PowerPoint Use in the Undergraduate Biology Classroom: Perceptions and Impacts on Student Learning

By Emily Smith-Peavler, Grant E. Gardner, and Ryan Otter

Visual representations of physical and natural phenomena are important components of the teaching and learning of biology. In current undergraduate biology classrooms, visual representations are most often provided to students on PowerPoint slides. This study focuses on the use of, and perceptions about, PowerPoint in undergraduate introductory biology classes to understand how PowerPoint composition can best promote student learning. Likert survey results from students and faculty along with course grades were used to assess these notions. Study findings show that all participants perceived PowerPoint images to be beneficial; however, not all participant groups found text beneficial. There were also differing perceptions of the teaching efficacy of PowerPoint found among groups. When test scores from two different PowerPoint slide treatments were examined, differences were found in overall student grades, with higher grades for students in an image-only treatment versus a text-and-image-combined treatment. The group with the most significant learning gains was students below the 75th quartile. The study indicates that simple adjustments to PowerPoint slides may help increase student learning for groups who customarily struggle with the science content.

The ability to move between visual representations of the physical and natural world is an important skill for any scientist (Arneson & Offerdahl, 2018). Visualizations can clearly and concisely represent multifaceted scientific information as well as provide models of natural phenomena that are not easily observable by the unaided eye (Tibell & Rundgren, 2010). For example, an image of a space-filling model of methane represents complex information about atomic interactions as well as molecular structure at a microscopic scale. Communicating and making meaning of visual representations in science is dependent both on image design and how the receiver perceives the image (Trumbo, 1999).

Compared with other sciences, the discipline of biology heavily relies on visualizations to communicate the complex interactions of biological systems across a wide range of scales (Tibell & Rundgren, 2010). This has direct impacts on classroom instruction. In addition to using visuals to communicate information, biology instructors may also expect students to decode and interpret representations, create their own visuals, and/or generate mental models (Arneson & Offerdahl, 2018). Specifically, instructors may expect students to relate (a) two-dimensional and three-dimensional representations of the same biological objects (Taylor & Jones, 2013), (b) emergent properties of biological phenomena at different size scales (Jones, Gardner, Taylor, Wiebe, & Forrester, 2011), (c) static representations to their dynamic processes (Wright, Cardenas, Liang, & Newman, 2018), and (d) the limitations of visual models to reality (Stefanski, Gardner, & Seipelt-Theiman, 2016). Because of this complexity, biology instructors may need to give careful consideration to how they present visual information to students, how students perceive this visual information, and how this may impact their learning.

The most frequently used tool to present visualizations in university classrooms is PowerPoint slides (Craig & Amernic, 2006; Noppe, Achterberg, Duquaine, Huebbe, & Williams, 2007). Previous research addresses how students perceive PowerPoint as a learning tool and rarely assess how it impacts learning. Parker, Bianchi, and Cheah (2008) found that although a majority of undergraduate students perceived that they retained information longer when PowerPoint was used in classrooms, professors perceived that they did not. Other studies have demonstrated student preference for PowerPoint over other instructional content delivery tools (Apperson, Laws, & Scepansky, 2006; Bartsch & Cobern, 2003; Szabo & Hastings, 2000). The effectiveness of PowerPoint as an instructional technology to support student learning through content organization and visual representation remains unclear. Amare (2006) found that PowerPoint produced inferior learning outcomes when compared with traditional unsupported lectures, whereas Erwin and Rieppi (1999) found that PowerPoint increased learning. Because of these conflicting results, Susskind (2005) and Szabo and Hastings (2000) suggested that efficacy of PowerPoint in classrooms is highly content or case specific.

In addition to considerations of *whether* PowerPoint is used in undergraduate science classrooms to impact student learning, it also matters *what* is on each slide. PowerPoint slides can contain visual representations or textual descriptions of scientific phenomena, and this can impact student learning and perception of its effectiveness. Students dislike PowerPoint slides with visuals only (Apperson et al., 2006) and retain less information when slides have visuals only (Buchko, Buchko, & Meyer, 2012). Conversely, Kustritz (2014) found that students retained more information when there was only a title accompanied by a pertinent graphic and little text. Johnson and Christensen (2011) noted that although students preferred slides with a pertinent graphic and small amount of text, they did not demonstrate higher exam performance than those in a text-only comparison group. A consideration of the design and use of the slides themselves is likely important in promoting student learning of particular content especially when considering how that content is represented (as a visual or as text).

No studies have directly looked at the effects of PowerPoint and slide structure on introductory biology classrooms (Apperson et al., 2006; Buchko et al., 2012; Susskind, 2005). Many professors may rely on personal experience to dictate how they design their lecture slides (Hurtado, Eagan, Pryor, Whang, & Tran, 2013). The overall goal of this study was to examine how content on PowerPoint slides is best represented to maximize student learning in biology. To achieve this goal, both indirect perceptual measures of students and faculty as well as more direct comparison measures of student learning were collected. We were interested in understanding *how* content presented on PowerPoint technology might impact student learning and perceptions in the context of the introductory biology course sequence. We also considered how these perceptions may change over time as biology students progress through the major. We considered this because students might develop different views on their own learning of biology as they matriculate through their program from introductory courses (which may be a large-enrollment, lecture-hall type context) to more intimate class sizes with applied content.

Research Question 1: What do biology faculty and students at particular stages in the major perceive the level of usefulness and effectiveness of PowerPoint to be in the introductory biology course sequence?

Research Question 2: Are there differences in the perceptions of usefulness and effectiveness of PowerPoint in the introductory biology course sequence between biology faculty and students at particular stages in the major?

Research Question 3: What components of PowerPoint slide composition do biology faculty and students at particular stages in the major perceive are most conducive to student learning?

Research Question 4: Which of two PowerPoint composition treatments (visual only versus text + visual) best promote student learning in an introductory biology course?

Methods

To better understand how PowerPoint slides are best represented to maximize student learning in biology, two independent studies were conducted. The first study used a cross-sectional survey design to investigate the perceived usefulness, effectiveness, and preference of PowerPoint slides in an introductory biology class of both instructors and students. The second study was a quasi-experimental empirical investigation of two different PowerPoint slide uses and their influence on student learning in an introductory biology class.

Study 1: Survey instrument construction and administration

On the basis of a review of previous research, three major themes on the impact of PowerPoint were identified as salient and measured: usefulness of, effectiveness of, and preference for PowerPoint. Specific items were generated for each theme, and the language of each item was reviewed to maintain relevance and face validity for both students and faculty participants. This resulted in a 17-item survey. Responses for items were recorded using a 7-point

Likert scale, where 1 = *strongly disagree* and 7 = *strongly agree*. For items pertaining to slide preference, participants selected the slide they preferred. The slide examples given contained four options related to prokaryotic cell structure: Slide 1 was bulleted text with an image of the cell, Slide 2 was bulleted text only, Slide 3 was full-sentence text descriptions only, and Slide 4 was an image of the cell only. After preliminary statistical analysis of results using exploratory factor analysis, six items were removed because of a lack of statistical convergence with factors and to strengthen the construct validity of the instrument.

The survey was administered to a sample of biology students and biology faculty members at a large-enrollment public university in the southeastern United States. The sample was broken into three different biology student groups who were at different stages in completion of their major: Bio 1, Bio 2, and Senior Bio. The Bio 1 participants were all actively taking the first required course for biology majors. The Bio 2 participants were all actively taking the second required course for biology majors. The Senior Bio participants were all actively taking the Senior Seminar course, which is typically taken during the last semester before graduation and only enrolls students that are biology majors (Table 1). All surveys were administered as a paper-and-pencil survey. Student surveys were administered at the beginning of class, and faculty surveys were administrated at the beginning of a faculty meeting (surveys approved under IRB #15-028).

Principal components factor analysis was utilized to determine relevant factors and to support construct validity. Only items with loading values greater than 0.50 were considered significant and were included in individual factors used for further analysis. Comparison of survey responses between different student groups and faculty were investigated using a nonparametric Kruskal-Wallis analysis of variance (appropriate for ordinal data) with post hoc pairwise comparisons. All analyses were performed using JMP Pro 9 software (Cary, NC). Significant differences were defined by *p*-values <.05.

TABLE 1

Demographic description of participants

	Total	Bio 1	Bio 2	Senior Bio	Faculty
Participants (*n*)	583	427	86	41	29
Gender					
Female	336	253	47	28	8
Male	247	174	39	13	21
# Credit hours					
<30	261	242	19	0	—
30–59	128	96	31	1	—
60–89	74	49	20	5	—
90+	89	38	16	35	—

Study 2: Student learning assessment and administration

To answer research Question 4, exam scores from seven individual classes of Bio 1 taught by the same instructor between spring 2010 and spring 2014 were evaluated. These eight classes had an average class size of 87 ± 7 students ($M \pm SE$). Statistical analysis of class size showed that no significant differences existed between class sizes for any of the factors examined. Classroom composition changes were monitored using composite ACT scores for the incoming student body at the university level across the course of the study, which showed a mean of 21.7 +/- 0.21 and science subscore of 21.44 +/- 0.23. Each class focused on the same learning objectives and grading consisted of three lecture-based exams. All exams utilized short-answer items, with most having a word maximum limit (e.g., "in 30 words or less, describe the difference between cellular respiration and fermentation").

Before the study, a test bank of questions was developed by the instructor for each exam, and from that test bank exactly 87% of the same items were used on every exam. This is an indicator of exam-item consistency across all exams. As another measure of consistency of item type within and between each exam, items were also "Bloomed" by one of the authors (Crowe, Dirks, & Wenderoth, 2008). On average, 61% of items were at the knowledge level, 29% at the comprehension level, and 10% at the application level. We acknowledge that these indicators of assessment reliability are not "perfect" but do provide some strong evidence of exam consistency across multiple administrations. To ensure integrity of assessment, exams were never handed back to students. The same instructor utilized the same grading rubric across all seven classes and personally graded all exams. Content validity of these assessments should be aligned with the instructors' course, but is less of a concern in this study because (a) common assessments were used across all conditions, (b) a common instructor taught all conditions, (c) comparisons are being made between these conditions only, and (d) the authors do not claim to comprehensively measure the whole of student knowledge in these content domains.

All exam scores were compiled into a single database with no personally identifying information and analyzed on the basis of two variables hypothesized to potentially impact student learning: (a) how PowerPoint was designed for the lecture (textual & visual vs. visual only) and (b) class meeting time (morning vs. afternoon). As class meeting time has been shown to affect test results, we wanted to be sure to account for this confounding variable in our analysis (Sievertsen, Gino, & Piovesan, 2016). For both classroom treatments, PowerPoint was the focal point of the class. For the first four classes taught in this study (spring 2010 to spring 2012), PowerPoint slides were the backbone of the lecture and contained key terms, definitions, and images. This lecture style was defined as a "textual & visual" because slides used contained both images and substantial text. For the last four classes of this study (spring 2013 to spring 2014), PowerPoint slides contained only images (the same images as the first four classes, but without key terms or definitions) and were occasionally supplemented by use of a whiteboard. This lecture style was defined as a "visual only" because PowerPoint slides were still heavily used, but they contained no key terms or definitions. Class meeting times were divided into two groups: (a) "morning" classes, which all had 8:00 a.m. start times, and (b) "afternoon" classes, which started between 1:00 p.m. and 3:00 p.m.

To ensure that the analysis of lecture style was not influenced by improved instructor quality over time, linear regression modeling was performed to determine the relationship between the amount of instructor experience teaching Bio 1 (measured in semesters) and student exam scores. Comparisons of lecture style and class meeting times were performed using a student's *t*-test. To investigate how PowerPoint lecture style impacted different groups, students' mean exam scores for the two styles were subtracted from one another and plotted based on quantile distribution.

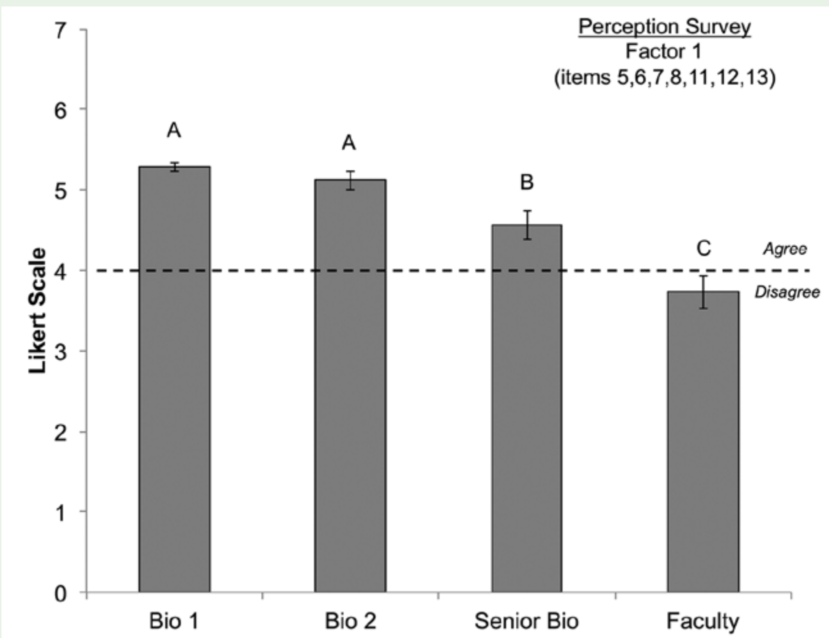
Results

Study 1

Survey response rates were 80.5%, 43.6%, 68.3%, and 80.5% for Bio 1, Bio 2, Senior Bio, and Faculty, respectively. Only one significant factor (usefulness and effectiveness of PowerPoint in introductory biology classrooms) resulted from the principal component factor analysis and included Items 5, 6, 7, 8, 11, 12, and 13. Using the Kruskal-Wallis H test, significant differences with a medium effect size between groups in response to Factor 1 were observed, $\chi^2(3, 572) = 43.98$, $p < .001$, $\eta^2 = 0.103$ (Figure 1). All student groups, on average, agreed that

FIGURE 1

Average Likert ratings for Factor 1, the usefulness and effectiveness of PowerPoint in introductory biology classrooms for the four sampled groups. Likert scale ranged between 7 (*strongly agree*) and 1 (*strongly disagree*).



PowerPoint is a useful and effective tool in teaching introductory biology classes (Bio 1: $M = 5.28$, $SE = 0.05$; Bio 2: $M = 5.12$, $SE = 0.12$; Senior Bio: $M = 4.56$, $SE = 0.17$; Faculty: $M = 3.73$, $SE = 0.21$). Post hoc analyses revealed that Bio 1 ($p = .004$) but not Bio 2 ($p = .155$) students agreed more strongly than the senior biology students. Faculty responses were significantly lower than all student groups including Bio 1 ($p < .0001$) and Bio 2 ($p < .0001$), but not Senior Bio ($p = .094$). On average, respondents slightly disagreed that PowerPoint is a useful and effective tool in introductory biology classrooms ($M = 3.70$, Mode = 5.29, $SE = 0.20$).

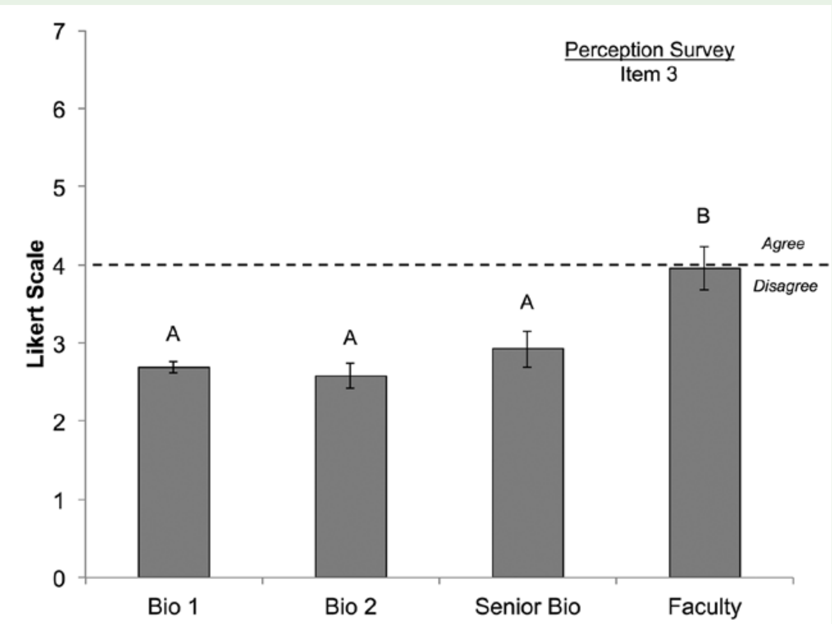
In general, participants disagreed that no text on PowerPoint slides is most helpful for student learning (Item 3), although faculty were neutral on this item and the differences showed a small to medium effect size, $\chi^2(3, N = 581) = 13.81$, $p = .003$, $\eta^2 = 0.034$ (Figure 2). Differences between perceptions arose only between faculty ($M = 3.96$, Mode = 3, $SE = 0.28$) and two of the student groups including Bio 1 ($M = 2.70$, Mode = 1, $SE = 0.07$, $p = .003$) and Bio 2 ($M = 2.58$, Mode = 2, $SE = 0.16$, $p = .004$) but not Senior Bio ($M = 2.93$, Mode = 3, $SE = 0.23$, $p = .251$).

In contrast, there were no significant differences between any student group or faculty when asked if visual elements were the most useful for student learning (Item 1), $\chi^2(3, N = 582) = 0.891$, $p = .828$, $\eta^2 = 0.00079$. The lack of differences in participants' perceptions are evident in the mean values with Bio 1 ($M = 1.96$, $SE = 0.06$, Bio 2 ($M = 1.91$, $SE = 0.12$), Senior Bio ($M = 1.88$, $SE = 0.18$), and Faculty ($M = 1.86$, $SE = 0.22$), which were qualitatively and statistically similar after post hoc analyses with each group having a Mode = 1 (Figure 3).

Results for slide preference for all student groups and faculty showed when asked to choose which slide was most helpful in communicating information, 81%, 86%, 90%, and 76% of participants selected Slide 1 (text + image) as the most helpful in the Bio 1, Bio 2, Senior Bio, and Faculty groups, respectively (Item 14). When asked to choose which slide would be most helpful for student learning, 81%, 85%, 80%, and 79% of participants selected Slide 1 as the most helpful in the Bio 1, Bio 2, Senior Bio, and Faculty groups, respectively (Item 17).

FIGURE 2

Average Likert ratings for Item 3. Bars represent ratings for the four sampled groups. Likert scale ranged between 7 (*strongly agree*) and 1 (*strongly disagree*) as seen on the *y*-axis.



Study 2

To account for potential temporal influences, linear regression modeling compared exam scores over time for the same instructor. During the time frame when the two different lecture styles were being taught, no significant increase in exam score as a result of increased instructor experience was observed: text and visual, $r^2_{(1,062)} = 0.046$, $P = .44$; visual only, $r^2_{(808)} = 0.039$, $P = .97$. A significant difference was present when comparing average exam scores between the two PowerPoint composition styles, $t(1,871) = -5.04$, $p < .001$; however, the effect size was very small (Hedges $g = 0.095$; Figure 4). Average semester exam scores were as follows: spring 2010, 62.69%; spring 2011, 64.45%; spring 2012, 59.04%; fall 2012, 66.19%; spring 2013, 69.25%; fall 2013, 67.95%; and spring 2014, 69.6%. On average, student exam scores were 5.73% higher when taught using the visual-only slides compared with those taught using the textual and visual slides.

Analysis of quantile distributions showed that the exam score difference between the two slide compositions was due to a score increases in students scoring at or below the 75th quartile (Figure 5). Analysis of the impact on class meeting time on average exam score showed no significant difference and a very small effect size between classes taught in the morning compared with those taught in the afternoon, $t(1871) = -0.052$, $p = .958$, Hedges $g = 0.0024$ (Figure 6).

Discussion

This study was developed to address the efficacy of the use of PowerPoint as an advanced organizer in introductory undergraduate biology classrooms. With the ubiquitous use of PowerPoint in undergraduate biology classrooms, the study concerned itself not only with relevant stakeholders' (students and faculty) perceptions of the technology as a teaching tool, but also with the reality of PowerPoint's impact on student learning. Components of the construction of PowerPoint slides were examined, specifically contrasting the use of text and visual representations to facilitate student learning.

The work of David Ausubel has indicated the importance of advanced organizers (AOs) in rapid learning and retention ability of students (Ausubel, 1978), which are common learning requirements to undergraduate biology classroom settings. New and meaningful learning occurs at the intersection of previously obtained knowledge structures and new information. Two conditions for appropriate AO use are that (a) students must process and understand the information presented in the AO and (b) the instructor must clearly indicate the relationships between basic concepts within the AO. These ideas complement calls for the need for increased visual literacy of biology students (Arneson & Offerdahl, 2018). Historically, PowerPoint slides provide an overall structure to the instructional episode, and each individual slide can be viewed as a mini AO in the context of the larger lesson (Ausubel, 1978).

Study 1

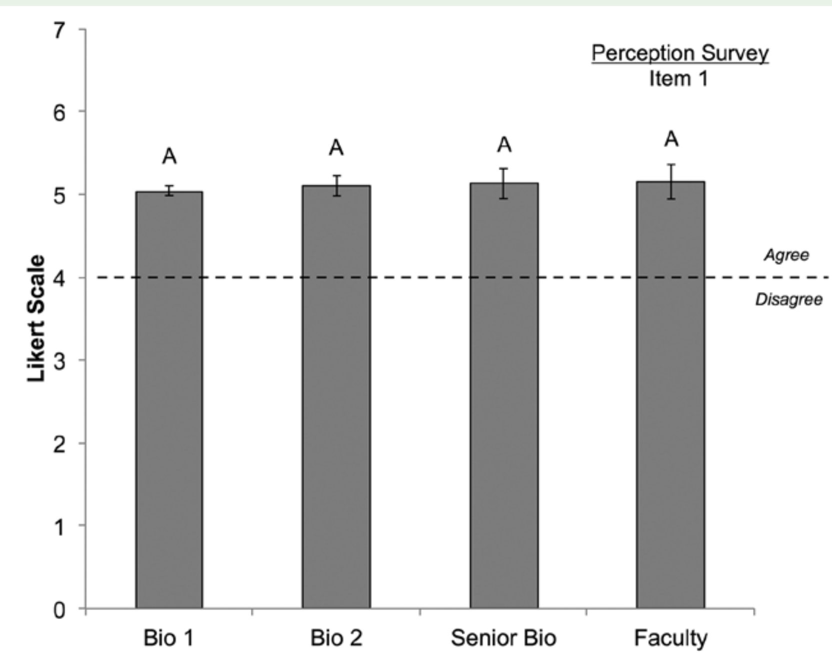
Collectively, all the participants perceived that PowerPoint was a useful and effective tool for their learning, with Likert scale rating typically above 4.0. The only participant group that was slightly below this value was faculty, who remained neutral. This aligns with previous literature that indicates a general consensus for the perception of usefulness and effectiveness of PowerPoint as an instructional tool (Parker et al., 2008) and may explain its continued and ubiquitous use in undergraduate biology classrooms.

It was found that early-career biology majors (Bio 1, Bio 2) found PowerPoint statistically significantly more useful and effective than later-stage biology majors (Senior Bio). To our knowledge, these results are unique in that they are the first demonstration of a potential progressive decline in biology majors' perceptions of the usefulness and effectiveness of PowerPoint as they proceed through their programs of study. As this was a cross-sectional survey design, future studies tracking particular cohorts longitudinally might find additional evidence to support this claim.

When examining the specific components that appear on PowerPoint slide construction, there is a statistical difference in the consensus between the effectiveness of text and the ef-

FIGURE 3

Average Likert ratings for Item 1. Bars represent average ratings for the four sampled groups. Likert scale ranged between 7 (*strongly agree*) and 1 (*strongly disagree*) as seen on the *y*-axis.



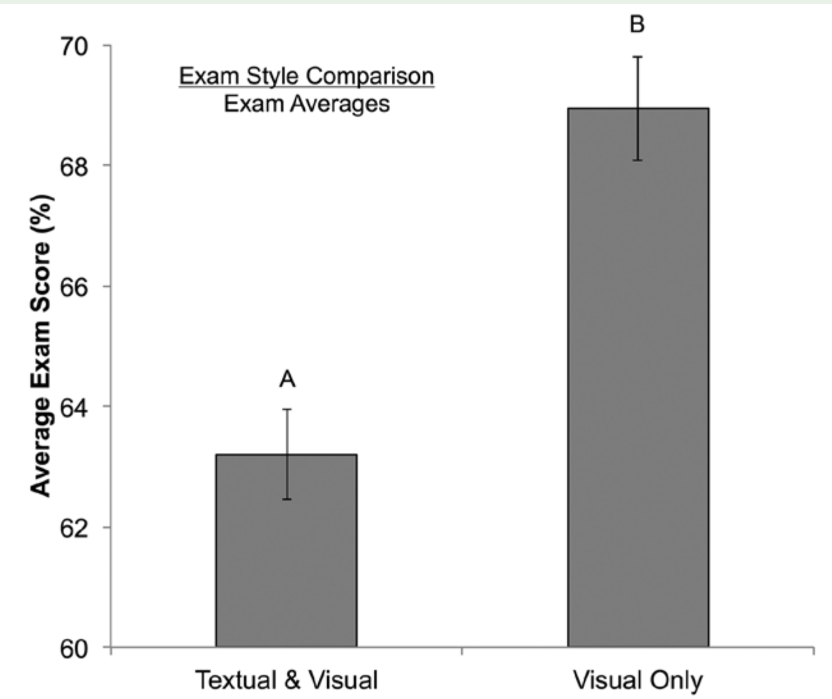
fectiveness of visuals on slides. All categories of participants perceived visual elements as both useful and effective. In support of the findings, Johnson and Christensen (2011) showed that when started from the beginning of the semester, students preferred to have simplified-visual slides with a pertinent graphic and short statement about the concept versus traditional presentation slides with a title and bulleted list of information. However, when asked about textual components, all students at particular stages in the major preferred to have textual elements on their PowerPoint slides in this study. Faculty remained neutral in their perceptions of the usefulness and effectiveness of text on PowerPoint slides, which differed from all student categories in this sample.

PowerPoint as a teaching tool is not going away. Its use remains rampant in undergraduate biology classrooms. Our data indicate this is not a negative thing at all, as study participants perceived it is useful and effective to their learning. However, our data indirectly indicate the potential decline in participants' perceptions of the usefulness of this tool over time. These data do not indicate whether this is an indication of the typical changing structure of classrooms as students proceed through their major (from large-enrollment, lecture-hall type context to more intimate class sizes with applied content). Future studies might want to examine *why* these trends exist utilizing cohort-based longitudinal designs.

This study also recognizes the limitations of self-report perceptual work. Although understanding student and faculty perceptions of instructional tools is important, perceptions of effective teaching and learning do not always align with evidence-based research on what is actually effective (Dunlosky, Rawson, March, Nathan, & Willingham, 2013). To address this limitation, the study did not confine itself to student and faculty *perceptions* of the critical components of PowerPoint slides for student learning, but also looked at the impact of these components to student learning in the subsequent study.

FIGURE 4

Average final scores of all students in the text + visual treatment versus those in the visual only treatment. Text + visual has an average exam score of 63.2, and visual only has an average exam score of 68.9, for a difference of 5.7%.



Study 2

The findings indicate that PowerPoints with visual components only were statistically better in promoting student learning compared with visual and textual components combined. This was true also when controlling for confounding variables including different class session times. It has been suggested that instructional best practices include text and images appearing together with the presenter narrating the slides (Berk 2012). These results align with the dual coding theory, which states that there are two channels through which information is processed: visual and auditory (Yue, Castel, & Bjork, 2013). Dual coding theory asserts that when both words and pictures are presented visually along with words verbally, the visual channel is overloaded; students try to make sense of both the text and visual and therefore do not fully process either (Mayer, 2001; Yue et al., 2013).

There was an impact that visual-only slides had on students who traditionally struggled in the introductory course. Lower quantile students enrolled in the class utilizing visual-only slides saw a statistically significant improvement in exam scores over lower quantile students enrolled in the visual + textual treatment (Figure 5). With calls to improve student learning in undergraduate biology classrooms (American Association for the Advancement of Science [AAAS], 2011) that traditionally see high attrition rates, our data indicate that simple fixes—such as what content components are included on slides—may increase student learning, especially in groups that struggle academically (students in the D/F/W groups).

Understanding the utility of PowerPoint as a learning tool is further complicated by the fact that any instructional technology does not in and of itself increase student knowledge. The impact of instructional technology on student learning is dependent on *how* an instructor uses it and the *context* in which it is used (Wiebe, Slykhuis, & Annetta, 2007). Several studies have concluded that perhaps there is not a universal way PowerPoint aids in student learning, but perhaps it is a subject-specific response that is related to the lecturer's presentation in association with the teaching tool (Szabo & Hastings, 2000; Wiebe et al., 2007). With the strong reliance of visuals in biology as a discipline, considerations of slide design beyond delivery of textual information are important to consider as well.

With active learning classrooms moving away from more traditional learning techniques, it might be important to consider that PowerPoint is not moving in a parallel direction. There are calls for a more fine-grained

FIGURE 5

Mean exam score differences between the two treatments broken down per quantile. Differences were seen predominantly in students below the 75th quantile. Students below that range were scoring higher in the visual only treatment.

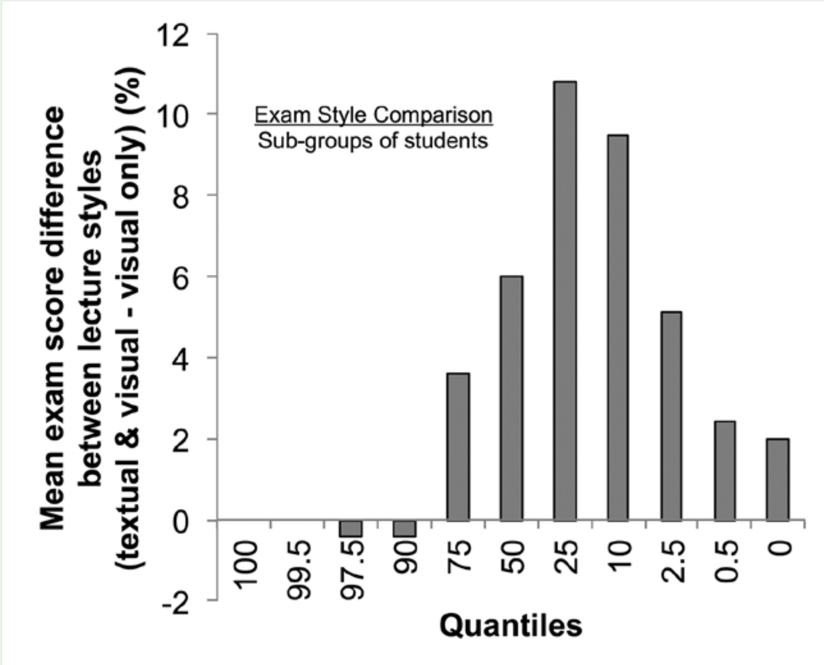
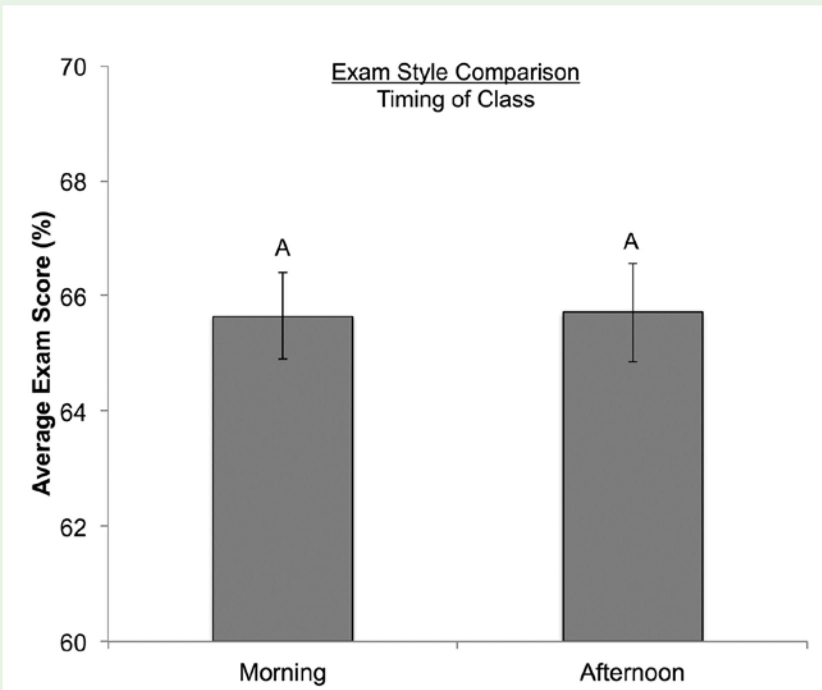


FIGURE 6

Final scores between students enrolled in morning classes versus afternoon classes. The average for the morning class was 65.65 and the afternoon was 65.71, with no significant difference.



analysis of what works and what does not work in biology classrooms. *Vision and Change* (AAAS, 2011) defines success as students being literate in biological concepts, which includes their ability to navigate complex biological visualizations (Arneson & Offerdahl, 2018). Our work suggests a simple and expedient way that biology instructors can affect student learning without completely overhauling their more traditional classroom methods. The results align with cognitive and learning science theories that situate PowerPoint as a tool that *supports* learning and not as an instructional tool that *promotes* learning, as it has more traditionally been envisioned. ■

References

Amare, N. (2006). To slideware or not to slideware: Students' experiences with PowerPoint vs. lecture. *Journal of Technical Writing and Communication, 36,* 297–308.

American Association for the Advancement of Sciences. (2011). *Vision and change in undergraduate biology education: A call to action.* Washington, DC: Author.

Apperson, J., Laws, E., & Scepansky, J. (2006). The impact of presentation graphics on students' experience in the classroom. *Computers and Education, 47,* 116–126.

Arneson, J. B., & Offerdahl, E. G. (2018). Visual literacy in bloom: Using Bloom's taxonomy to support visual learning skills. *CBE—Life Sciences Education, 17*(1), ar7.

Ausubel, D. P. (1978). In defense of advance organizers. A reply to critics. *Review of Educational Research, 48,* 251–257.

Bartsch, R., & Cobern, K. (2003). Effectiveness of PowerPoint presentations in lectures. *Computers and Education 41,* 77–86.

Berk, R. (2012). Top 10 evidence-based, best practices for PowerPoint in the classroom. *Transformative Dialogues: Teaching & Learning Journal, 5,* 1–7.

Buchko, A., Buchko, K., & Meyer, J. (2012). Is there power in PowerPoint? A field test of the efficacy of PowerPoint on memory and recall of religious sermons. *Computers and Human Behavior, 28,* 688–695.

Craig, R. J., & Amernic, J. H. (2006). PowerPoint presentation technology and the dynamics of teaching. *Innovative Higher Education, 31,* 147–160.

Crowe, A., Dirks, C., & Wenderoth, M. P. (2008). Biology in bloom: Implementing Bloom's taxonomy to enhance student learning in biology. *CBE—Life Sciences Education, 7,* 368–381.

Dunlosky, J., Rawson, K. A., March, E. J., Nathan, M. J., & Willingham, D. T. (2013). Improving students' learning with effective learning techniques: Promising directions from cognitive and educational psychology. *Psychological Science in the Public Interest, 14,* 1–55.

Erwin, T. D., & Rieppi, R. (1999). Comparing multimedia and traditional approaches in undergraduate psychology classes. *Teaching of Psychology, 56,* 58–61.

Hurtado, S., Eagan, K., Pryor, J. H., Whang, H., & Tran, S. (2013). *Undergraduate teaching faculty: The 2010–2011 HERI survey.* Los Angeles, CA: Higher Education Research Institute.

Johnson, E., & Christensen, J. (2011). A comparison of simplified-visually rich and traditional presentation styles. *Teaching of Psychology, 38,* 293–297.

Jones, M. G., Gardner, G. E., Taylor, A. R., Wiebe, E., & Forrester, J. (2011). Conceptualizing magnification and scale: The roles of spatial visualization and logical thinking. *Research in Science Education, 41*, 357–368.

Kustritz, M. V. R. (2014). Effect of differing PowerPoint design on multiple-choice test scores for assessment of knowledge and retention in a theriogenology course. *Journal of Veterinary Medical Education, 41*(3), 1–22.

Mayer, R. E. (2001). *Multimedia learning.* New York, NY: Cambridge University Press.

Noppe, A., Achterberg, J., Duquaine, L. Huebbe M., & Williams, C. (2007). PowerPoint presentation handouts and college student learning outcomes. *International Journal for the Scholarship of Teaching and Learning, 1*(1), ar9.

Parker, R. E., Bianchi, A., & Cheah, T. Y. (2008). Perceptions of instructional technology: Factors of influence and anticipated consequences. *Educational Technology & Society, 11,* 274–293.

Sievertsen, H. H., Gino, F., & Piovesan, M. (2016). Cognitive fatigue influences students' performance on standardized tests. *Proceedings of the National Academy of Sciences, USA, 113*, 2621–2624. Available at http://www.pnas.org/content/pnas/early/2016/02/09/1516947113.full.pdf

Stefanski, K. M., Gardner, G. E., & Seipelt-Theiman, R. L. (2016). Development of a Lac Operon Concept Inventory (LOCI). *CBE—Life Sciences Education*, *15*(2), ar24.

Susskind, J. (2005). PowerPoint's

power in the classroom: Enhancing students' self-efficacy and attitudes. *Computers and Education, 45,* 203–215.

Szabo, A., & Hastings, N. (2000). Using IT in the undergraduate classroom: Should we replace the blackboard with PowerPoint? *Computers and Education, 35,* 175–187.

Taylor, A., & Jones, M. G. (2013). Students' and teachers' application of surface area to volume relationships. *Research in Science Education, 43*(1), 395–411.

Tibell, L. A. E., & Rundgren, C. J. (2010). Educational challenges of molecular life science: Characteristics and implications for education and research. *CBE—Life Sciences Education, 9*, 25–33.

Trumbo, J. (1999). Visual literacy and science communication. *Science Communication, 20,* 409–425.

Wiebe, E., Slykhuis, D., & Annetta, L. (2007). Evaluating the effectiveness of scientific visualization in two PowerPoint delivery strategies on science learning for preservice science teachers. *International Journal of Science and Mathematics Education 5,* 329–348.

Wright, L. K., Cardenas, J. J., Liang, P., & Newman, D. L. (2018). Arrows in biology: Lack of clarity and consistency points to confusion for learners. *CBE—Life Sciences Education, 17*(1), ar6.

Yue, C. L., Castel, A. D., & Bjork, R. A. (2013). When disfluency is—and is not—a desirable difficulty: The influence of typeface clarity on metacognitive judgments and memory. *Memory & Cognition, 41,* 229–241.

Ryan Otter *is a professor and* ***Grant E. Gardner*** (grant.gardner@mtsu.edu) *is an assistant professor, both in the Department of Biology at Middle Tennessee State University in Murfreesboro.* ***Emily Smith-Peavler*** *was a graduate student at Middle Tennessee State University at the time this article was written.*