Metacognition: An Effective Tool to Promote Success in College Science Learning

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Metacognition has been shown to lead to deeper, more durable, and more transferable learning (Bransford, Brown, & Cocking, 2000). This article describes a case study in which metacognition was introduced to undergraduate science (chemistry) classrooms. Students came to understand the difference between superficial memorization and real learning through specific classroom interventions, which were also designed to help students develop metacognitive learning strategies. The aim of the study was to instruct educators how to incorporate metacognition in college science classrooms, and the improved cognitive and affective learning of students indicated its significance. On the basis of students' reflections, we assert that implementation of these strategies will contribute to increased learning not just in chemistry but also across other courses and curricula.

The constructivist theory of learning (Bodner, 1986, 2001) posits that students construct knowledge from their own experiences. Knowledge construction includes cognitive learning, acquisition of content knowledge, and the ability to apply that knowledge to new situations (Bretz, 2001). In order to engage in constructivist learning, students must possess the necessary learning strategies, but not all do. In addition to the cognitive domain, real learning also includes the affective and metacognitive domains (Vermunt & Verloop, 1999). The affective learning domain comprises a student's attitude about learning, willingness to actively engage in learning activities, and skill in evaluating his own ability and performance in a subject area. In 1976, Flavell defined metacognition as "knowledge concerning one's own cognitive processes and products or anything related to them" (Flavell, 1976, p. 232). Often metacognition is described as "thinking about one's own thinking" (Cooper & Sandi-Urena, 2009, p. 240) and "monitoring and controlling one's mental processing" (Rickey & Stacy, 2000, p. 915).

In the classroom setting, metacognitive learning demands that students develop a plan for learning the content, monitor their learning process through reflection, and adjust their plan accordingly ("self-regulate") in order to ensure deeper, more durable, and more transferable learning (Francisco, Nicoll, & Trautmann, 1998; Schraw, Brooks, & Crippen, 2005; Tsai, 2001). Our consultations with students have suggested it is crucial to introduce them to metacognitive learning strategies, thereby giving them the opportunity to self-regulate (Hoffmann & McGuire, 2009). Our findings apply especially to students who come to college with few time-management or learning skills (Robbins et al., 2004; Tai, Sadler, & Loehr, 2005). In this article, we do not present the full scope of the philosophy underlying metacognition; instead, we aim to instruct educators how to make college students aware of the gap between superficial and real learning and how to help them develop effective learning strategies through metacognition. We begin by presenting the surveys used to gauge students' effective use of learning strategies prior to and after the classroom intervention. We then describe the intervention and discuss its impact on student performance and how it changed students' perceptions of themselves as skilled learners. We conclude by presenting the limitations of the study and implications for future research.

Instruments

Table 1 shows the Effective Learning Strategies Survey. The questions in the survey appear in a specific order designed to prepare students for the intervention to follow. The first two questions help students differentiate among the various levels of intellectual behavior according to the revised Bloom's taxonomy (Anderson & Krathwohl, 2001), in which each level builds on the foundation that precedes it. Although traditionally Remembering and Understanding might be adequate for high school, higher levels of learning (e.g., Applying and Analyzing) are required in college and Evaluating and Creating are critical skills for graduate school (Bereiter & Scardamalia, 2005; Biggs, 1999; Louisiana State University Center for Academic Success, 2013). Statements 3–12 correspond to the learning strategies we suggest to students during the intervention. These strategies constitute the stages of the Study Cycle (Christ, 1998). Each statement targets active participation in class, absorption of material, and self-assessment outside class (Hoffmann & McGuire, 2009, 2010). Statements 3–6 appear rather straightforward: Come to class prepared by previewing materials, arrive on time, take notes by hand, and review those notes after each class. Statement 7 corresponds to the introduction of the Intense Study Session (ISS), the core of the Study Cycle. The student begins the ISS by setting specific, well-defined goals, followed by 30–50 minutes of intense learning activities such as actively reading the textbook; working on problems; and creating supplemental materials like flash cards, concept maps, and outlines. After a short break (~10 minutes), the student is encouraged to spend another 5 minutes reviewing what he or she has just studied. The ISS should be repeated often, and students should also undertake weekly reviews of the course content. Statement 8 corresponds to the recommendation that students join study groups outside the classroom (Bowen, 2000). During the intervention, it is recommended to students that they not just ask questions but also answer other students' questions. Peer-teaching experience has been repeatedly shown to lead to deeper understanding (Gosser, Kampmeier, & Varma-Nelson, 2010). During the intervention we also suggest that students engage in real time learning, continuously monitor their thinking, and try to tease out any confusion (S9–S10) in class or while applying the Study Cycle. We advise students that when they are doing homework problems, they should study the text and lecture information before solving the relevant problems and without referring to the solved examples (S11). To test their levels of learning, students are advised to take "self-exams" (S12). They are explicitly taught that both the correct procedure (instead of the answer alone) and the ability to work a problem without using an example are essential for good performance on exams.

In order for students to realize the required levels of learning (S1–S2), as well as become metacognitively aware of their own engagement (S3–S6) and learning strategies (S7–S12), they were asked to complete the Effective Learning Strategies Survey (Table 1) shortly after the first exam. In addition, we used the Chemistry Self-Concept Inventory to assess students' perception of themselves as learners of chemistry (Bauer, 2005; Lewis, Shaw, Heitz, & Webster, 2009). The Chemistry Self-Concept Inventory was designed to measure students' self-concept with five distinct subscales: chemistry, mathematics, academic skill, academic enjoyment, and creativity. For each subscale students rate themselves on a scale from 1 to 7, from *very inaccurate* to *very accurate* regarding phrases that might describe themselves.

Classroom intervention

The classroom intervention was conducted in General Chemistry I (fall 2011) and II (spring 2012) courses at a large, public, research-intensive university. Both courses counted for 3-credit hours and were taught through three 55-minute lecture periods per week. The intervention was designed to help students gauge and improve their learning strategies through metacognition. The first exam was administered, graded, and returned during the 3rd week of each semester. This particular timing allowed students to gather adequate information about the demands of the course and their performance. The exam was then reviewed at the beginning of the first lecture of the 4th week. Toward the end of the lecture, each student spent 5 minutes listing the top three reasons for his or her successful or unsuccessful exam performance and approximately 15 minutes taking the

TABLE 1

Effective Learning Strategies Survey.

S1	What is the level of learning you need to make A's or B's in high school? (a) Remembering, (b) Understanding, (c) Applying, (d) Analyzing, (e) Evaluating, (f) Creating
S2	What is the level of learning you need to make A's or B's in college? (a) Remembering, (b) Understanding, (c) Applying, (d) Analyzing, (e) Evaluating, (f) Creating
S3	I preview the lecture material before I go to class.
S4	I attend class on time.
S5	I take notes in class by hand.
S6	I review my notes and textbook after each class.
S7	I study with concentrated time and specific goals.
S8	I join study groups.
S9	I understand the lecture and classroom discussions while I am taking notes.
S10	I try to determine what confuses me.
S11	I try to work out the homework problems without looking at the example problems or my notes from class.
S12	I review the textbook, lecture notes, and homework problems and do practice test before the exam.

Note: Survey scales for S3–S12: 1 = *almost never*, 2 = *sometimes*, 3 = *usually*, 4 = *always*

Effective Learning Strategies Survey and Chemistry Self-Concept Inventory. The following lecture period was devoted entirely to introducing the concepts of metacognition and the Study Cycle. Students' top three reasons—their self-reflections—were first presented to demonstrate the usefulness of the metacognitive learning strategies. During the next 15 minutes the revised Bloom's Taxonomy was applied to the story of "Goldilocks and the Three Bears" to help students understand both the distinctions between the levels of learning (Hoffmann & McGuire, 2010) and the higher levels of thinking required in college. The rest of the lecture was devoted to the concept of metacognition and its relevance to effective learning as well as the details of the Study Cycle. Throughout the remainder of both semesters, students were reminded to metacognitively monitor their learning strategies before each exam and solicited for feedback afterward. Surveys were conducted again during the last lecture of the semester. In fall 2011, the survey data were collected twice—once before the metacognition lecture (presurvey) and at the end of the course (postsurvey). Seventy-eight out of 91 students took the presurveys, and 77 out of 90 students took the postsurveys. The results from General Chemistry I in fall 2011 (discussed next) inspired the collection of paired pre- and postdata from 49 students enrolled in General

TABLE 2

Results of the Effective Learning Strategies Survey.

Questions			**Fall 2011** Pre α = 0.97 Post α = 0.97		**Spring 2012** Pre α = 0.70, Post α = 0.69			
					First-time participants		Dual participants	
			Pre (N = 78)	Post (N = 77)	Pre (N = 38)	Post (N = 38)	Pre (N = 11)	Post (N = 11)
S1	What is the level of learning you need to make A's or B's in high school?	Remembering & Understanding	87.9%	96.1%	94.7%	97.3%	100%	100%
		Applying & Analyzing	8.97%	2.60%	2.63%	2.63%	0.0%	0.0%
		Evaluating & Creating	1.28%	1.30%	2.63%	0.0%	0.0%	0.0%
S2	What is the level of learning you need to make A's or B's in college?	Remembering & Understanding	55.1%	3.90%	60.5%	21.05%	27.27%	0.0%
		Applying & Analyzing	38.5%	89.6%	31.6%	76.3%	63.6%	100%
		Evaluating & Creating	6.41%	6.49%	7.89%	2.63%	9.09%	0.0%
S3	I preview the lecture material before I go to class.		2.47	2.21	2.21	2.08	2.45	2.00
S4	I attend class on time.		3.86	3.57	3.55	3.53	3.91	3.73
S5	I take notes in class by hand.		3.77	3.48	3.53	3.55	3.55	3.55
S6	I review my notes and textbook after each class.		2.60	2.44	2.26	2.18	2.45	2.45
S7	I study chemistry with concentrated time and specific goals.		2.28	2.52	2.66	***2.92**	2.82	2.82
S8	I join study groups.		1.96	2.12	2.11	2.13	1.91	2.18
S9	I understand the lecture and classroom discussions while I am taking notes.		2.90	2.95	2.79	2.92	3.00	3.12
S10	I try to determine what confuses me.		3.58	3.66	3.45	3.58	3.73	3.82
S11	I try to work out the homework problems without looking at the example problems or my notes from class.		2.63	3.23	2.63	***3.00**	3.00	3.18
S12	I review the textbook, lecture notes, and homework problems and do the practice test before the exam.		3.44	3.56	3.39	***3.68**	3.82	3.73

Note: Red indicates a decreased tendency, blue indicates an increased tendency, and bold font highlights any significant changes.
*indicates significant difference against the presurvey at $p < .01$.

TABLE 3

Results of the Chemistry Self-Concept Inventory.

Chemistry Self-Concept Inventory	Fall 2011		Spring 2012			
			First-time participants		Dual participants	
	Pre ($N = 78$)	Post ($N = 77$)	Pre ($N = 38$)	Post ($N = 38$)	Pre ($N = 11$)	Post ($N = 11$)
Chemistry Self-Concept	4.52	4.85	4.36	4.29	4.87	4.75
Math Self-Concept	5.00	5.17	4.88	***5.10**	4.95	5.05
Academic Self-Concept	5.44	5.46	5.24	5.30	5.70	5.77
Academic Enjoyment	5.20	5.20	4.80	***5.09**	5.52	5.42
Creativity Self-Concept	4.55	4.63	4.80	4.80	4.82	4.84

Note: Red indicates a decreased tendency, blue indicates an increased tendency, and bold font highlights any significant changes.
*indicates significant difference against the presurvey at $p < .05$.

Chemistry II in spring 2012. Among them, 11 students were identified as dual participants as they were exposed to the learning strategies in both fall 2011 (taught by the first author) and then again in spring 2012 (taught by the second author).

Results and reflections

The results of the presurvey indicated that students almost unanimously agreed that only Remembering and Understanding were necessary in high school (Statement 1). Correspondingly, only 38.5% (fall 2011) and 31.6% (spring 2012) of students realized that Applying and Analyzing skills were required in college (Statement 2) in the presurvey, whereas 89.6% and 76.3% of students indicated their importance in the postsurvey, respectively. The Cronbach α coefficient values of the Effective Learning Strategies Survey were mostly above 0.7 for Statements 3–12 (Table 2), suggesting that the survey items have relatively high internal consistency.

Students provided a variety of reasons for their low performance on the first exam, and the top three reasons are summarized below:

> I studied but blanked out during [the] exam. I thought I knew it but I didn't. It made perfect sense on [the] board [during lecturing], but not when I did it [in the exam]. I couldn't figure out why I didn't know it.

> There were not examples of problems like the ones on the test. I have never seen these problems before. [There were] a few problems [that] we never introduced in class.

> You [the instructor] went through materials fast in lecture, and people answered [questions] quickly [so] I didn't follow.

These responses corresponded to information we learned during our consultations with students, indicating that they lacked metacognitive learning strategies and had a hard time judging how thoroughly they had learned.

At first, the data for Statements 3–6 seemed counterintuitive. Although the Study Cycle encouraged preparation before and engagement during the class, when compared with the presurvey, the postsurvey demonstrated a generally decreased tendency for students to apply these strategies during both semesters (Table 2 in red). A change in workload might be a reason here. As the presurvey was conducted early on in both semesters, when workloads were relatively light, students might have been overly optimistic about their time management skills. As each semester progressed, however, the workload increased, and students had less time to prepare for the class or review the material on a regular basis. These results suggest the importance of informing students of the learning expectations and requirements during the early stage of college courses and continuing to remind them of metacognitive learning strategies throughout the semester.

Interestingly, there was a generally increased interest in the application of the strategies encompassed by the next six statements (S7–S12), as illustrated by students' replies to the pre- and postsurvey (Table 2 in blue). Introduction to the Study Cycle appeared to help students incorporate some effective learning strategies and assess their chemistry learning through metacognition despite the increased workload. For the paired study in spring 2012, significant increases were shown from paired sample t-test in Statement 11: "I try to work out the homework problems without looking at the example problems or my notes from class" and Statement 12: "I review the textbook, lecture notes and homework problems, and do the practice test before the exam." These two strategies focused on the efficiency and assessment of students' learning, which might have contributed to the increased performance on the exams (discussed next). Although statistical randomness could account for the insignificant differences between the pre- and postsurveys, the same patterns of change (i.e., decreased tendency for S3–S6 and increased tendency for S7–S12) in both semesters might suggest a change in students' learning strategies.

The Chemistry Self-Concept Inventory is an effective instrument with proven reliability (Bauer, 2005). In fall 2011, the postsurvey showed higher means in almost all categories, with the largest improvement in chemistry self-concept (Table 3 in blue), suggesting that through metacognition and implementation of effective learning strategies, students became more effective and confident chemistry learners. The postsurvey in spring 2012 showed significant improvements in math self-concept and academic enjoyment from paired sample *t*-test for the first-time participants (Table 3 in blue). The intensive involvement of mathematics in General Chemistry II, such as kinetics and equilibrium calculations, might have contributed here. Again, through metacognition and effective learning strategies, students felt more confident in applying their math skills to chemistry topics. Consequently, they reported improved academic enjoyment. Somewhat surprisingly, the postsurvey in spring 2012 showed a decrease in the chemistry self-concept (Table 3 in red). Although not significant, this decrease might be related to the breadth and depth of topics involved in the full-year general chemistry courses. Considering the much more intensive study each of these topics requires, students might have realized the limits of their chemistry knowledge and/or become more critical of themselves.

FIGURE 1

Student exam performance for the fall semesters.

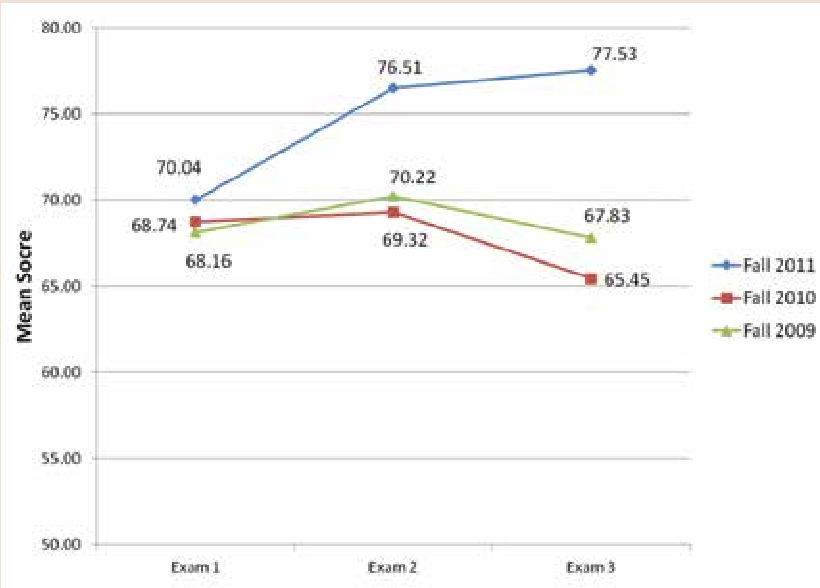
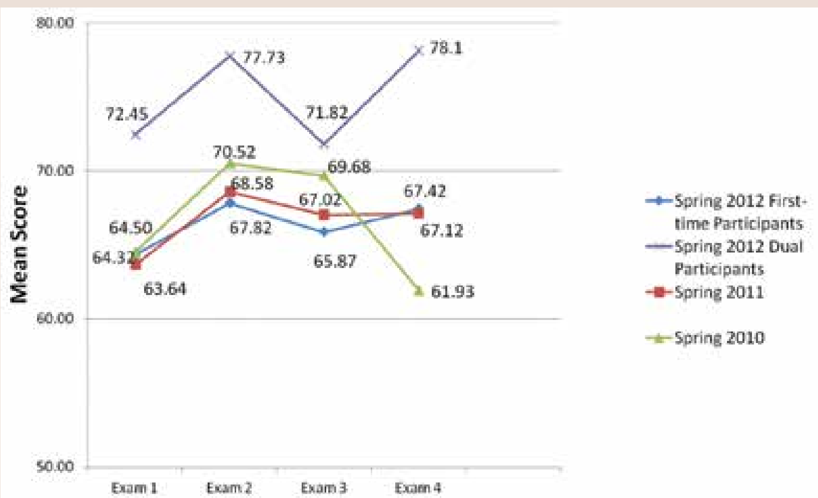


FIGURE 2

Student exam performance for the spring semesters.

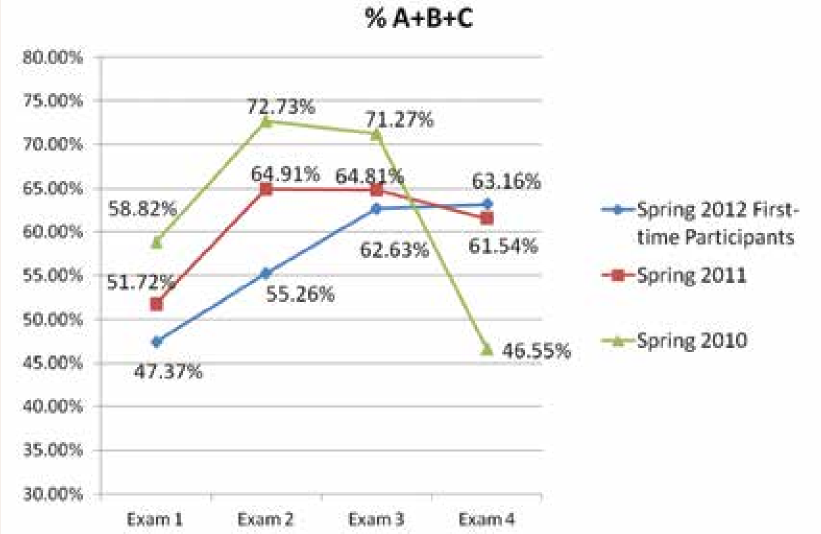


Data collected from the 11 dual participants (those who were also participants in fall 2011) in spring 2012 were analyzed separately. Not surprisingly, they had a better understanding of the required levels of learning in college, as well as generally higher means in both presurveys when compared with their peers in spring 2012, who had not learned the strategies in fall 2011. For the postsurvey of the Effective Learning Strategies Survey, they also had generally lower means for Statements 3–6 and higher means for Statements 7–12 (Table 2). For the Chemistry Self-Concept Inventory, there were similar improvements in math, academic, and creativity self-concepts, and decline in chemistry self-concept (Table 3).

The first author taught General Chemistry I in fall 2011, 2010, and 2009, and the second author taught General Chemistry II in spring 2012, 2011, and 2010 with the same curriculum and schedule. In this pilot study, comparisons were not established for equivalence of students or exams from year to year. Nevertheless, exam questions were selected from the same test bank (http://www.wileyplus.com) with already predetermined levels of difficulty for each question (i.e., easy, medium, or hard). In addition, corresponding exams were made by the same instructor with an effort to keep them comparable. For example, in General Chemistry I, the first exam always focused on elements and compounds, as well as mole and stoichiometry calculations. Of the 12 questions, there were two easy, seven medium, and three hard ones. Thus the comparison of students' performance from each year might be indicative of differences in learning. As shown in Figure 1, although the mean score for the first exam in fall 2011 was comparable to those from fall 2010 and 2009, the performance on the second and third exams was much better. The improvement might be attributed to the introduction of metacognition and the Study Cycle after the first exam. However, such improvement was less significant in spring 2012 for the first-time participants. Nevertheless, the dual participants provided the most compelling evidence of improved performance due to metacognitive awareness, as they greatly outperformed their peers in the spring for all four exams (Figure 2). Despite the lack of increased performance on exam means, the distribution of scores of the first-time participants in spring 2012 looked very different from those of the previous two springs, as shown in Figure 3. The percentiles of A, B, and C grades in spring 2012 showed an increasing trend over the exams, distinguished from the overall decreasing trends of spring 2011 and 2010. This suggests the positive impact of the application of metacognitive learning strategies.

FIGURE 3

The percentiles of A, B, and C grades for the spring semester.



Conclusions and future work

Students' voluntary responses were solicited and recorded through email after each exam. A total of 18 responses were collected in fall 2011 and 11 responses in spring 2012. All respondents agreed that the learning strategies introduced via the intervention had helped them become more effective learners, as exemplified in these responses:

> I have continued to look at the effective learning strategies you introduced to the class last week. I have been going to group tutoring sessions (offered from the University Center for Academic Achievement) and they helped tremendously . . .

> I have taken a new approach to studying by using some of your suggestions and it does seem to be helping. By prereviewing the chapter before lecture and studying the notes online, I better understand the material as you go over it . . .

> Thank you for setting aside our class time for this, because I feel that it was really informative and helpful. I identified a few problems with my own study methods, and have since made some changes as you suggested . . .

Students' responses indicated the value of the introduction of the Bloom's taxonomy, concept of metacognition, and the Study Cycle in college science classrooms. Although students appeared to have a tendency of decreased engagement as the course progressed (e.g., they spent less time previewing and reviewing), they had an increasing interest in applying the effective learning strategies during both semesters. The improved exam performance and Chemistry Self-Concept Inventory demonstrated the effectiveness of teaching students about metacognition and self-regulation. In addition, the increased performance of the dual participants in spring 2012 indicated the importance of introducing metacognition during the early stage of students' college experience and its potential to cumulatively facilitate student learning. The introduction and implementation of these strategies will likely contribute to increased learning not just in chemistry, but also across other courses and curricula (Pintrich, 2012).

The limitations of the study could also guide our future work. The dual participants might have influenced the study results by disseminating particular learning strategies outside of the study, affecting other students' performance. In addition, although the dual participants completed General Chemistry I and II in two successive semesters (fall 2011 and spring 2012), some of the first-time participants in spring 2012 might not have, which could have potentially affected their performance. As a self-reporting instrument, the Effective Learning Strategies Survey did help students reflect on the ways they learn and how they facilitate and assess their learning. However, the validity and reliability of the survey have not been tested. Because we used no control groups, the effect sizes of students' improvements could not be determined. However, adoption of standard exams could ensure the equivalency of exams from year to year and more properly measure the improvement in students' cognitive leaning. ■

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