchical pattern (Jegede, Alaiyemola, & Okebukola, 1989). It is therefore not surprising that the concept map has been touted as the “most important metacognitive tool in science education today” (Mintzes, Wandersee, & Novak, 1997, p. 424).

Motivating Learners to Achieve

While learning strategies are necessary to developing conceptual understanding, being motivated to use them to achieve academic goals is equally, if not more, important. Wigfield and Eccles (1992) provide the most comprehensive theory for explaining how the value components in an expectancy/value framework motivate learners to achieve. Expectancy and task value are the two most important predictors of achievement behavior. Wigfield and Eccles found that students who perceive high value in a task also possess a high expectancy for success. Other researchers have also found students’ expectancies and perceptions of ability to be linked to their level of cognitive engagement through elaboration (paraphrasing, summarizing), use of metacognitive learning strategies (planning, checking, and monitoring work), and "deeper processing" of course content (Pintrich, 1989; Pintrich & De Groot, 1990; Pintrich & Garcia, 1991; Pintrich & Schrauben, 1992).

Concept mapping has been well established as an effective metacognitive strategy to foster and enhance meaningful learning in science classrooms (Arnaudin, Mintzes, Dunn, & Shafer, 1984; Bascones & Novak, 1985; Edmondson, 2000; Georghiades, 2004; Heinz-Fry & Novak, 1990; Horton et al., 1993; Kinchin, 2000; Martin, Mintzes, & Clavijo, 2000; Mintzes, Wandersee, & Novak, 1998, 2000; Novak, 1990, 1993a, 1993b, 1998; Novak & Gowin, 1984; Novak, Gowin, & Johansen, 1983; Novak & Musonda, 1991; Novak & Wandersee, 1990; Pearsall, Skipper, & Mintzes, 1997; Starr & Krajcik, 1990; Willerman & MacHarg, 1991). Nonetheless, no one has addressed the extent to which it is effective with all learners.

The literature review of Horton et al. (1993) found only three studies (Bodolus, 1986; Jegede, Alaiyemola, & Okebukola, 1989; Okebukola & Jegede, 1989) that explored the effect size of concept mapping on student attitudes. However, in none of the studies was *attitude* defined in terms of specific motivational components (e.g., self-efficacy, control beliefs, or task value), which affect motivation to engage in a task. Additionally, while many educational researchers (Ames & Archer, 1988; Dweck & Elliott, 1983; Meece, Blumenfeld, & Hoyle, 1988; Pintrich, 1989; Pintrich & Garcia, 1991; Pintrich, Marx, & Boyle, 1993; Pintrich & Schrauben, 1992; Risemberg & Zimmerman, 1992; Schunk, 1994; Zimmerman, 1990) have examined the role that motivation plays in relation to employment of cognitive learning strategies**,** no one has empirically investigated the role that motivation plays in affecting the depth of students' conceptual understanding as a result of using concept mapping. Therefore, it is of interest to this researcher to know the extent to which students are receptive and motivated to utilizing, and becoming proficient in, concept mapping. This paper discusses the results of a study which investigated the extent to which concept mapping motivates students to become more self-regulated learners by adopting a more meaningful approach to learning biology.

Methodology

Concept Mapping

This study incorporated a quasi-experimental, pre-post test design and mixed methodology that included a quantitative analysis of the relationship between concept-mapping proficiency, test performance, and motivational and learning strategy use profiles. Additionally, students were randomly selected to respond to a set of structured interview questions. Four homogeneously-grouped classes comprising a total of 82 high-ability, 10th-grade biology students served as subjects. All 82 students were in the top ability-level grouping due to their past academic performance as high achievers in science. Therefore, it was implicitly assumed that all students were more or less equally capable of learning biology. Additionally, with the exception of the unit on Cells, which is only superficially taught in seventh-grade Life Science, all other content units represented new concepts not covered in earlier grades. This was especially true for the more conceptually abstract units including Photosynthesis & Respiration, DNA & Protein Synthesis, and Mitosis & Meiosis. Furthermore, since there was a hiatus of 3 years between a superficial exposure to "Cell" concepts and that covered in this study, it was assumed that all students had, at best, a minimal exposure to the concepts taught in this course, precluding any need to assess prior knowledge.

Early on in the fall semester, all 82 students were taught how to construct concept maps, as well as how to do so using Inspiration™ Version 6 software. Sessions were held until all students became proficient in generating, saving, and editing concept maps using this software. Proficiency was defined as a demonstrated understanding of: (1) how to hierarchically organize concepts from most to least inclusive, (2) how to propositionally link together several different concepts provided to the student by the teacher, and (3) how to cross-link two related “branches” of a concept map. The instructors did not offer any personal opinions, nor critiquing of the efficacy, utility, or practical nature of concept mapping as a means to assess and/or foster conceptual understanding, other than what is described in this introduction to concept-mapping procedure.

Once students demonstrated an understanding of the concept-mapping technique, they were asked to individually construct concept maps for specific clusters of concepts (provided by their teacher) and which serve as the foundation of a course unit (e.g., ecology). Throughout each teaching unit, teachers collected and provided constructive feedback to students with reference to propositional validity and structural complexity of their maps. The feedback did not include correcting students’ mistakes or misconceptions, nor filling in missing concepts. The feedback took the form of providing students with questions designed to encourage a more meaningful approach to the construction of their concept maps. Subsequent to this, the concept maps were returned to the students and they were asked to revise, modify, and expand them. This process continued until a final concept map was turned in to the teacher on the day of the test. Maps were scored using the following procedure developed by Novak & Gowin (1984), with scores then tallied and recorded for each student:

A. *Structural complexity* was assessed on two levels:
   (1) *Hierarchical design*, scoring 5 points for each subordinate level beneath the most superordinate concept (the branch with the most levels).
   (2) *Crosslinks*, scoring 10 points for each valid and scientifically correct link between two segments of the concept map.
B. *Propositional validity* was assessed by scoring 1 point for each nonredundant, scientifically correct, and meaningful linkage between two concepts.

Using Two Teachers

In order to generate a sufficient quantity of data that could be subsequently subjected to quantitative analysis, four separate classes of Level 1 (top ability level) students were selected that necessitated utilizing 2 different teachers. Teacher effect was reduced due to the fact that both teachers shared a constructivist educational philosophy as a basis for their teaching and agreed to follow the same curricula, use the same laboratory activities, and design similar tests to assess for meaningful understanding rather than mere recall of information. However, having 2 teachers led to considering a method that ensured all concept mappers were provided with similar levels of constructive feedback that enabled them to effectively modify their maps over time to reflect a higher degree of conceptual understanding. To ensure this, both teachers were provided with exemplar concept maps, which served to present them with a clearer framework from which to base effective and constructive feedback remarks. It is important to emphasize that exemplar maps were not used to ensure that all student maps ended up resembling the exemplar. Concept maps are, after all, the graphical construction of what students perceive to be their level of conceptual understanding. Therefore, while some maps are qualitatively and/or quantitatively better than others, no one map, including the exemplar, is intrinsically “the best map” which could be used as a standard against which all others should be measured.

The Motivated Strategies for Learning Questionnaire (MSLQ)

The Motivated Strategies for Learning Questionnaire (MSLQ) is a self-report instrument designed by Pintrich, Smith, Garcia, & McKeachie (1991) that can be used by secondary and post-secondary students to self-assess their level of motivation and use of cognitive and metacognitive learning strategies in a specific context (e.g., a biology course). The theoretical framework of the MSLQ is predicated on a cognitive view of motivation and learning strategies previously discussed by McKeachie, Pintrich, Lin, and Smith (1986), Pintrich (1988, 1989), Pintrich and Garcia (1991), and Pintrich and De Groot (1990). The MSLQ was administered to all 82 students early in the fall semester (September) and prior to instruction on concept mapping, and then re-administered the following April during the spring semester.

Subscales

The MSLQ questionnaire is divided into two major subscales: motivational and learning strategies. The motivation section contains 31 items that assess *value* (intrinsic and extrinsic goals and task value), *expectancy* (control beliefs and self-efficacy), and *affect* (test anxiety). The learning strategies section consists of 31 items that assess use of different *cognitive* and *metacognitive* learning items, including rehearsal, elaboration, organization, critical thinking, and self-regulation, as well as 19 items that assess *student resource management*, including time and study environment, peer learning, help-seeking, and effort regulation. The 15 subscales of the MSLQ can be used alone, or in combination with others, to reflect different motivational and learning strategy use student profiles. All of the motivation subscales were used to assess student motivation. Learning strategy use profiles consisted of the learning strategy use subscales that assessed deep processing strategies, and included elaboration, organization, critical thinking, and self-regulation. The only student resource management subscale used was effort regulation.

Identifying Levels of Concept-Mapping Proficiency

Once the study had ended, the effect of concept mapping on enhancing achievement was measured on the basis of whether concept-mapping skill proficiency was related to test performance. Towards this end, students were placed into one of three groups consisting of upper, middle, and lower concept-mapping proficiency. Once all the concept map and test scores were compiled, students were grouped according to their measured level of concept-mapping proficiency as follows.

Determining concept-mapping proficiency groups. There were two different teachers included in the study, and each with two classes, and students were divided into three equal concept-mapping proficiency groups on the basis of whether they were in the upper-third, middle-third, or lower-third of the array for each teacher. Additionally, since the assumption is that concept-mapping proficiency should correlate with conceptual understanding and thus test performance, 2-way ANOVAs were performed with teacher and concept-mapping proficiency group as fixed factors and test scores as dependent variables in order to assess any variance between students’ map and test scores relationship: Ecology, F(2,76) 0.5 ns (i.e., no significance); Chemistry, F(2,76) 0.9 ns; Cells, F(2,76)1.2 ns; Photosynthesis & Respiration, F(2,76) 1.7 ns; DNA & Protein Synthesis, F(2,76) 0.7 ns; Mitosis & Meiosis, F(2,76) 0.47 ns. Additionally, ANOVAs did not reveal any interaction effect. Thus there was no indication of any significant teacher effect. Subsequently, concept map scores were normalized and then all 82 students were placed into upper-, middle-, or lower-third proficiency mapping groups.

Determining test performance groups. Tests administered by both teachers consisted of similar objective (60%) and subjective (40%) questions, which primarily evaluated student understanding and application of conceptual knowledge rather than mere recall of factual knowledge. Test scores from students of each teacher were normalized as follows. Student test scores, for each of the six biology units covered over the course of the study, were compiled, averaged, arranged, and divided up in an identical manner to that used to establish concept-map proficiency groups. Students were then grouped on the basis of their concept-mapping proficiency and test performance. As a result, students were placed into one of nine different categories using a 3 x 3 matrix, as follows:

Concept-Mapping Proficiency/Test Performance Groups

Group 1: Upper-Third Concept Mappers/Upper-Third Test Performers
Group 2: Upper-Third Concept Mappers/Middle-Third Test Performers
Group 3: Upper-Third Concept Mappers/Lower-Third Test Performers

Group 4: Middle-Third Concept Mappers/Upper-Third Test Performers
Group 5: Middle-Third Concept Mappers/Middle-Third Test Performers
Group 6: Middle-Third Concept Mappers/Lower-Third Test Performers

Group 7: Lower-Third Concept Mappers/Upper-Third Test Performers
Group 8: Lower-Third Concept Mappers/Middle-Third Test Performers
Group 9: Lower-Third Concept Mappers/Lower-Third Test Performers

In order to minimize teacher bias, map and test scores were compiled to place students into one of the above nine groups after the study was concluded.

Determination of Inter-Rater Reliability Coefficient

Another teacher with a similar level of expertise in both knowledge of biological concepts and Novak's concept-mapping procedure and rubric was chosen and asked to randomly select and re-score, throughout the year, previously-scored student concept maps. The percentage difference in map score between that scored by the two teachers was determined for 20 randomly-selected maps. All the percentage differences were then compiled and averaged in computing an inter-rater reliability score of 98%.

Structured Interview Responses

Halfway into the study, 40 of the 82 students were randomly selected to be interviewed using a set of structured interview questions. Specifically, students were assigned a number and then selected using sequences from a random numbers table. After the study was concluded, transcripts were divided into three groups according to whether students were classified as an upper-, middle-, or lower-proficiency concept mapper. For the purposes of this study, only transcripts of upper- and lower-mapping-proficiency students were analyzed, summarized, and reported.

Analysis of Data

ANOVAs were performed on the basis of students' upper-, middle-, and lower-concept-mapping proficiency and test performance, and ANCOVAs were performed for spring responses to the motivational and learning strategy subscores of the MSLQ, with fall scores serving as the covariate. ANOVAs were then conducted between crosslink mean and either concept-mapping proficiency or test means. Finally, a correlational analysis was conducted between crosslink, concept map, and test means.

Results and Interpretation

Is Test Performance Related to Concept-Mapping Proficiency?

Figure 1 shows the histogram of the relationship between concept-map proficiency and test performance. The majority of high-proficiency mappers were also found to be high test performers. The numbers of high-proficiency mappers decreased from high to low test performance groups. In stark contrast, the majority of low-proficiency mappers were found to be low test performers and the numbers of low-proficiency mappers increased from high to low test score groups. The number of middle-proficiency group concept mappers was relatively evenly distributed amongst all test performance groups. In terms of actual numbers, it should be noted that 25 of the 27 upper-third mappers scored in the upper- or middle-third for average test score (17 of which scored in the upper-third for test performance), whereas 27 of the 28 lower-third mappers scored in the lower- or middle-third for test performance (18 of whom scored in the lower). It is of further interest to note that the Pearson moment correlation value for concept-mapping proficiency group and test performance group was statistically significant (0.58, $p<0.01$). In summary, these results show that students' level of mapping proficiency is significantly correlated with subsequent test performance.

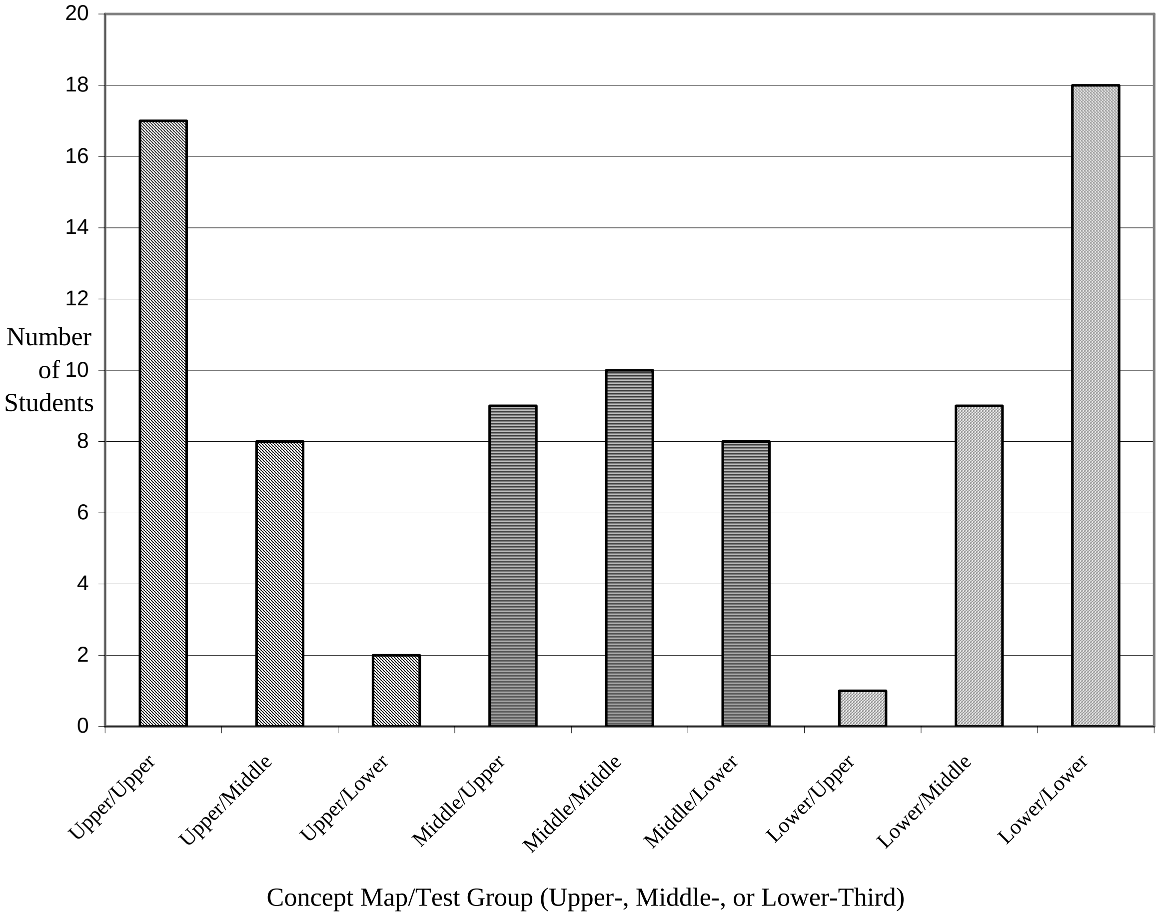

Figure 1. Distribution of students within the nine concept-mapping proficiency and test performance groups.

This is also expressed in an examination of the ANOVAs for unit test scores in relation to concept-mapping proficiency group (Table 1). An analysis of these data reveals that concept-mapping proficiency showed a positive and statistically significant relationship with test score. Mean test analyses show that students in the upper-third mapping proficiency group consistently outperformed those in the middle-third proficiency group, who in turn consistently outperformed those in the lower-third proficiency group. Furthermore, Tukey post hoc analyses revealed that the total test mean differences were positive and significant (upper with middle third, $p<0.05$; upper and middle with low, $p<0.001$). Thus, this data, together with that of Figure 1, provide evidence to suggest that higher concept-mapping proficiency may have contributed to higher test performance. In support of this, it should also be noted that Tukey post hoc analyses of individual test results (data not shown) revealed that, beginning with the third test, the middle-third concept mappers began to significantly outperform lower-third proficiency mappers in test performance and continued to do so for the remainder of the year.

Table 1
One-Way ANOVA's for Unit Tests Amongst Upper-, Middle-, and Lower-Third Concept-Mapping Proficiency Groups

Unit test	Concept-mapping proficiency group mean scores			1-Way ANOVA
	High (N=27)	Middle (N=27)	Low (N=28)	
Ecology	84.4	82.4	77.2	F(2,79) 4.7 **
Chemistry	90.4	85.2	78.7	F(2,79) 12.1***
Cells	89.9	86.6	79.1	F(2,79) 12.68 ***
Photosynthesis & Respiration	91.2	86.0	79.9	F(2,79) 19.9 ***
DNA & Protein Synthesis	89.9	84.0	74.0	F(2,79) 24.7 ***
Mitosis & Meiosis	88.7	84.5	76.1	F(2,79) 14.9 ***

**p<0.01, ***p<0.001

Crosslinks Alone as a Measure of Concept-Mapping Proficiency

Crosslinks are reflective of what Ausubel (2000) referred to as integrative reconciliations. They are a consequence of students making deeper and more meaningful leaps in understanding, and can therefore represent large gains in conceptual learning. An implicit assumption of this study was that the level of concept-mapping proficiency is reflective of the depth of conceptual understanding. Prior classroom experience with concept mapping led the author to realize that becoming proficient at crosslinking took the longest amount of time, even for the most competent mappers. As a result, in the present study it was only after the first two unit tests were administered that differences in the number of crosslinks were recorded. Subsequently, a correlation study was performed to investigate the relationship between crosslink score, concept-mapping proficiency group, test performance group, test means, and concept-map mean. The results of this study are shown in Table 2.

Table 2
Pearson Moment Correlation Values for Test, Concept Map Score, and Crosslink Means

Item	Two-tailed Pearson's moment correlation coefficient		
	Test mean	Concept map mean	Crosslink mean
Test mean	X	0.36	0.66
Concept map mean	0.36	X	0.68
Crosslink mean	0.66	0.68	X

Note. All correlations were significant at the $p<0.01$ level.

Figure 1 and Table 1 indicate that mean test score was found to be positively correlated with concept-mapping proficiency. However, it was of interest to note that a more positive and significant correlation was observed between test means and crosslink mean (0.66, $p<0.01$) than with concept-map mean score (0.36, $p<0.01$). Table 3 displays ANOVAs for mean number of crosslinks as related to concept mapping proficiency and test performance. The results indicate that the most proficient mappers had the highest crosslink scores. Additionally, Tukey post hoc analysis revealed significant mean differences ($p<0.001$) between crosslink number amongst upper-third proficiency mappers and those in the middle- and lower-third proficiency groups. Statistically significant mean differences ($p<0.001$) were also observed between middle-proficiency and low-proficiency mappers. As a consequence, hereafter in this report students in the upper-, middle-, and low-proficiency mapping groups will be referred to as the high-, middle-, and low-proficiency groups, respectively.

Table 3
One-Way ANOVA's of Number of Crosslinks for Upper-, Middle-, and Lower-Third Concept Mapping Proficiency and Test Performance Groups

Group	Crosslink mean	
	Concept-mapping proficiency groups F(2,79) 43.8***	Test performance groups F(2,79) 24.3***
Upper-third	57	56
Middle-third	39	35
Lower-third	17	22

***$p<0.001$

A further analysis of crosslinks by each unit test (Table 4) revealed that students in the high proficiency group consistently had higher crosslink means relative to those in the middle proficiency group, who in turn had consistently higher crosslink means than those in the lower proficiency group. Tukey post hoc analyses revealed that students in the middle proficiency group consistently and significantly had more crosslinks relative to those in the lower proficiency group.

It is therefore plausible to suggest that students in the high- and middle-proficiency groups also possessed a deeper understanding of biological concepts relative to those in the low-proficiency group. Additionally, these results, together with the correlation study findings shown in Table 2, suggest that crosslink score was more predictive of test performance than total concept map score.

Table 4
One-Way ANOVA's for Crosslink Means Amongst High, Middle, and Low Concept-Mapping Proficiency Groups

Unit test	Crosslink mean score			ANOVA	Tukey post hoc analyses
	High (N=27)	Middle (N=27)	Low (N=28)		
Cells	56	42	12	F(2,79) 11.7***	High with Low *** Middle with Low**
Photosynthesis & Respiration	91	62	39	F(2,79) 18.9***	High with Low *** High with Middle ** Middle with Low**
DNA & Protein Synthesis	40	24	11	F(2,79) 12.6***	High with Middle ** High with Low***
Mitosis & Meiosis	40	33	6	F(2,79) 15.3***	High with Low*** Middle with Low***

**p<0.01, ***p<0.001

Differences in Student-Constructed Concept Maps From High- and Low-Proficiency Groups

Figures 2 and 3 are examples of concept maps constructed by high- and low-proficiency mappers. Both students constructed their concept maps using the concept mapping software program, Inspiration™. Figure 2 shows the final concept map constructed by the less proficient student. Here one can see that, while the student demonstrated some knowledge of the subject, it was limited to mere descriptive terms and examples. While the concept of matter is discussed in some detail, no mention is made of types of either energy (potential & kinetic) or their relationship to one another and matter. Furthermore, there are numerous incomplete propositional statements, as well as misconceptions. For instance, while chemical reactions have products and reactants, it is unclear what the student means by stating that they "cause" physical and chemical change. Some of the obvious misconceptions include suggesting "water performs hydrolysis," that "pH is a mixture," and that "inorganic compounds are phosphorus, carbon, nitrogen and sulphur." Likewise, while the student recognizes that proteins can be enzymes, she assumes that all enzymes are "structural proteins like hair or skin," whereas in actuality some proteins can be enzymes, or serve as structural proteins. Most conspicuous is the lack of any crosslinks. In summary, the student demonstrated only a superficial understanding of chemical concepts and their relationship to one another.

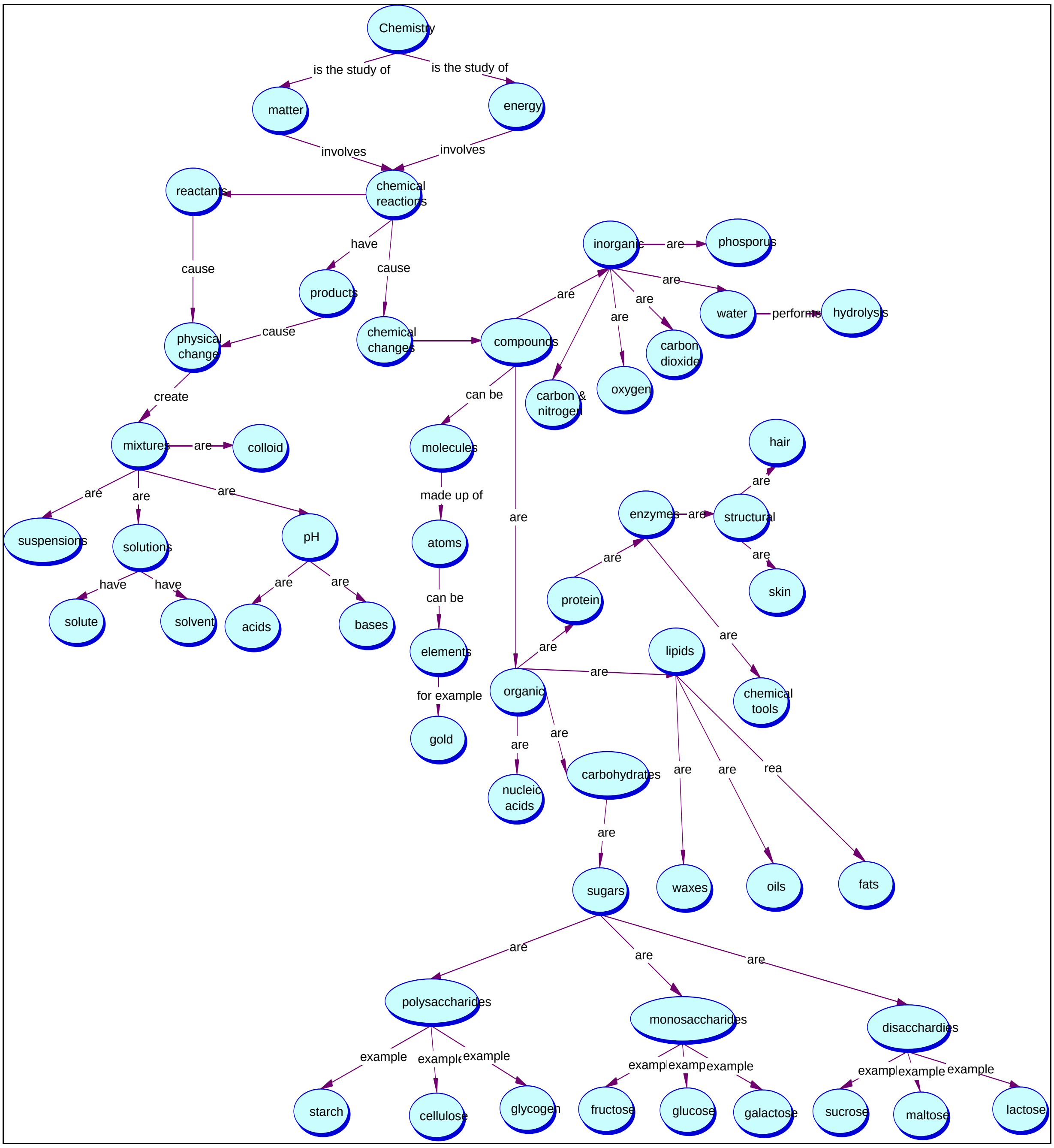

Figure 2. Concept map for Chemistry unit concepts constructed by a low-proficiency mapper.

In contrast, Figure 3 shows the concept map of a high-proficiency student. One can easily see that she has revealed a much deeper understanding of the relationship between the concepts than her less proficient peer. This is most easily shown through her much more hierarchically-organized map, conceptual detail, lack of misconceptions, and, most importantly, large number of crosslinks. First, she recognizes that energy not only takes the form of potential versus kinetic, but that they are interconvertible. She also recognizes that some kinds of organic molecules (i.e., lipids) are used for energy. Additionally, she understands that "compounds require chemical changes" and that "chemical change involves the sharing of electrons." She also reveals an understanding that chemical reactions involve molecules and that two significant types of chemical reactions involve creating (dehydration synthesis) or breaking down (hydrolysis) organic compounds. Furthermore, she relates each of these processes to the creation of complex carbohydrates (dissacharides and polysaccharides) from, as well as the breaking down of them into, monosaccharides. In summary, this student reveals a much more meaningful understanding of the interrelationships between chemical concepts. The high-proficiency mapper received an A while her low-mapping proficiency peer received a C- on the unit test in Chemistry.

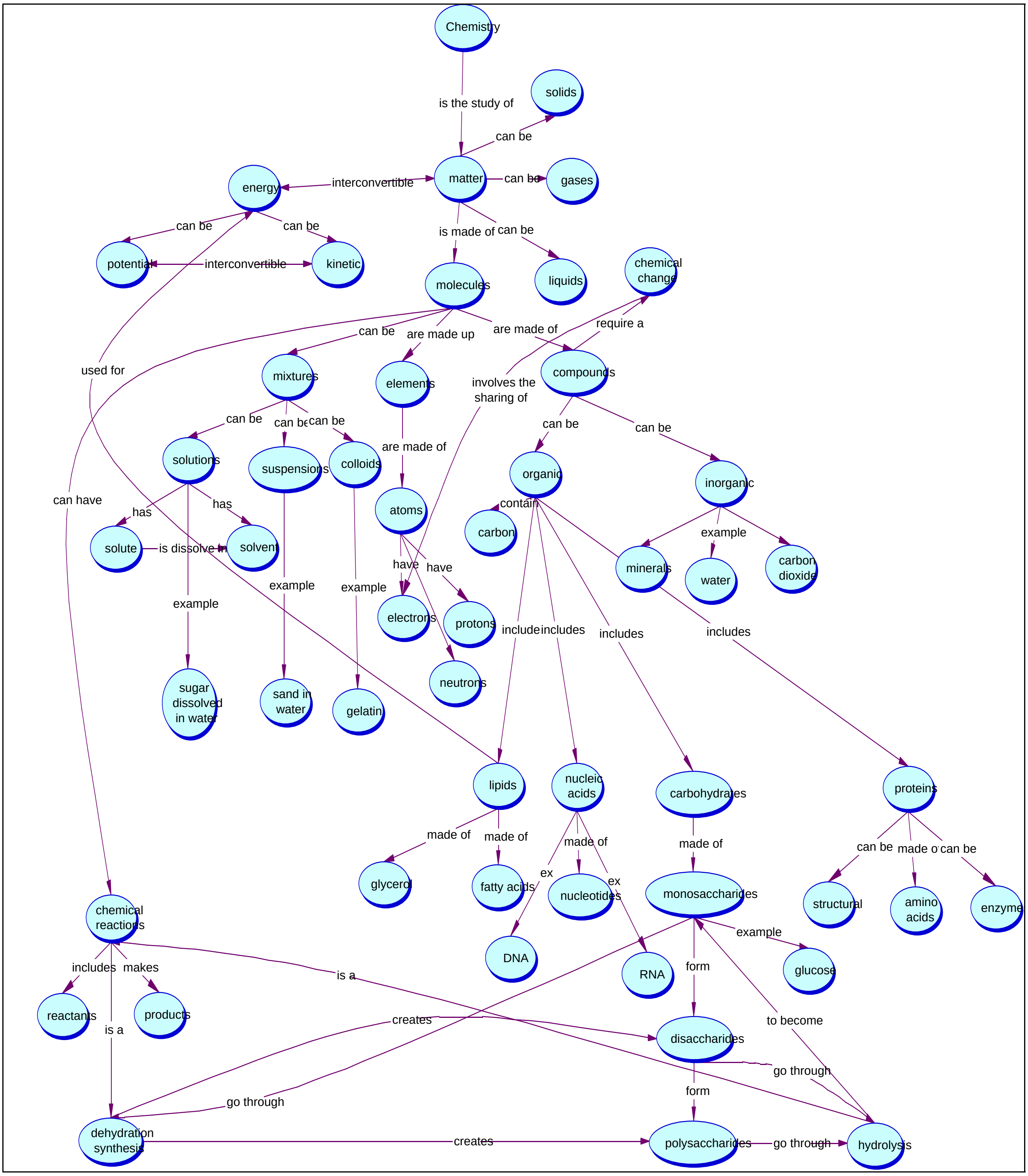

Figure 3. Concept map for Chemistry unit concepts constructed by a high-proficiency mapper.

During interviews, high-proficiency mappers reported they frequently and actively look deeper into the relationships between concepts when constructing their maps. While many, if not most, of the high-proficiency mappers indicated they initially had trouble finding crosslinks, they nonetheless eventually learned how to flesh out crosslinks. Tables 3 and 4 support this finding, since the high-proficiency mappers had the highest percentage of crosslinks of any group. All of these students reported that while learning how to construct crosslinks was initially difficult, they now feel more comfortable with doing so and actively look for connections between concepts. Typical comments included the following: “I am now looking a little bit deeper into the meaning of the concepts to find crosslinks”; “This is not something I would ordinarily do on my own. I usually would just review the chapter”; and “Now I can find crosslinks. Before that was hard. I really enjoy to work on the concept map and think about crosslink relationships between terms.”

While the majority of the low-proficiency mappers also indicated they had trouble initially with finding crosslinks, unlike their more high-proficiency peers they continued to experience trouble with finding them throughout the rest of the year. This is supported more quantitatively in Table 4 by the fact that low-proficiency mappers consistently had the fewest number of crosslinks on every test. The following are reflective of the sentiment of many of these students who had difficulty with making crosslinks: “It’s really so hard to find something between two concepts that relates them in one particular way. It takes a lot of critical thinking . . . I’m a book learner” and “The crosslinks have been the hardest thing for me to do. I guess I don’t know how to find them.”

Thus, these results suggest that there are major qualitative, as well as quantitative, differences between the maps of high-, middle-, and low-proficiency mappers. Finding crosslinks involves more than just looking up the terms and incorporating them into a concept map. Rather, crosslinks represent deeper and more profound insights into more subtle relationships between groups of concepts. It is therefore not surprising to see that students with higher crosslink scores performed better on unit tests, which were all designed to assess deeper conceptual understanding as opposed to simply memorizing and regurgitating facts. Overall, there appears to exist a positive and significant correlation between levels of mapping proficiency and mean crosslink score, as well as test performance. Hence, a good argument can be made for suggesting that students with higher mean crosslink scores took a more meaningful approach to learning and acquired a deeper conceptual understanding, which may have been responsible for their higher test performance.

Can Concept Mapping Encourage Adaptive Changes in Learners’ Motivational and Learning Strategy Use Profiles?

A critical ingredient for taking a meaningful approach to one’s learning lies in being motivated to do so in the first place. Therefore, along with investigating the extent to which students became proficient at concept mapping, as well as translating that into achievement gains, was exploring the fall-to-spring changes in motivation as a consequence of using concept mapping. Pre-study MSLQ responses revealed that the low-proficiency mappers self-assessed higher mean levels for self-efficacy (5.6 vs. 5.38) and control beliefs (5.81 vs. 5.51) than high-proficiency mappers. Additionally, both had similar means for task value (5.62 vs. 5.63). Since pre-study motivational responses were made prior to students knowing they would be using concept mapping, it can be argued that all three subscores were indicative of students’ initial expectancy-value beliefs to learn biology. Analyses of students’ fall and spring MSLQ subscores will be discussed in terms of fall-to-spring changes in motivational and learning strategy use profiles. Table 5 shows an ANCOVA between fall and spring MSLQ motivational subscores in relation to concept-mapping proficiency. The fall-to-spring score changes in MSLQ means were obtained by using the estimated marginal spring means from the ANCOVA determination (adjusted for fall covariate score). Least significant differences between pair-wise determinations revealed statistically significant motivational profile differences between students in the upper-, middle-, and low-proficiency groups.

Table 5
ANOVA's of Adjusted Spring Mean Changes (With Fall Score as the Covariate) for MSLQ Motivational Subscores as a Function of Concept-Mapping Proficiency Group

Concept-mapping proficiency group	MSLQ subscore Spring estimated marginal mean (Fall score as covariate)	ANCOVA Dependent variable: Adjusted Spring mean	Least significant difference
	Intrinsic goals	F(2,78) 3.1*	
High	4.7		
Middle	4.7		High & Middle with Low*
Low	4.3		
	Extrinsic goals	F(2,78) <1	
High	5.3		
Middle	5.4		
Low	5.3		
	Task value	F(2,78) 3.9*	
High	5.4		
Middle	5.0		High with Low**
Low	4.8		
	Control beliefs	F(2,78) 3.3*	
High	5.7		
Middle	5.3		High with Low**
Low	5.1		
	Self efficacy	F(2,78) 6.5***	
High	5.7		
Middle	5.3		High with Middle*; Low***
Low	5.0		
	Test anxiety	F(2,78) 2.47ns	
High	3.1		
Middle	3.5		High with Low*
Low	3.7		

*p<0.05, **p<0.01, ***p<0.001, ns (no significance)

Of particular interest are the polarized contrasts in fall-to-spring changes in motivational profiles between high- and low-proficiency mappers. Specifically, relative to low-proficiency mappers, those in the high-proficiency group reported positive and significant changes in intrinsic goals, task value, control beliefs, and self-efficacy. On the other hand, relative to high-proficiency mappers, those in the low-proficiency group only reported higher and significant mean changes in test anxiety. Thus, high-proficiency mappers showed adaptive changes in their motivational profile, while low-proficiency mappers reported more maladaptive changes.

Table 6 displays the analyses of covariance for fall and spring MSLQ learning strategy use scores. Positive and statistically significant adaptive changes in fall-to-spring learning strategy use for elaboration, critical thinking, self-regulation, and effort regulation were observed only amongst students in the high-proficiency group. These results parallel those observed for fall-to-spring changes in the motivational profiles of the high- and low-proficiency groups. Specifically, high-proficiency mappers self-reported statistically significant adaptive changes in fall-to-spring learning strategy profiles, while low-proficiency mappers reported significant maladaptive fall-to-spring changes.

Table 6
ANOVA's of Adjusted Spring Mean Changes (With Fall Score as the Covariate) for MSLQ Learning Strategy Use Subscores as a Function of Concept-Mapping Proficiency Group

Concept-mapping proficiency group	MSLQ subscore Spring estimated marginal mean (Fall score as covariate)	ANCOVA Dependent variable: Adjusted Spring mean	Least significant difference
	Elaboration	F(2,78) 9.3***	
High	4.7		
Middle	4.2		High with Middle**; Low***
Low	3.9		
	Organization	F(2,78) <1	
High	3.9		
Middle	3.8		
Low	3.7		
	Critical thinking	F(2,78) 2.0 n.s.	
High	4.0		
Middle	3.8		High with Low*
Low	3.5		
	Self regulation	F(2,78) 4.1*	
High	4.8		
Middle	4.3		High with Middle*;
Low	4.3		Low**
	Effort regulation	F(2,78) 5.8**	
High	5.8		
Middle	5.4		High with Low***
Low	5.0		

*$p<0.05$, **$p<0.01$, ***$p<0.001$

Interview transcripts provided insight into possible reasons for the observed differences in fall-to-spring motivational and learning strategy profile changes between high- and low-proficiency mappers. One of the assumptions of this study was that students who experience success with concept mapping, particularly if it is unexpected success, should develop higher levels of self-efficacy, which should promote higher levels of motivation to using it to learn biology. Conversely, it would be expected that students who did not experience success in using it, particularly if it was expected, should experience a loss in motivation to learn biology. Interviews disclosed that, in contrast to low-proficiency mappers, the majority of high-proficiency mappers perceived that their interest and/or motivation increased over the course of the year. Furthermore, they stated that it occurred as a direct consequence of using concept mapping to help them understand the subject matter to a greater extent and translating that to performing better on tests (e.g., “I’m a lot more interested now because I found that I can succeed. Learning biology is not some impossible thing to do” and “More. It has to do with my level of success. If you don’t do so well you want to put the subject off. But if you do well then you want to keep at this and keep the grades up. I think my test grades and my concept mapping are correlated"). The major difference between low-proficiency mapper responses and those of the high-proficiency group was that the former made no mention of concept mapping. Rather, their interest varied and was dependent upon either having a previous interest in science or the specific topic being studied. Some reported they were not so much more interested in the subject but felt they had to pay more attention than they normally would in order to understand the material. Others reported loss of interest due to difficulty of the material.

Generally, high-proficiency mappers collectively responded in a way that reflected a more meaningful learning approach. Specifically, they indicated that concept mapping worked for them because they were motivated to actively construct their own learning of the subject. As a result, they were willing to spend the requisite time necessary to make very detailed and meaningful maps (e.g., "I like doing concept maps because it helps me to see connections while I'm learning that I normally wouldn't have seen if I was just reading notes" and "I think what you get out of mapping is how much you put into it"). Low-proficiency mappers had distinctly different responses from their more mapping-proficient peers. Specifically, most of their comments reflected their inability to recognize the utility of concept mapping as a learning strategy. Their comments indicated that concept mapping is useful only if you understand the meaning of the concepts first. Other students responded in a way that reflected a hardened reliance on their old ways of learning and studying which basically took the form of a more rote-learning approach. Additionally, many suggested that it would only be useful to those who are visual learners. Responses from all but one indicated that concept mapping itself was a difficult strategy for them due to the amount of time that was required to make the maps. Thus, these comments support the notion that many less-proficient mappers were so because they continued to believe that using learning strategies that had worked for them in the past should still work for them in this course. Some students actually realized that their old ways of learning and studying were not as effective in this course. Nonetheless, they found using concept mapping to learn more meaningfully very difficult. Thus, it would appear that they would be the least likely to put in the time and effort requisite to become proficient at concept mapping.

One of the biggest discrepancies noted between high- and low-proficiency mappers was the extent to which concept mapping was perceived as a form of studying. A quick perusal of the responses from the high-proficiency mappers indicated that all of them viewed concept mapping as a form of studying. All high-proficiency mappers' responses suggested that their study habits--the way they learn and create meaning--changed as a consequence of concept mapping. They tended to view working on their concept maps as time spent studying. Furthermore, when the time came to review for the test, they needed less time to go over the material because they already knew it. In general, their comments indicated concept mapping forced them to delve more deeply into the nature of the meaning of the concepts in relation to one another and in so doing, fostered an active and meaningful approach to studying the material (e.g., "It helps me to work with the stuff that I should be learning, instead of just reading and memorizing it"). They also said they found themselves using their textbooks more effectively to learn the concepts and organize them on their concept maps (e.g., "It has aided me in that it has forced me to read the text and to understand it before the test. It's not just the test I'm studying for but to get the concepts right as well"). The responses here clearly point to students taking a more reflective, active, and meaningful approach to learning. Relative to low-proficiency mappers, those in the high-proficiency group reported differences in their interview responses to expended effort, achievement, understanding ability, and motivation to learn biology as a direct result of using concept mapping. These response patterns were supportive of findings that showed adaptive fall-to-spring changes in motivational and learning strategies use profiles for high-proficiency mappers, in contrast to the maladaptive profile changes for those in the low-proficiency group. Additionally, differences were observed for high-proficiency mappers relative to low-proficiency mappers with respect to reporting that concept mapping helped them pace their learning in approaching an understanding of biological concepts. This is not surprising, seeing that the high-proficiency mappers consistently scored the highest on tests. The result was quite different for the low-proficiency mappers, who perceived that they tended more to cram at the end of a unit prior to taking a test.

In direct contrast to the responses made by the high-proficiency mappers, about 75% of the low-proficiency mappers indicated they considered concept mapping to be different from what they typically thought of as "studying." Studying to most of them appears to involve more traditional approaches like going over notes and reading the textbook just before the test (e.g., "When I study I look over the notes, first of all then I go into the book and look through the sections and make sure that I understand the material"). In fact, many viewed concept mapping as an extra assignment or project to be done rather than perceiving it as a metacognitive learning strategy for developing a deeper and more meaningful conceptual understanding (e.g., "I think of doing concept maps more like doing a project than studying. It's something separate from studying. I have to do the maps because I have to"). Some even commented that time spent on concept mapping took away time they would normally spend "studying" (e.g., "I take too much time finding crosslinks and that takes away from some of the real studying like sitting down and looking at your notes or re-writing them"). Apparently, only those who recognized the value of concept mapping spent adequate time making the crosslinks and propositional links needed to construct a meaningful concept map.

The ability to view concept mapping as an active strategy for developing a conceptual understanding is crucial in providing students with a reason to spend the requisite time necessary to make concept maps a useful means to construct meaning. However, this may require a significant change in students' strategy for learning a subject. Specifically, since the majority of low-proficiency mappers reported that the product (the map) was more important than the process (making the map), the switch to using concept mapping did not appear to come automatically (e.g., "The final product is more valuable than the process of making the map cause everything is in one spot when I need it. Working on my concept map does not enhance my ability to understand the material"). It is easy to see how students with this kind of perception would tend to resent having to spend the time to work on their concept maps. This would truly make them frustrated if they performed poorly on unit tests, which many of these students did. It would seem unlikely that these students would perceive concept mapping as a valuable tool for learning.

Further Discussion

This study was designed to explore the extent to which concept mapping can motivate students to take a more meaningful approach to learning biology. In so far as this is concerned, the results of the study provide support for other studies (Bascones & Novak, 1985; Edmondson, 2000; Georgihades, 2004; Horton et al., 1993; Kinchin, 2000; Novak, 1990, 1993a, 1993b, 1998; Novak & Gowin, 1984; Novak& Musonda, 1991; Novak & Wandersee, 1990) that concept mapping is an effective learning strategy to support and enhance learning of science concepts. Furthermore, it also supports the published findings demonstrating the validity of concept mapping as a learning strategy to foster a meaningful approach to learning (see Arnaudin et al., 1984; Heinz-Fry & Novak, 1990; Martin et al., 2000; Mintzes et al., 1998, 2000; Novak, 1983, 1990; Novak & Wandersee, 1990; Pearsall et al., 1997; Starr & Krajcik, 1990; Willerman & MacHarg, 1991).

Nonetheless, the findings of this study also demonstrate that concept mapping is a learning strategy that is not embraced to the same extent by all learners. Specifically, while mapping proficiency was found to be significantly related to adaptive gains in motivation and learning strategy use profiles amongst some learners (i.e., those in the high-proficiency group), other learners (i.e., those in the low-proficiency group) appeared more resistant to its use and displayed maladaptive changes in the same motivational and learning strategy use profiles. As noted earlier, all the students in this study were drawn from the same homogenous, high-ability science grouping and, as such, had a similar history of experiencing high success in learning science concepts. Therefore, one cannot readily conclude that the more proficient mappers were simply better science students. Furthermore, since pre-study means for expectancy-value measures (i.e., task value, control beliefs, and self-efficacy) were either the same or higher amongst lower-proficiency mappers compared with those in the upper-proficiency group, one cannot simply conclude that only students who were highly motivated and self-regulated learners to begin with chose to become proficient as concept mappers. It is therefore puzzling as to why there was such an observed disparity in test performance, as well as concept-mapping proficiency, amongst them. Therefore, these findings raise the question as to why some students became proficient at mapping while others did not.

Differences in Receptiveness to Adopting Concept Mapping as an Alternative Learning Strategy

One of the possible explanations for the observed disparity in receptiveness to becoming proficient at concept mapping might lie in the extent to which students were able to find, and make meaningful connections between, concepts. Interview transcripts revealed that low-proficiency mappers tended to view concept mapping as a difficult and time-consuming activity that prevented them from studying, and as such was actually responsible for their poorer test performance relative to other class members.

The responses from the high-proficiency mappers were quite the opposite. They attributed their overall high test performance to using concept mapping because it helped them pace and develop a deep conceptual understanding requisite to performing well on tests. Additionally, while they also reported mapping was time consuming, doing so led to less time studying for tests because they had already learned the material as a consequence of constructing their maps. To them, the value in concept mapping was in the process of doing it, which was in contrast to the product view of mapping reported by the low-proficiency mappers. Thus, there appeared to be significant differences between the ways these two types of students responded to the use of concept mapping. Interview results support the notion that high-proficiency mappers appeared more willing than low-proficiency mappers to put time and effort into concept mapping. One of the reasons for this increased willingness might have resided in the fact that most high-proficiency mappers attributed their enhanced test performance to using concept mapping. It is also possible that, for at least some students, concept mapping was a learning strategy that just did not feel as comfortable to use as other strategies.

The implications of these findings suggest that while concept mapping appears to be an effective learning strategy, it is so only for students who opt to use it in lieu of, or at least in addition to, learning strategies that have worked for them in the past. Thus, these findings are supportive of expectancy-value theory (Wigfield & Eccles, 1992), particularly with respect to the level of attainment value, intrinsic interest value, and extrinsic utility they perceived concept mapping provided them in achieving their learning goals. Hence, a perceived low self-efficacy, together with a low perceived value with respect to successfully using a metacognitive learning strategy that promotes a more meaningful approach to learning, may have been responsible for low-mapping-proficiency students' reticence in becoming proficient in using concept mapping to learn biology. However, the more important implication is that unless teachers begin encouraging students to take a more meaningful approach to learning (i.e.,learning for understanding instead of just memorization) in the earlier grades, many of them will, in all likelihood, have difficulty in adopting strategies like concept mapping which promote meaningful learning when they enter higher grades.

Differences in Students' Decision to Learn Meaningfully

Concept mapping requires a lot of time and effort. This is particularly the case the more elaborate a student's map is. It is here that perhaps an explanation can be offered for the disparity of map and test scores between students. If a student is unwilling to put in the time, they will not produce highly meaningful maps. This would particularly be the case for students who, over the years, have adopted a rote-learning approach. Unfortunately, this may be a consequence of a more rote-learning approach typical of classroom practices in most United States schools (Stigler & Hiebert, 1999). As such, the fact that many students adopt a more rote-learning approach is an indictment of the educational system rather than individual students' choice not to learn meaningfully. With the current emphasis in the United States on mastering content, teachers are pressed into "teaching towards the test" and assessing for quantitative accretion of material. This necessitates "covering the curriculum" rather than providing learners with opportunities to construct meaning (which typically takes more time) and develop a more qualitative conceptual understanding. Thus, the educational practices in many, if not most, classrooms in the United States tend to foster knowledge acquisition (a rote learning approach) over understanding (a meaningful learning approach). In so doing, it most likely reduces students' ability to self-regulate their learning. Concept mapping does anything but encourage a rote-learning approach. As such, it requires a lot of deep reflection and thinking about the real meaning of a concept and its relationship to others.

The results of this study concur with Novak's (1998) assertion that meaningful learning occurs only if the learner chooses to do so. Therefore, teachers simply requiring their students to use concept mapping to learn more meaningfully is not sufficient to ensure more meaningful learning. Hence, if learning meaningfully requires utilizing a specific learning strategy, learners need to be willing to adopt alternative strategies, as well as be motivated and interested in using them. The findings of this study suggest that for concept mapping to be an effective learning strategy, students need to "buy into using it." Becoming proficient in mapping concepts requires a lot of time and effort. Unless students perceive that it is worth investing that extra time and effort, they will not develop proficiency and experience deeper conceptual understanding that can lead to enhancing their test performance. To see this change in their students, teachers need to play an active role in fostering a more meaningful approach to learning.

Should Concept Mapping be Used to Enhance the Learning of Biology?

The findings of this study suggest that concept mapping may provide the instructor with an epistemological "window" to see what students know in order to assess the learning demand (i.e., to appraise the difference between students' everyday understanding of a concept, expressed in their own language, relative to the accepted scientific meaning) (Leach & Scott, 1995, 2002) and then determine the appropriate constructive feedback to enable students to bridge the gap between what they know and what the instructor would like them to know. As such, concept mapping can be used to implement a differentiated learning approach for students. Differentiated learning has recently become an important educational initiative of schools in the United States. Central to providing differentiated instruction is identifying students' level of understanding. Concept mapping presents itself as a means to provide teachers of biology with a mechanism to know what students know and thus afford them opportunities to provide differentiated instruction through the feedback on the progress of their concept maps. Thus, the ongoing and constructive feedback provided to students on the progress of their concept maps offers students the necessary scaffolding to aid in developing deeper levels of conceptual understanding.

The conclusions drawn from this study suggest that becoming proficient in concept mapping can potentially lead to higher levels of self-efficacy and self-regulation, both of which can produce higher levels of motivation to learn. Hence, using concept mapping in the manner described in this study may provide biology teachers with one strategy for incorporating Zimmerman, Bonner, & Kovach's (1996) self-regulated learning model into classroom instruction by providing teachers with the means for (1) assessing and evaluating students' current level of understanding, (2) breaking down learning tasks into separate goals, (3) choosing and implementing specific learning strategies to allow students to achieve those goals, and (4) monitoring the progress of students' work to attain higher performance outcomes.

Furthermore, as a result of the above, concept mapping can serve as an effective learning strategy to create the conditions (Gunstone & Mitchell, 1998), and provide effective metacognitive feedback (Georghiades, 2000, 2004), necessary to foster conceptual change learning by providing students with opportunities to recognize their conceptions or misconceptions, evaluate the validity of these, and reconstruct them in ways that produce more suitable and meaningful conceptions that are consistent with their actual experience. However, the caveat to observing the effectiveness of concept mapping in promoting deeper conceptual understanding is encouraging learners to perceive the value of expending the time and effort required to become sufficiently proficient in the use of the technique.

Summary

The qualitative and quantitative findings of this study suggest a mixed response by learners to being motivated to take a more meaningful approach in learning biology using concept mapping. On the one hand, amongst high-proficiency concept mappers, the findings imply a supportive role of concept mapping in leading to deeper conceptual understanding and enhanced test performance, as well as significant adaptive fall-to-spring changes in motivational and learning strategy use profiles. Together, these changes contribute to producing a more meaningful approach to learning. Nonetheless, amongst low-proficiency concept mappers, the findings also implicate concept mapping in contributing to significant maladaptive fall-to-spring changes in motivational and learning strategy use profiles. Thus, the findings of this study suggest that this dichotomous relationship may be a consequence of whether learners' perceive that concept mapping can provide them with a more effective learning strategy than those already in their possession, as well as whether they are willing to put in the requisite time and effort to develop proficiency in using it to take a more self-regulated and meaningful approach to their learning. Concept mapping appears to benefit most of those learners who perceive a high incentive or task value, as well as a high level of expectancy of receiving positive results from investing the time and effort in using it effectively. The disparity in results obtained in this study with respect to differential success with concept mapping might best be explained by the tenets of expectancy/value theory. The results support the notion that metacognitive learning strategies like concept mapping are effective in promoting learning only to the extent to which students view them as such. Therefore, while the literature is replete with studies to substantiate that concept mapping is an effective learning strategy to enhance conceptual understanding and contribute towards a more meaningful approach to learning biology, this study provides evidence that this is the case only in so far as students believe it can provide them with a more effective way to learn, above and beyond other techniques they have used to facilitate success in the past. It therefore behooves the educator interested in using concept mapping to encourage learners to perceive the value of expending the time and effort required to become sufficiently proficient in its use.

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