Literature Review of Teaching Strategies for College Level Chemistry

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Introduction

Chemical concepts confuse many students due to their abstract nature. Additionally, it is difficult for students to visualize and relate to chemical principles. The rigor of strict memorization of facts and formulas also turns many students away from science based subjects. It is important to consider how chemistry educators can employ diverse strategies in order to help students gain meaningful insight and develop enthusiasm for the science field. Upon review of relevant literature, it was determined that the most discussed teaching strategies for chemical instruction were metacognition, metaphorical constructional adjuncts, and inquiry based learning.

Metacognition

Cook, Kennedy, and McGuire (2013) explained that metacognition falls under the constructive perspective teaching style which holds that students must remain actively engaged in the learning process, and that students shall not be reduced to the terms of passive, receivers of information. While adjusting teaching practices in order to better fit the needs of students can improve student performance in a particular class, the metacognitive perspective suggests students benefit more from being taught how to better learn the material themselves so that they can apply these strategies to every class. The metacognitive perspective dictates that students should be given the tools that they need in order to learn and develop meaningful skills such as retaining information, applying information, and creatively solving problems. Metacognition can be defined as an introspective cognitive process guiding one's learning. Implementing the metacognitive approach in chemistry classes has the potential to improve students' competencies in regards to complex problem solving.

In a 2013 study conducted by Cook, Kennedy, and McGuire, it was considered whether General Chemistry students would improve their performance after being taught metacognitive learning skills. This study was conducted due to the increasing rate of attrition exhibited in LSU undergraduate chemistry classes. In their study, 700 Louisiana State University science majors enrolled in General Chemistry participated. After the first exam, students who attended class were lectured for 50 minutes on metacognitive strategies. This lecture discussed topics such as paraphrasing and rewriting notes, working homework problems through without using an example, previewing materials, studying productively in groups, pretending to teach information, and integrating new material into past knowledge. This lecture also discussed the Study Cycle or the plan-attend-learn-review-study (PALRS) model. Cook et al. found when considering the final grades of all the students enrolled in that particular General Chemistry course, those who attended the metacognition lecture averaged a full letter grade higher than those who were absent. This study shows that teaching chemistry students how to better learn, retain, and apply knowledge improves their performance.

Another study considered the notion of how metacognitive learning skills impact performance in a classroom domain. This study conducted by Zhao, Wardeska, McGuire, and Cook, (2013) explored the effect of integrating metacognition principles into the General Chemistry classroom setting. For their study, a General Chemistry course at a large, public, and research-intensive university was chosen. At the beginning of the course, students were surveyed regarding their current learning strategies, and they were asked to set well defined goals for themselves in regards to their chemistry education. Classroom intervention first occurred following the return of the first exam. Metacognition strategies and the Study Cycle were taught in this class for the duration of two full semesters (General Chemistry I and II) in addition to the traditional related classroom topics. Students were reminded about metacognitive strategies before and after each exam. Although the same exams were not given to students every year, the teachers developed a system of rating test questions so that each year's students would receive tests containing the same frequency of easy, moderately difficult, and challenging questions. When comparing students from the metacognition group and students from the previous year (who received no metacognition instruction), researchers found that student performance among the two groups for the first exam was comparable. Further, the mean exam scores for the students from the year not exposed to metacognition instruction exhibited a sharp decrease in performance after the third exam. The mean scores of the students exposed to metacognition instruction reflected an increasing trend after the first exam which continued until the last exam. These findings indicate that it is possible to integrate metacognition topics in the classroom environment successfully in order to improve students' performance.

Rickey and Stacy (2000) analyzed the importance of metacognition in regards to teaching and learning chemistry. They suggested that there are four principle facets of metacognition: descriptive and declarative knowledge of one's own mental processes, the ability to monitor one's own thinking and understanding, and the ability to regulate that thinking as well as the flexibility and inclination to apply those practices to solving problems. In their work, Rickey and Stacy suggested metacognition is central to helping students to develop their learning skills because it provides them with more transferrable and dynamic knowledge banks from which to draw ideas. Further, they argued students unaware of their own cognitive processes were unlikely to recognize when their ideas are unproductive, and these students often struggled when they come across contradictions within data and observations. In this regard, Rickey and Stacey proposed students with heightened metacognitive abilities were better able to recognize inaccurate thinking directions and consider alternative paths. For teaching purposes, Rickey and Stacy stated the most effective and productive metacognitive strategies are taught within specific domains. They suggest that chemistry educators use concept maps, Predict-Observe-Explain (POE) tasks, and Model-Observe-Reflect-Explain (MORE) thinking frames as instructional tools. This research is relevant because it suggested specific instructional tools which could be used and integrated into a wide variety of chemistry classrooms. As exhibited thus far, the metacognitive approach is advantageous due to its flexibility of use in the classroom. Cook et al. (2013) demonstrated the success of metacognition taught as a brief lecture, as Zhao et al. (2013) showed that metacognition could be useful when taught in conjunction with traditional lecture. Rickey and Stacey (2000) affirmed the idea that metacognition could be integrated into primarily lecture based classrooms, and they suggested specific tactics for teaching chemically domain specific metacognitive skills.

Siburt, Bissell, and Macphail (2011) studied the effects of a domain specific metacognitive teaching style. First developed at Duke University, the problem manipulation method, or PM, is a teaching tactic which forces students to change standard problems in order to better analyze their understanding of a particular concept. Siburt et al. (2011) claimed that students would be able to achieve higher levels of conceptual understanding of chemical concepts when they considered problems from multiple perspectives. In a second semester General Chemistry course, certain sections were taught using PM recitations and others were taught in traditional lecture style. Within each recitation, students were put in small groups and asked to explore and manipulate problems. Participation and discussion was encouraged by awarding points, and a teacher’s assistant facilitated the conversation and answered any questions. Problem manipulation was assigned to students individually pre-class and post-class as well as to groups of students during class. The process involved the instructor providing an initial problem, and the students were asked to identify what the problem was asking. Then, students would define in words what strategies they would utilize to solve the problem, and they would solve the problem. Next, students would manipulate the original problem and construct a new problem around the same concept. Finally, they would solve the new problem and evaluate how the two problems were conceptually linked.

Siburt et al. (2011) found among students that were taught using the PM recitations and traditional lectures, there was no significant difference in final exam scores. However, since the study only compared final exam scores, it is impossible to know how the PM method influenced student achievement down the road. As metacognition is theorized to instill a deeper understanding of concepts and improve problem solving tactics, it is possible that the students taught using PM recitations were able to outperform the other students in further chemistry courses. Additionally the students taught using PM recitations in this study were also surveyed. The surveys revealed that 87% of these students preferred being instructed using PM recitations as opposed to traditional lectures. Further, 88% of the students claimed that they would prefer to be taught using PM recitations in the future, and 80% of these students responded that every component of the recitation style was helpful. This study gives evidence that metacognitive teaching in chemistry can improve students’ attitudes toward chemistry instruction, and their chemistry education. Students are more likely to stick with a particular subject when they feel as though they are engaged in their learning, and they enjoy the way that the particular subject is presented. Thus, it is possible that metacognitive teaching may have the potential to decrease the attrition rate among chemistry students.

Literature investigation into applications of metacognitive teaching practices in chemical domains revealed a favorable relationship. In a study conducted by Cook et al. (2013) it was discovered that students who attended a lecture on metacognitive strategies, including the learning cycle, outperformed students who missed the lecture by an entire letter grade in regards to final grades for that class. In another study by Zhao et al. (2013) it was found that students who were taught metacognition in the classroom, performed better on the last exam as opposed to students who were taught using traditional lecture. Rickey and Stacey's (2000) suggested that metacognitive, domain-specific, teaching could improve students' abilities to problem solve and determine when their course of thinking must be modified. Siburt et al. (2011) found students taught using the problem manipulation metacognitive style formed mostly positive attitudes regarding their instruction and learning. While Siburt et al. (2011) did not determine a discrepancy between academic achievements of the two groups of students, this result could potentially be explained by Zhao et al.'s (2013) findings. Zhao et al. (2013) discovered that students taught using metacognitive strategies in the classroom performed similarly to the students taught with traditional lectures during the first two exams. It was not until the third exam that students in the metacognitive group started to outperform students in the traditional lecture group. Thus, in regards to Siburt et al.'s (2011) results, it is possible that the inability to evaluate student performance further resulted in the missing positive correlation between metacognition and academic achievement. Overall, metacognition has been presented as a flexible teaching style to incorporate into classrooms and a productive source of students' improved academic achievements and attitudes toward chemical instruction.

Constructional Adjunct: Metaphors

A constructional adjunct is an instructional tool which can facilitate student development of connections and application of complex topics (Stroud & Schwartz, 2010). The most common constructional adjunct used widespread throughout DePaul University's chemistry curriculums are online homework modules. According to Stroud and Shwart'z (2010) work, proponents of instructional adjuncts believe that they have the power to enhance students' comprehension of taught material in comparison to text alone. Metaphors have been studied as instructional adjuncts due to their ability to increase comprehension of discussed material. It is believed that metaphors prime learners for particular features of an idea, thus they can be used as tools for building understanding. Another realm of thought, considers that metaphors can be used as syntactical gap fillers in terms of events and ideas, thus they can improve understanding of unstructured concepts.

In a study conducted by Stroud and Schwartz (2010), the role of metaphors and graphics as tools to enhance students' learning of complex topics was investigated. Stroud and Shwartz suggested that students struggle learning chemistry due to the abstract nature of certain concepts which can also be hard to visualize. Traditional style lectures develop students' verbal processing, but they do not stimulate visual processing or encoding to the same degree. Thus, they explained that metaphorical graphics have the potential to help learners recall information better by forming new connections in their schema for a particular topic. In their experiment, students enrolled in a midsized United States university participated. This experiment tested the effect that metaphorical graphics had on students' recognition of elements' properties. Students in the metaphorical graphic group were shown representations of each element as a person conveyed information regarding the reactivity and behavior of each element. Stroud and Schwartz found that metaphorical graphics helped students develop better understanding of elements' behavior and reactivity. Students who were shown metaphorical graphics were also better able to answer inference questions regarding the characteristics of the elements which they were shown. This experiment demonstrated that metaphorical graphics have the ability to act as a constructional adjunct for teaching chemistry.

Metaphors have been studied widely as teaching aids, and Stroud and Schwartz (2010) showed that metaphorical graphics had the power to deliver information regarding chemical concepts. Further work by Diehl and Reese (2010) explored how metaphors could function to help learners establish a better frame of reference in order to attain useful knowledge regarding targeted concepts. In their study, Diehl and Reese (2010) constructed elaborated metaphors in order to instill a clear relationship between the target concepts and the metaphor. It was hypothesized that these types of metaphors would help chemistry learners to make inferences. During Diehl and Reese's (2010) study participants were split into two groups – an elaborated metaphor group and a verbal teaching group. All participants were taught stoichiometry. Then, learners were asked to report all that they could think of related to a similar concept not directly discussed. The categories of similar concepts included: low-level, medium-level and high-level thinking. The results showed that participants in the elaborated metaphor group performed similarly to the participants in the verbal teaching group in low-level concepts. It was also found that those in the elaborated metaphor group, outperformed those in the verbal teaching group in medium-level and high-level thinking categories. This study provided evidence which suggested that metaphors, when elaborated upon, can be used as instructional aids to facilitate learning and acquisition of higher level thinking inferences.

As Stroud and Schwartz (2010), and Diehl and Reese (2010), have demonstrated that metaphorical graphics and metaphors have the ability to assist students in their learning of chemical concepts, other literature concerning metaphors as instructional adjuncts suggests that metaphors also have the potential to help students develop metacognitive skills. In Gregory and McRobbie's study (1999), they sought to determine whether high school students' chemical metaphors were congruent with their attitudes and opinions regarding their own learning process. Gregory and McRobbie (1999) argued metaphors have the potential to reveal invaluable information concerning students' metacognitions because of their ability to act as a common language concerning conceptual chemical concepts and learning. Thus, in this study, metaphors are considered for their ability to increase students' awareness and communication of their learning strategies for ascertaining chemical principles, not for their ability to increase students' comprehension of chemical concepts. The students were given a metaphor task in which they were asked to select one image from four and explain why this selection was made. Gregory and McRobbie (1999) found that it was possible for students to utilize metaphors in order to describe their learning of chemical concepts. The metaphors selected by the students revealed that metaphors have the potential to transcend linguistic expressions and instill the development of ontological maps across subjects. This study verified that metaphors play a role in establishing a relationship between a students' understanding of chemical concepts and their attitudes toward their own learning and metacognition. Although this study considered high school students, it is relevant due to its unique perspective and consideration for the relationship between metacognition and constructional adjunct metaphors.

As discussed through literature, metaphors have the ability to act as constructional adjuncts due to their ability to improve students' understandings of discussed topics and their own learning and metacognition. In 2010, Stroud and Schwartz showed how metaphorical graphics could help students infer deeper meaning in regards to elements' behavior and properties. Diehl and Reese (2010) revealed that students who were shown elaborated metaphors reflected better performance in higher level thinking inferences. Moreover, Gregory and McRobbie (1999) documented the relationship between metaphors as constructional adjuncts and metacognition. Although metaphors are not popularly discussed, work surrounding their use as constructional adjuncts revealed encouraging conclusions. However, it is important to note that metaphors in this regard should not be considered as encompassing teaching approaches. Rather, their use should be assessed within the scope of a particular teaching style. This feature gives chemical metaphors the flexibility to be applied in conjunction to any other teaching approach or style.

Inquiry Based Learning

Khan, Hussain, Ali, Majoka, and Ramzan (2011) presented the inquiry based learning perspective as a belief that traditional teaching practices (lectures, power-points etc.) are teacher-centered not student-centered. They explained that teachers have the obligation to support students' learning not direct it. They proposed an inquiry based learning curriculum which aimed to develop higher order thinking and practical skills by allowing students to act as practitioners, or problem solvers.

A study conducted by Khan et al. (2011) sought to determine how an inquiry based learning curriculum would affect students' academic achievements. Their study compared 10^{th} grade students who had chosen chemistry as an elective. The students were separated into two groups, the control group was taught traditionally with no inquiry based instruction and the experimental group was taught using inquiry based instruction techniques. The injury based instruction focused on developing problem solving skills and applying concepts discussed to the real world. The results of Khan et al.'s study indicated that there was no significant difference among the groups in regards to previous academic achievements in chemistry. However, post-class testing indicated that the students who were taught using inquiry based instruction reflected significantly higher academic achievement than those students who were taught using traditional methods. This study indicated that inquiry based instruction has the potential to improve students' learning in the domain of chemistry. While this article is geared more towards high school chemistry, it raises the implication that these instruction tactics could also be beneficial in regards to chemistry at the university level.

In fact, Walker, Sampson, Grooms, Anderson, and Zimmerman (2012) conducted a study which considered what effects an argument-driven inquiry based teaching style might have in undergraduate General Chemistry Lab courses. Walker et al. suggested that argumentation has the potential to enhance students' learning in scientific domains due to its utilization of scientific reasoning and its development of conceptual understanding. Their goal for argument-driven inquiry based teaching was to allow students to design their own methods for organizing, acquiring, and analyzing data. Argument-driven inquiry based teaching was applied in one section of General Chemistry Lab at a large community college while the other sections were taught using traditional instruction. After a year of General Chemistry Lab instruction, it was found that the students who were taught using argument-driven inquiry based learning showed no significant difference in regards to their conceptual understand as compared to students taught using traditional methods. However, it was found that those in the argument-driven inquiry learning group showed greater ability to use evidence to support conclusions than those in the traditional learning group. Students in the argument-driven inquiry learning group also reflected better attitudes towards science than those in the traditional learning group. In this particular case, it was possible that the nature of the course being a lab contributed in the lack of disparity in regards to achievement between control and experimental groups. In comparison to lecture courses, lab courses typically cover fewer conceptual concepts and focus more on implementation and description of chemical processes. These results do suggest that argument-driven inquiry style teaching has the potential to improve students' reasoning skills and foster greater interest in students' perceptions of chemical subject matter.

Another study conducted by Ferrel, Moog, and Spencer (1999) demonstrated an effective approach for applying guided inquiry style teaching within the context of General Chemistry. Ferrel et al. studied students enrolled in General Chemistry at Franklin and Marshall College, a small private institution. The goal of their approach was to encourage active engagement in learning and facilitate a student-focused environment. They divided their students into small sections, at no more than 25 students per section, and taught their classes within flexible rooms which were capable of hosting labs and lectures. During the course of the two semesters of General Chemistry, there were no lectures given. Rather, students were divided into groups during each class period and assigned roles within those groups. The students took turns being the manager, recorder, technician, reflector, and presenter of their group. Together, they would complete a worksheet which asked them critical thinking, application, or data modeling questions. Groups were used to model the learning cycle in a cooperative and collaborative manner. Prior to each class period, students were given a brief quiz regarding the instruction of the previous lesson. It was discovered that classes taught using the guided inquiry based teaching style reflected lower withdrawal rates, and showed a lower percentage of student failures. Furthermore, post-course questionnaires revealed that students taught using the inquiry based approach had adopted an extremely positive attitude towards the approach itself. This study shows how inquiry based teaching has the potential to be beneficial to chemistry students.

A similar study conducted by Hanson and Wolfskill (2000) further affirmed the benefits of the inquiry based learning approach, but also proposed a method for integrating this approach into lecture-based classrooms. At Stony Brook University, chemistry teachers became concerned with the lack of engagement demonstrated by students in regards to their course work, and the difficulty students faced when trying to apply concepts in order to solve problems. Thus, a new model for instruction founded on the “Process Workshop Classroom” principle was applied to General Chemistry courses. The process within their model meant that students must be actively engaged in their learning through the use of critical thinking and problem solving within student-managed teams which investigate concepts through a guided discovery. The workshop aspect of their model suggests that the teams will learn together through their completion of given tasks, or active agents. When this model was applied, classes held no more than 40 students, and within each class, students were divided into learning teams of three or four students. After each class, students were given a take home quiz to complete which was designed to reinforce the material covered in class. The goal of this teaching style was to help students develop processing skills while mastering the subject content. Implementation of this teaching style at Stony Brook showed tremendous success. Researchers found that after the Process Workshop Classroom model was applied, student attendance increased significantly. Further, student course evaluations found that a significant amount of students claimed that participation in the workshops increased their interest in chemistry as well as their confidence in regards to learning and studying chemistry. The exams reflected these trends, as the scores of students who participated in the workshops marked an increasing shift among previously high-scoring and low-scoring students. Finally, enrollment in second year, Organic Chemistry, courses increased among students who participated in the workshops.

Hanson and Wolfskill's model (2000) was most interesting due to their suggestions in regards to integrating an inquiry based model into a traditional lecture classroom. They suggested that process workshops have the ability to replace lectures gradually. As typical chemistry courses are held multiple times during one week, they suggested that a process workshop can initially replace one lecture and so on. Still, Hanson and Wolfskill (200) do assert that lectures are not necessary in conjunction to the process workshops. They state that lectures are most effective in facilitating students' learning only when they are short, straightforward, and presented on an as needed basis during the workshops. Stony Brook University demonstrated so much success with this approach, that they further utilized it in higher level undergraduate and graduate courses. Hanson and Wolfskill's (2000) research provides encouraging evidence that an inquiry based learning approach can be smoothly integrated into a traditional classroom setting to better improve students' relationships with learning chemistry.

Literature investigation of the inquiry based learning approach demonstrated a positive correlation between inquiry based learning and students' chemistry success. In 2011 Khan et al. showed that an inquiry based learning curriculum has the potential to increase academic achievement among high school chemistry students. In 2012 Walker et al. showed that argument-driven inquiry based teaching style in college level General Chemistry Laboratory had the potential to increase students' abilities to utilize information in order to support conclusions and improve students' attitudes toward the subject. Ferrel et al. (1999) further illustrated in that inquiry based learning had the ability to significantly improve students' perceptions of chemistry learning in the context of General Chemistry. They also discovered that this approach decreased withdrawal. Finally, in 2000 Hanson and Wolfskill showed that the inquiry based learning method in General Chemistry was able to increase exam performance among previously low-scoring and high-scoring students as well as increase enrollment among second year chemistry courses. Hanson and Wolfskill also provided a methodology for the integration of an inquiry based teaching style within the context of a traditional teaching environment.

Discussion

It is vital to assess potential ways in which educators can better reach students struggling with chemical concepts. Cook et al. (2013) suggested that due to the inherently abstract, or seemingly unstructured, character of many chemical concepts, students often find great difficulty trying to relate and understand. They further explained the heavy reliance on strict memorization of facts and formulas deters pupils from continuing down a science path. As our society becomes more and more obsessed with technological and mechanical advances, the demand for scientists and engineers grows accordingly. Thus, it is important to discuss ways in which teaching chemistry may be improved, so the rates of attrition decrease.

Literature research revealed three distinct approaches in regards to chemical education which demonstrated the potential to positively impact chemistry curriculum. As previously disused, the metacognition perspective of teaching suggests that students learn better when first taught strategies to facilitate cognitive introspection. Additionally, the literature considered for metaphors as constructional adjuncts revealed that metaphors have the ability to prime chemical concepts and convey chemical meaning through the establishment of analogous relationships. Lastly, the inquiry based learning style has revealed that it has the potential to improve academic achievement by focusing on the students and their abilities to function as active, participatory, problem solvers and facilitate their own learning. Both metacognition and the inquiry based learning style hold the opinion that typical lectures alone can be ineffective because they are typically teacher oriented and not student centered. Metacognition and inquiry based learning suggest that students learn most effectively when they are actively engaged, and self-aware of their learning approaches. While metacognition focuses on student-reflection, inquiry based learning utilizes reflection as a sub-section within the problem solving framework. Literature suggested methods in which metacognition, and inquiry based teaching, could be integrated into typical lecture Hanson and Wolfskill (2000) proposed a model to integrate inquiry based learning into traditional lecture style classrooms as Rickey and Stacy (2000) suggested practices to integrate metacognitive teaching into a traditional classroom. Metacognition and inquiry based teaching were the most well supported styles discussed.

Of the teaching strategies, the inquiry based learning approach and metacognition were the most clearly documented and discussed in literature. Additionally, Stroud and Schwartz (2010) demonstrated that the principles associated with metacognition and metaphorical constructional adjuncts have the ability to be integrated into an unique and effective teaching style. It is recommended more research consider how successful the inquiry based learning approach might be if it were combined with a metacognitive principles or metaphorical constructional adjuncts. On the other hand, research revealed that metacognition and metaphors as constructional adjuncts have the potential to be utilized together. Gregory and McRobbie's study (1999) illustrated metaphorical constructional adjuncts have the versatile potential to be utilized as tools in the development of metacognitive strategies. It is also advised that more research be done to consider how integrating all of these teaching styles together may influence academic performance. Teaching chemistry is both an honor and a challenge, and it is vital to continue exploration in chemical teaching strategies in order to provide students with the newest and most effective aids to their learning.

References

Cook, E., Kennedy E., & McGuire, S. Y. (2013). The Effect of Teaching Metacognitive Learning Strategies on Performance in General Chemistry Courses. *Journal of Chemical Education*, 90, 961- 967.

Diehl, V. & Reese, D.D. (2010). Elaborated Metaphors Support Viable Inferences About Difficult Science Concepts. *Educational Psychology: An International Journal of Experimental Educational Psychology*, 30, 7, 771-791.

Farrel, J. J., Moog, R. S., & Spencer, J. N. (1999). A Guided Inquiry General Chemistry Course. *Journal of Chemical Education,* 76, 4, 570-574.

Hanson, D., & Wolfskill, T. (2000). Process Workshops- A New Model for Instruction. *Journal of Chemical Education*, 77, 1, 120-130.

Khan, S. M., Hussain, S., Ali, R., Majoka, I. M., & Ramzan, M. (2011). Effect of Inquiry Method on Achievement of Students in Chemistry at Secondary Level. *International Journal of Academic Research*, 3, 955-959.

Rickey, D. & Stacey, A. M. (2000). The Role of Metacognition in Learning Chemistry. *Journal of Chemical Education*, 77, 7, 915-920.

Siburt, C. J., Bissel, A. N., & Macphail, R. A. (2011) Developing Metacognitive and Problem Solving Skills Through Problem Manipulation. *Journal of Chemical Education*, 88, 1489-1495.

Stroud, M. J., & Schwartz, N. H. (2010) Summoning Prior Knowledge Through Metaphorical Graphics: An Example in Chemistry Instruction. *Journal of Education Research,* 103, 5, 351-365.

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

Zhao, N., Wardeska, J. G., McGuire, S. Y., & Cook, E. (2013). Metacognition: An Effective Tool to Promote Success in College Science Learning. *Journal of College Science Teaching,* 43, 4, 48-54.