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Textbook-Bundled Metacognitive Tools: A Study of LearnSmart's Efficacy in General Chemistry

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College textbook publishers increasingly bundle sophisticated technology-based study tools with their texts. These tools appear promising, but empirical work on their efficacy is needed. We examined whether LearnSmart, a study tool bundled with McGraw-Hill's textbook Chemistry *(Chang & Goldsby, 2013), improved learning in an undergraduate general chemistry course. Content-knowledge gains of those students who used LearnSmart, those who did not use it, and those who used it with scaffolding questions that supported use of the tool's metacognitive features were compared. The metacognitive scaffolding questions appeared to help students use LearnSmart more effectively than did using LearnSmart by itself, which did not confer learning benefits. Implications for adopting LearnSmart and similar tools are discussed.*

Students in introductory chemistry courses need to wrestle with conceptual ideas and to practice problem-solving skills outside of lecture. Online homework systems, such as those bundled with course textbooks, have become a popular means of providing such study and practice opportunities. The undisputed benefit of these tools is the time and labor saved on assignment delivery, student feedback, and grading—particularly in courses that enroll large numbers of students. However, it is unclear whether online assignments significantly increase student learning in General Chemistry, particularly as compared to traditional handwritten assignments (Arasasingham, Martorell, & Mcintire, 2011; Arasasingham, Taagepera, Potter, Martorell, & Lonjers, 2005; Cole & Todd, 2003; Fynewever, 2008; Richards-Babb, Drelick, Henry, & Robertson-Honecker, 2011).

In recent years, textbook publishers have expanded the scope of online assignments made available with their textbooks. These expanded study tools imbed sophisticated features such as adaptive learning technologies, which tailor learning opportunities to students' existing skills, and metacognitive scaffolds, which assist students in monitoring and regulating their learning. Metacognitive scaffolds—which are the focus of this investigation—appear particularly promising because educational initiatives that foster student metacognition have been found to enhance learning (Adey & Shayer, 1993; Georghiades, 2004; Koch, 2001; Mevarech & Kramarski, 2003; Smith, Rook, & Smith, 2007; Teong, 2003; White & Frederiksen, 1998). Thus, metacognitive features may make textbook study tools more appealing than paper-and-pencil or online problem sets without such capacity.

Are textbook-bundled learning tools with metacognitive aids effective for learning? Empirical investigation of this question is much needed. First, although research has shown that assisting students to think metacognitively enhances their learning, these studies have been conducted on interventions that are carefully designed and/or supported by researchers (a review of such work is provided below); this research has not targeted textbook-bundled tools. Thus, drawing conclusions about textbook-bundled tools based on extant metacognitive-intervention research is not warranted. Furthermore, textbook-bundled tools pose financial and opportunity costs. Students either pay extra fees to use these tools or forgo buying used textbooks in order to obtain valid license codes. Additionally, given the finite time that students can dedicate to any one course and the finite amount of work that instructors can assign, both groups may use textbook-bundled tools in lieu of other, potentially more effective study strategies.

LearnSmart: A Textbook-Bundled Study Tool With Metacognitive Aids

This investigation focused on LearnSmart, a study tool that McGraw-Hill bundles with its textbook *Chemistry* (Chang & Goldsby, 2013). LearnSmart allows instructors to set up online assignments by content area (usually, chapters or chapter sub-sections). In any given assignment, students are presented with problems, one question at a time. For each question, students receive immediate feedback on the accuracy of their solution; they also receive additional diagnostic information, described below.

On its face, the tool appears to imbed some sophisticated features that have demonstrated efficacy. First, according to the publisher, LearnSmart incorporates adaptive learning technologies (http://learnsmartadvantage.com), which tailor learning experiences to students' existing skills by delivering problems and feedback to students based on their current performance and on the problems they have already been administered (Mettler, Massey, & Kellman, 2011). It is beyond the scope of this article to evaluate LearnSmart's adaptive algorithms; we mention this feature here because it is particularly touted by the publisher. Not all adaptive learning algorithms are equally effective (Mettler et al., 2011); nonetheless, studies outside of the context of textbook-bundled study tools have shown that when adaptive learning tools are well designed, student learning improves in domains such as language acquisition, geography, math, and the medical sciences (Atkinson, 1972; Kellman, 2013; Mettler et al., 2011).

Second, and more pertinent to this study, LearnSmart imbeds metacognitive aids to help students monitor strengths/weaknesses in their understanding in order to steer their learning. Metacognition is colloquially described as thinking about one's thinking. It encompasses knowledge about oneself as a learner as well as regulatory processes such as goal-setting, monitoring, evaluating, and revising to improve learning (McCormick, 2003; Schraw, Crippen, & Hartley, 2006). For example, a student who is thinking metacognitively monitors how well she has understood material and then adjusts her learning and study strategies to address areas of difficulty. Metacognitive skills benefit learning (Bruer, 2000; Davis, 2003; Flavell, 1979; Halpern, 1998; Kuhn, 2000; McCormick, 2003; Schraw et al., 2006), and, as stated previously, well-designed educational interventions that support metacognition have been shown to improve student outcomes in many domains, including science (Adey & Shayer, 1993; Georghiades, 2004; Koch, 2001; Mevarech & Kramarski, 2003; Smith et al., 2007; Teong, 2003; White & Frederiksen, 1998). Because science teachers have difficulty integrating metacognitive support into their teaching practices (White & Gunstone, 1989; Zohar, 2006), and because students do not always effectively use metacognitive processes in technology-based learning environments (Azevedo & Cromley, 2004; Azevedo, Guthrie, & Siebert, 2004), tools that can be easily integrated into coursework and that also imbed metacognitive scaffolds for students have great promise for benefiting learning.

LearnSmart's metacognition-supporting features include the following: For each question, before submitting an answer,[1] students must rate their confidence in their solution. Immediately after solving the problem, students receive real-time feedback on the accuracy of their solution, allowing them to monitor their performance as well as the accuracy of their confidence assessments. After completing the assignment, students can view reports that list topics or subsections on which they had high or low performance and, importantly, the percent of the assignment on which the following occurred: (1) They were aware they knew the answer, (2) they were unaware that they knew the answer, (3) they were aware they did not know the answer, and (4) they were unaware they did not know the answer. Finally, for students who wish to review their areas of difficulty, the tool allows access to an electronic version of the text with specific references for each question. If used robustly, these features could potentially aid students' metacognition and self-regulation of learning.

On its face, then, LearnSmart appears promising because such features have demonstrated efficacy in other learning environments. However, research by Azevedo and colleagues (Azevedo & Cromley, 2004; Azevedo et al., 2004) casts doubt on whether students can engage effectively in metacognitive thinking in technology-based learning environments. These researchers' studies on science learning in hypermedia environments have found that some students have difficulty using self-regulated learning strategies—which include metacognition—when they are not explicitly trained in how to do so. Furthermore, empirical work on the efficacy of LearnSmart in real-world classrooms is, at best, inconclusive. One study, conducted in undergraduate anatomy and physiology courses at six institutions, compared the test performance of students who used LearnSmart against those who used publisher test-bank quizzes. At two of the institutions, students in the LearnSmart condition outperformed the control students; at another, the control students outperformed the LearnSmart students; at the remaining three institutions, there was no significant effect of condition (Griff & Matter, 2013). Similarly, a master's thesis study conducted in an undergraduate biology course also showed no relationship between students' LearnSmart usage and performance on most analyses (James, 2012). Thus, overall, the evidence that LearnSmart use improves science learning is inconclusive.[2]

Overview of the Study

This study examined whether and under what circumstances LearnSmart could be used to improve students' science learning. The study was conducted on two topics covered in a first-semester General Chemistry course and addressed the following research questions:

- Did students who used LearnSmart for their first-semester undergraduate General Chemistry course demonstrate greater content knowledge gains than those who did not?
- How did these groups' content knowledge gains compare to gains of students who used LearnSmart but also received scaffolded support to use the tool's metacognitive features through materials we developed?

The rationale for including this third comparison condition was based on existing findings that metacognitive thinking poses challenges for some students (Azevedo & Cromley, 2004; Azevedo et al., 2004; Chi et al., 1989; White & Gunstone, 1989); thus, prior studies' null findings may have resulted simply because students needed more support to use LearnSmart's metacognitive features effectively.

Method

Participants

First-year students at a private Southern California university were recruited to participate in the study. The students were enrolled in one of three sections of a first-semester General Chemistry course. The sections were taught by different instructors, all of them using *Chemistry* (Chang & Goldsby, 2013), a McGraw-Hill textbook. The text was bundled with the publisher's online learning environment, *Connect*, which includes LearnSmart. Participation was voluntary. Of 160 students who returned consent forms, 97 (61 female and 36 male; 26, 33, and 38 from each of the three sections, respectively) completed pre- and post-tests and met the criteria for the quasi-experimental conditions described below. They comprised the study's final sample.

Design and Procedure

Two considerations guided the study's design: First, we wanted to generalize findings to authentic college courses. Moreover, ethically, we were uncomfortable depriving students of LearnSmart if they wished to use it. Thus, we examined the effects of LearnSmart in naturalistic classrooms, where the tool was used in conjunction with coursework and where concerns about grades likely contributed to students' efforts. This was accomplished by constructing three conditions from three different sections of a General Chemistry course that were already using LearnSmart to varying degrees. This strategy made our design a quasi-experiment (Campbell & Stanley, 1963), which is commonly used in naturalistic settings where interventions are in place and where random assignment of participants to conditions is not possible.

Specifically, the study involved three quasi-experimental conditions, with pre-post data collected on two units. Each unit corresponded to a chapter in the textbook. The first chapter covered, on "Gases" (Chapter 5 in the text), served a baseline function. Learning data from this baseline chapter were used as a covariate to control for pre-existing classroom effects, such as differences in students' abilities, instructors' effectiveness, or both. To the extent that any of the three sections tended generally to perform better or worse than the others, the covariate statistically controlled for this pre-existing difference *before* differences due to condition were examined. The second chapter covered, on "Thermochemistry" (Chapter 6 in the text) served as the experimental unit in which the use of LearnSmart was manipulated.

The construction of the learning conditions was based on how the sections of General Chemistry were already using LearnSmart. At baseline (the Gases unit), no special instructions were given, and no changes were made to existing course policies. In two of the sections (Sections 1 and 3), the instructors were providing either nominal extra credit or no credit for completing LearnSmart. We expected lower rates of LearnSmart use in these sections and, thus, created two conditions, which, at baseline, comprised students who did not complete LearnSmart's Gases module. In the remaining section (Section 2), completion of the LearnSmart modules was required for homework credit. We expected more regular use of LearnSmart here; thus, the third condition comprised students who did complete the LearnSmart Gases module at baseline.

For the experimental unit (Thermochemistry), instructors were asked to provide the following instructions to students: In Section 1, students were told that, for this chapter only, they would *not* receive any extra credit for completing the LearnSmart module; this manipulation was meant to keep rates of LS usage low for this chapter. In Section 2, the instructor reiterated the course policy of homework credit for completing the LearnSmart module (meant to keep rates of LearnSmart use high). And in Section 3, the instructor assigned homework credit to the LearnSmart module for this chapter along with guiding questions that we developed to scaffold students' use of the imbedded metacognitive features.

To conduct a fair assessment of the LearnSmart's efficacy, it was important that the three conditions reflected LearnSmart and/or guiding question completion, as described above for each condition. Thus, the sample was restricted to students who met the criteria for both baseline and experimental conditionals; "completion" of LearnSmart was operationalized as completion of greater than 50% of the module for that chapter.

In summary, the study's design included three quasi-experimental conditions (see Table 1): Condition 1 (No-LS/No-LS), which involved no LearnSmart use for both the baseline and experimental units; Condition 2 (LS/LS), which involved LearnSmart use for both the baseline and experimental units; and Condition 3, (No-LS/LS-MSQ), which involved no LearnSmart use at baseline and LearnSmart use with completion of metacognition-scaffolding questions for the experimental unit. Of the volunteering students, 26, 33, and 38 students ($N = 97$) completed pre- and post-tests and met the criteria for the No-LS/No-LS, LS/LS and No-LS/LS-MSQ conditions, respectively.

In all three conditions, pre-tests covering content knowledge of both Gases and Thermochemistry were administered before instructors began lectures on the Gases unit. Gases were then covered in lecture, followed by a post-test on this unit. Finally, Thermochemistry was covered, followed by the post-test on this unit. For each of the units, pre-tests were identical to post-tests. To further promote authentic classroom conditions, all instructors agreed to use the post-test data for some aspect of student assessment.

Measures

Students' content knowledge on the Gases and Thermochemistry chapters was measured using pre- and post-test assessments; questions on the assessments were modeled on items that second author Bouvier-Brown had adapted over the years for her own course exams from online/text-bank resources (see Appendix A). Five multiple-choice questions were used for each chapter, which were each scored as either correct or incorrect. The final question on each test required students to show their work in obtaining the answer; Bouvier-Brown scored this work blind to students' assignment into the conditions. Scoring of the qualitative work was done on a 4-point scale (0 = *incorrect or missing work/reasoning*; 1 = *partially correct work/reasoning*; 2 = *mostly correct work/reasoning*; 3 = *correct work/reasoning*). Final pre- and post-test scores were computed as a sum of the number of correct responses on the five items and the number of points assigned for the qualitative work on the final question. Finally, for the data analyses, gain scores were computed for each chapter by subtracting the pre-test score from the post-test score.

Table 1
Summary of Study Design and Quasi-Experimental Conditions

	Condition 1 (No-LS)	*Condition 2 (LS)*	*Condition 3 (No-LS/LS-MSQ)*
	Section 1	**Section 2**	**Section 3**
Baseline Unit (Gases)	No LearnSmart	LearnSmart	No LearnSmart
Experimental Unit (Thermochemistry)	No LearnSmart	LearnSmart	LearnSmart + Metacognition-Scaffolding Questions

Metacognition Scaffolding Questions

Students in Condition 3 (No-LS/LS+MSQ) had to complete guiding questions that we developed to scaffold use of LearnSmart's metacognitive features.[3] The questions prompted students to look at available diagnostics, identify the three sections in the chapter on which they had the most difficulty, and diagnose sources of difficulty. Students were then prompted to re-read the textbook material pertaining to areas of difficulty, and, finally, they evaluated whether their prior confusions had been resolved. The scaffolding questions ended with suggestions to students for resolving any persistent issues. To receive homework credit, students in this section had to complete both LearnSmart and the scaffolding questions. Students completed these questions first on paper and then submitted their responses online through *Qualtrics,* an online survey tool.

Results

Quantitative Analyses

Descriptive statistics for learning gains on both chapters are provided in Table 2. A between-subjects analysis of variance (ANOVA) was first run on the baseline chapter (Gases). Recall that students in Condition 1 (No-LS) and Condition 3 (No-LS/LS+MSQ) did not use LearnSmart for this chapter, while those in Condition 2 (LS/LS) did. This analysis showed a significant effect of condition ($F[2, 89] = 6.21$; $p = .003$; partial $\eta^2 = .12$).[4] *Post-hoc* tests revealed that students in the No-LS/No-LS and No-LS/

Table 2
Means (and *SD*) for Pre-Tests, Post-Tests, and Pre-to-Post Test Gains

	Condition 1 (No-LS/No-LS)	*Condition 2 (LS/LS)*	*Condition 3 (No-LS/LS-MSQ)*
Baseline Unit (Gases)	**Mean (*SD*)**	**Mean (*SD*)**	**Mean (*SD*)**
Pre-test	2.24 (1.51)	3.00 (1.95)	2.26 (1.46)
Post-test	5.21 (1.59)	4.28 (1.99)	4.97 (1.64)
Pre-to-Post Gain	3.00 (1.78)	1.32 (2.09)	2.71 (1.93)
Experimental Unit (Thermochemistry)*			
Pre-test	2.12 (1.54)	1.91 (1.38)	2.03 (1.57)
Post-test	5.17 (1.95)	3.72 (1.73)	5.64 (1.88)
Pre-to-Post Gain	3.09 (1.72)	1.87 (2.00)	3.61 (2.27)

Note. *These are raw values, not adjusted for the covariate. Adjusted means are presented in Figure 1.

LS-MSQ conditions outperformed those in the LS/LS condition ($p = .007$ and $p = .01$, respectively). Performance in the No-LS and No-LS/LS-MSQ conditions did not differ significantly ($p > .05$), although the gain for the No-LS/No-LS condition was slightly higher than for No-LS/LS-MSQ. These results pointed to pre-existing differences between groups (for example, instructor/student effects or the existing use of study strategies that were more effective than LearnSmart).

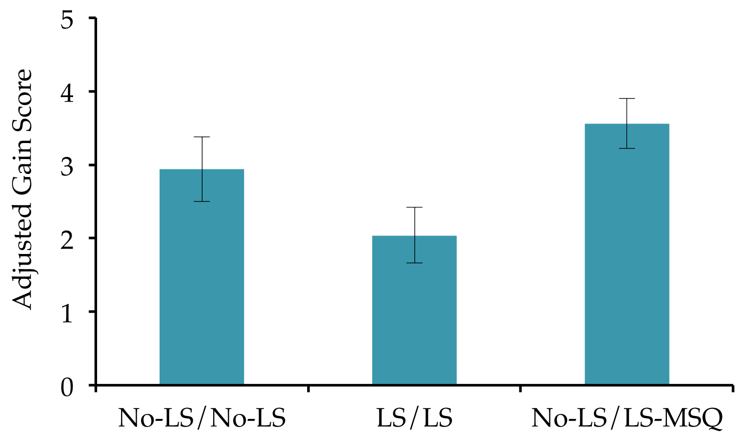
Next, an analysis of covariance (ANCOVA) was used to examine the effect of condition for the experimental chapter (Thermochemistry). Gain scores on the Gases chapter were used as a covariate to control for pre-existing group differences. Recall that for the experimental chapter, students in the LS/LS condition continued using LearnSmart with no additional support; those in the No-LS/No-LS condition continued not using the tool; and those in the No-LS/LS-MSQ used LearnSmart with scaffolding questions, although they had not used the tool for the baseline chapter. This analysis allowed us to compare LearnSmart use with and without scaffolding questions against no LearnSmart use, controlling for learning differences between the groups at baseline. There was a significant effect of condition even after controlling for baseline learning ($F[2, 84] = 4.25$; $p = .02$; partial $\eta^2 = .09$). *Post-hoc* tests showed students in the No-LS/LS-MSQ condition (adjusted $M = 3.56$; $SE = .34$) outperformed those in the LS/LS condition (adjusted $M = 2.04$; $SE = .38$; $p = .005$). The No-LS/No-LS condition (adjusted $M = 2.94$; $SE = .44$) did not differ significantly from either the LS/LS or No-LS/LS-MSQ conditions (see Figure 1); however, whereas baseline gain had been higher for No-LS/No-LS than for No-LS/LS-MSQ, this trend reversed when means for the experimental unit were adjusted for baseline performance. The findings suggest that use of the metacognitive scaffolding questions did appear to help students use LearnSmart's features more effectively than LearnSmart use by itself, which did not confer any learning benefits.

Students' Responses to Metacognition-Scaffolding Questions

Students' responses to scaffolding questions in the No-LS/LS-MSQ condition were used to shed light on the quantitative findings. Again, these questions prompted students to use LearnSmart's diagnostic features to identify areas of weakness. Students described what was unclear and were prompted to re-read the corresponding textbook sections. Finally, they identified which concepts were still confusing and which were now clear, and they were prompted to seek instructor assistance for the former.

Qualitative examination of students' responses revealed two trends.

Figure 1
Content Learning Gain Scores (+SE Bars)
on the Thermochemistry Unit,
Statistically Adjusted for Performance on the Gases Unit



First, responses ranged in the specificity of problems identified, with some students merely stating that they were confused in general (for example, "I am still confused on some concepts," or "I still need further explanation in class") without identifying what concepts needed explanations, and others identifying specific areas of confusion (for example, "I now understand how dissolving actually occurs, but I am wondering if those salt ions are still, in theory, in gaseous state when they are hydrated"; "I didn't quite understand Hess's Law"; or "What is standard enthalpy formation?").

Second, students' diagnoses varied in the perceived source of weak performance. Many attributed their weak performance to difficulty in recalling definitions or formulas (for example, "My main issue with this section was confusing exothermic and endothermic processes," "[I didn't understand] what a system is and what the surroundings around it do," or "The formulas are something I just have to go over and get them in my head and remember them.") Thus, these students, instead of using LearnSmart to pinpoint conceptual problems, focused on issues that could be easily addressed by re-reading the textbook. In contrast, other students identified more complex, conceptual issues (for example, "I did not know how to apply the equations given," or "I did not know that enthalpy changes occur when a solute dissolves in a solvent or when a solution is diluted”). Resolving confusion at this level potentially could contribute to students’ deeper understanding of the content.

The variability of students’ responses—both in the specificity and complexity of issues identified—suggests that even with metacognitive scaffolding questions, students had trouble using LearnSmart’s features to monitor and steer their performance.

Discussion

This study examined the efficacy of LearnSmart with and without metacognition-scaffolding questions. We conducted the study because, on its face, LearnSmart imbeds features (adaptive learning, which was not a focus of this study, and metacognitive features) that have empirical support in existing psychological and educational research. However, we were skeptical about assuming that LearnSmart was efficacious because of these features, particularly because prior research on the tool is scant and inconclusive (Griff & Matter, 2013; James, 2012).

We found that LearnSmart by itself did not provide a learning benefit to students; after controlling for pre-existing classroom differences, there were no differences in learning between students who used the tool without scaffolding questions and students who did not use it at all. The findings are consistent with Bowen and Lack’s (2012) assertion, based on reviews of existing research, that LearnSmart does not deliver on the improvements in learning claimed by the publisher.

Recognizing the difficulty students have in thinking metacognitively (Azevedo & Cromley, 2004; Azevedo et al., 2004; Chi et al., 1989; White & Gunstone, 1989), we included an alternative comparison condition in which students used the tool with metacognition scaffolding questions that assisted them to monitor, diagnose, and, if possible, repair areas of difficulty. The tool showed more promise in this condition, with these students demonstrating greater learning gains than those who used LearnSmart on its own. Not surprisingly, this effect, though statistically significant, was modest. Qualitative analyses of students’ responses to scaffolding questions revealed that many students engaged with reading material and LearnSmart at a surface level. When prompted by scaffolding questions to reflect on areas of difficulty, these students either made general statements, without identifying their specific areas of weakness, or they identified problems with recalling definitions and formulas rather than conceptual issues. Thus, even with scaffolding questions, some students had trouble reflecting on their understanding. In the absence of such scaffolds, it is possible that students fail to reflect at all or do so in ineffective ways. In other words, it is likely that the metacognitive features within the tool are not useful without significant training about how to use them. This is an important point, because LearnSmart provides students access to their metacognitive data for each module, but no support for what to do with the information. The scaffolding questions used in this study were a first attempt at providing some direction for students on how to use available data.

Additionally, other limitations to LearnSmart might hinder instructors' abilities to integrate it into assignments effectively. At the writing of this article, training for instructors on the tool was limited largely to an overview of its features and reporting capabilities. No pedagogical support was provided. Furthermore, although instructors have access to module completion and accuracy rates, LearnSmart compiles and averages data on metacognitive awareness over *all* attempted chapters or modules for each student. Thus, instructors cannot easily track whether students' metacognitive skills have improved or remained stagnant across chapters.

Limitations of the Study

Limitations of the study included the following: First, we wanted to investigate LearnSmart's effects in a naturalistic context, with students using it for coursework and concerns about grades, time, and other factors affecting how they engaged with the tool. We reasoned that findings under these conditions would generalize to real-world classrooms more than to artificial, laboratory-based conditions. Thus, this study employed a quasi-experimental design with comparison conditions created from pre-existing groups. Quasi-experiments tend to have higher external validity than laboratory-based experiments; a drawback, however, is that, in the absence of random assignment, pre-existing differences between comparison groups can be present (see, for instance, Campbell & Stanley, 1963). We corrected for this issue statistically by using learning gains on a baseline chapter as a covariate. However, we recognize that the covariate itself may have been imperfect because of inherent differences in the topics covered by the Gas and Thermochemistry chapters (for example, in their difficulty or the prior knowledge required for solving problems). Second, we studied the effects of LearnSmart (with and without scaffolding questions) on only one unit; the effects of scaffolding questions may have been strengthened across a semester of use, particularly if instructors were to discuss explicitly the value of engaging in metacognitive thinking. Finally, the scaffolding questions used in the No-LS/LS-MSQ condition likely increased the time that those students spent studying. It is possible the additional study time alone would have been sufficient to produce the advantage we observed in this condition. The study's naturalistic design precluded control of this variable.

Conclusions

Because of the financial and opportunity costs they pose, textbook-bundled study tools cannot be assumed to be effective simply because they integrate sophisticated features such as metacognitive aids. Our investigation of LearnSmart suggested that the metacognitive features in this tool require considerably more support for students and instructors than is currently provided. In other words, based on our study, we are skeptical of the tool's efficacy in typical college-level science classroom contexts—with instructors who may not be well-versed in supporting students' metacognitive thinking and with students who do not routinely, robustly, and spontaneously engage in metacognitive activity. At the same time, the tool may have promise if it is coupled with more extensive scaffolds that aid the use of its features for both instructors and students. This study would ideally be one of a number of studies examining the efficacy of textbook study tools, the specifics of their features, the contexts in which they are used, and the ways in which they do/do not benefit learning. Future work by publishers and chemistry education researchers could, then, use these findings to design supports that can be effectively integrated into tools for enhancing students' learning.

Footnotes

[1]The current version of LearnSmart allows students to answer the question and then assess their confidence in the answer.

[2]Our conclusions about LearnSmart's efficacy, based on reviews of these works, differ from those of the publisher (http://learnsmartadvantage.com).

[3]Interested readers can obtain the metacognition scaffolding questions by contacting the first author.

[4]For readers who are unfamiliar with it, partial-eta-squared (η^2) is a measure of effect size.

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Appendix A
Pre/Post Test Items

These questions were used for the pre-and post-tests; a periodic table was provided and calculator could be used. Students were provided extra paper to show their work for Question 5 of each test. Correct answers are in bolded font.

Gases

1. At a constant temperature, a gas is compressed so that its volume changes from 2.0 L to 1.0 L. How does the pressure change?

   a) Pressure will increase by a factor of 1
   b) Pressure will decrease by a factor of 1
   c) Pressure will increase by a factor of 2
   d) Pressure will decrease by a factor of 2
   e) Pressure will increase by a factor of 4

2. Two moles of chlorine gas at 20.0°C are heated to 350.°C while the volume is kept constant. The density of the gas

   a) Increases
   b) Decreases
   c) Remains the same
   d) Is highly variable at higher temperature
   e) Not enough information is given to correctly answer the question

3. The molecules of different samples of an ideal gas have the same average kinetic energies, at the same

   a) Density
   b) Pressure
   c) Volume
   d) Temperature
   e) Concentration

4. Which statement is NOT true about gases?

   a) Gases have higher densities than liquids
   b) Gases expand to fill the volume of a container
   c) All gases respond the same way to physical changes, despite their chemical differences
   d) Gases readily mix with one another
   e) Both (a) and (c) are FALSE

5. A 1.07 g sample of a Noble gas occupies a volume of 363 mL at 35°C and 0.892 atm. Identify the Noble gas in this sample?

$$R = 0.08206 \frac{L \cdot atm}{mol \cdot K} = 8.314 \frac{J}{mol \cdot K} = 8.314 \frac{kg \cdot m^2}{s^2 \cdot mol \cdot K}$$

   a) He
   b) Ne
   c) Ar
   d) Kr
   e) Xe

Thermochemistry

1. How do you calculate heat flow (q)?

a) Mass × specific heat (s) × change in temperature
b) Mass × heat capacity (C) × change in temperature
c) Heat capacity (C) × change in temperature
d) a and c
e) None of the above is correct

2. Suppose a 50.0 g block of silver at 100°C is placed in contact with a 50.0 g block of iron at 0°C, and the two blocks are insulated from the rest of the universe. The final temperature of the iron

a) will be higher than the silver
b) will be lower than the silver
c) will be the same as the silver
d) will be 50°C
e) will vary depending of the pressure of the system

3. Use the following reaction to answer the question below:

$$Ca(s) + Cl_2(g) \rightarrow CaCl_2(s) \qquad \Delta H° = 177.8 \text{ kJ/mol}$$

This reaction causes the surroundings to

a) warm up
b) become acidic
c) condense
d) decrease in temperature
e) release CO_2

4. Water has a specific heat of 4.184 J/g deg while glass (Pyrex) has a specific heat of 0.780 J/g deg. If 10.0 J of heat is added to 1.00 g of each of these, which will experience the larger increase of temperature?

a) Glass will experience a larger increase
b) Water will experience a larger increase
c) The water's temperature will increase, but the glass's temperature will not change
d) Both will experience the same change in temperature
e) Not enough information is given to answer the question

5. Determine the amount of heat (in kJ) given off when 1.26×10^4 g of ammonia are produced according to the equation:

$$N_2 (g) + 3H_2 (g) \rightarrow 2NH_3 (g) \quad \Delta H°_{rxn} = -92.6 \text{ kJ/mol}$$

(Assume that the reaction takes place under standard-state conditions at 25°C.)

a) 92.6 kJ
b) 3.43×10^4 kJ
c) 6.85×10^4 kJ
d) 8.33×10^4 kJ
e) Not enough information to determine the answer