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Research

Case Study Teaching Method Improves Student Performance and Perceptions of Learning Gains †

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Following years of widespread use in business and medical education, the case study teaching method is becoming an increasingly common teaching strategy in science education. However, the current body of research provides limited evidence that the use of published case studies effectively promotes the fulfillment of specific learning objectives integral to many biology courses. This study tested the hypothesis that case studies are more effective than classroom discussions and textbook reading at promoting learning of key biological concepts, development of written and oral communication skills, and comprehension of the relevance of biological concepts to everyday life. This study also tested the hypothesis that case studies produced by the instructor of a course are more effective at promoting learning than those produced by unaffiliated instructors. Additionally, performance on quantitative learning assessments and student perceptions of learning gains were analyzed to determine whether reported perceptions of learning gains accurately reflect academic performance. The results reported here suggest that case studies, regardless of the source, are significantly more effective than other methods of content delivery at increasing performance on examination questions related to chemical bonds, osmosis and diffusion, mitosis and meiosis, and DNA structure and replication. This finding was positively correlated to increased student perceptions of learning gains associated with oral and written communication skills and the ability to recognize connections between biological concepts and other aspects of life. Based on these findings, case studies should be considered as a preferred method for teaching about a variety of concepts in science courses.

INTRODUCTION

The case study teaching method is a highly adaptable style of teaching that involves problem-based learning and promotes the development of analytical skills (8). By presenting content in the format of a narrative accompanied by questions and activities that promote group discussion and solving of complex problems, case studies facilitate development of the higher levels of Bloom's taxonomy of cognitive learning; moving beyond recall of knowledge to analysis, evaluation, and application (1, 9). Similarly, case studies facilitate interdisciplinary learning and can be used to highlight connections between specific academic topics and real-world societal issues and applications (3, 9). This has been reported to increase student motivation to participate in class activities, which promotes learning and increases performance on assessments (7, 16, 19, 23). For these reasons, case-based teaching has been widely used in business and medical education for many years (4, 11, 12, 14). Although case studies were considered a novel method of science education just 20 years ago, the case study teaching method has gained popularity in recent years among an array of scientific disciplines such as biology, chemistry, nursing, and psychology (5–7, 9, 11, 13, 15–17, 21, 22, 24).

Although there is now a substantive and growing body of literature describing how to develop and use case studies in science teaching, current research on the effectiveness of case study teaching at meeting specific learning objectives is of limited scope and depth. Studies have shown that working in groups during completion of case studies significantly improves student perceptions of learning and may increase performance on assessment questions, and that the use of clickers can increase student engagement in case study activities, particularly among non-science majors, women, and freshmen (7, 21, 22). Case study teaching has been shown to improve exam performance in an anatomy and physiology course, increasing the mean score across all exams given in a two-semester sequence from 66% to 73% (5). Use of case studies was also shown to improve students' ability to synthesize complex analytical questions about the real-world issues associated with a scientific topic (6). In a high school chemistry course, it was demonstrated that the case study teaching method

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produces significant increases in self-reported control of learning, task value, and self-efficacy for learning and performance (24). This effect on student motivation is important because enhanced motivation for learning activities has been shown to promote student engagement and academic performance (19, 24). Additionally, faculty from a number of institutions have reported that using case studies promotes critical thinking, learning, and participation among students, especially in terms of the ability to view an issue from multiple perspectives and to grasp the practical application of core course concepts (23).

Despite what is known about the effectiveness of case studies in science education, questions remain about the functionality of the case study teaching method at promoting specific learning objectives that are important to many undergraduate biology courses. A recent survey of teachers who use case studies found that the topics most often covered in general biology courses included genetics and heredity, cell structure, cells and energy, chemistry of life, and cell cycle and cancer, suggesting that these topics should be of particular interest in studies that examine the effectiveness of the case study teaching method (8). However, the existing body of literature lacks direct evidence that the case study method is an effective tool for teaching about this collection of important topics in biology courses. Further, the extent to which case study teaching promotes development of science communication skills and the ability to understand the connections between biological concepts and everyday life has not been examined, yet these are core learning objectives shared by a variety of science courses. Although many instructors have produced case studies for use in their own classrooms, the production of novel case studies is time-consuming and requires skills that not all instructors have perfected. It is therefore important to determine whether case studies published by instructors who are unaffiliated with a particular course can be used effectively and obviate the need for each instructor to develop new case studies for their own courses. The results reported herein indicate that teaching with case studies results in significantly higher performance on examination questions about chemical bonds, osmosis and diffusion, mitosis and meiosis, and DNA structure and replication than that achieved by class discussions and textbook reading for topics of similar complexity. Case studies also increased overall student perceptions of learning gains and perceptions of learning gains specifically related to written and oral communication skills and the ability to grasp connections between scientific topics and their real-world applications. The effectiveness of the case study teaching method at increasing academic performance was not correlated to whether the case study used was authored by the instructor of the course or by an unaffiliated instructor. These findings support increased use of published case studies in the teaching of a variety of biological concepts and learning objectives.

METHOD

Student population

This study was conducted at Kingsborough Community College, which is part of the City University of New York system, located in Brooklyn, New York. Kingsborough Community College has a diverse population of approximately 19,000 undergraduate students. The student population included in this study was enrolled in the first semester of a two-semester sequence of general (introductory) biology for biology majors during the spring, winter, or summer semester of 2014. A total of 63 students completed the course during this time period; 56 students consented to the inclusion of their data in the study. Of the students included in the study, 23 (41%) were male and 33 (59%) were female; 40 (71%) were registered as college freshmen and 16 (29%) were registered as college sophomores. To normalize participant groups, the same student population pooled from three classes taught by the same instructor was used to assess both experimental and control teaching methods.

Course material

The four biological concepts assessed during this study (chemical bonds, osmosis and diffusion, mitosis and meiosis, and DNA structure and replication) were selected as topics for studying the effectiveness of case study teaching because they were the key concepts addressed by this particular course that were most likely to be taught in a number of other courses, including biology courses for both majors and nonmajors at outside institutions. At the start of this study, relevant existing case studies were freely available from the National Center for Case Study Teaching in Science (NCCSTS) to address mitosis and meiosis and DNA structure and replication, but published case studies that appropriately addressed chemical bonds and osmosis and diffusion were not available. Therefore, original case studies that addressed the latter two topics were produced as part of this study, and case studies produced by unaffiliated instructors and published by the NCCSTS were used to address the former two topics. By the conclusion of this study, all four case studies had been peer-reviewed and accepted for publication by the NCCSTS (http://sciencecases.lib.buffalo.edu/cs/). Four of the remaining core topics covered in this course (macromolecules, photosynthesis, genetic inheritance, and translation) were selected as control lessons to provide control assessment data.

To minimize extraneous variation, control topics and assessments were carefully matched in complexity, format, and number with case studies, and an equal amount of class time was allocated for each case study and the corresponding control lesson. Instruction related to control lessons was delivered using minimal slide-based lectures, with emphasis on textbook reading assignments accompanied by worksheets completed by students in and out of the classroom, and small and large group discussion of key points. Completion of activities and discussion related to all case studies and control topics that were analyzed was conducted in the classroom, with the exception of the take-home portion of the osmosis and diffusion case study.

Data collection and analysis

This study was performed in accordance with a protocol approved by the Kingsborough Community College Human Research Protection Program and the Institutional Review Board (IRB) of the City University of New York (CUNY IRB reference 539938-1; KCC IRB application #: KCC 13-12-126-0138). Assessment scores were collected from regularly scheduled course examinations. For each case study, control questions were included on the same examination that were similar in number, format, point value, and difficulty level, but related to a different topic covered in the course that was of similar complexity. Complexity and difficulty of both case study and control questions were evaluated using experiential data from previous iterations of the course; the Bloom's taxonomy designation and amount of material covered by each question, as well as the average score on similar questions achieved by students in previous iterations of the course was considered in determining appropriate controls. All assessment questions were scored using a standardized, pre-determined rubric. Student perceptions of learning gains were assessed using a modified version of the Student Assessment of Learning Gains (SALG) course evaluation tool (http://www.salgsite.org), distributed in hardcopy and completed anonymously during the last week of the course. Students were presented with a consent form to opt-in to having their data included in the data analysis. After the course had concluded and final course grades had been posted, data from consenting students were pooled in a database and identifying information was removed prior to analysis. Statistical analysis of data was conducted using the Kruskal-Wallis one-way analysis of variance and calculation of the R^2 coefficient of determination.

RESULTS

Teaching with case studies improves performance on learning assessments, independent of case study origin

To evaluate the effectiveness of the case study teaching method at promoting learning, student performance on examination questions related to material covered by case studies was compared with performance on questions that covered material addressed through classroom discussions and textbook reading. The latter questions served as control items; assessment items for each case study were compared with control items that were of similar format, difficulty, and point value (Appendix 1). Each of the four case studies resulted in an increase in examination performance compared with control questions that was statistically significant, with an average difference of 18% (Fig. 1). The mean score on case study-related questions was 73% for the chemical bonds case study, 79% for osmosis and diffusion, 76% for mitosis and meiosis, and 70% for DNA structure and replication (Fig. 1). The mean score for non-case study-related control questions was 60%, 54%, 60%, and 52%, respectively (Fig. 1). In terms of examination performance, no significant difference between case studies produced by the instructor of the course (chemical bonds and osmosis and diffusion) and those produced by unaffiliated instructors (mitosis and meiosis and DNA structure and replication) was indicated by the Kruskal-Wallis one-way analysis of variance. However, the 25% difference between the mean score on questions related to the osmosis and diffusion case study and the mean score on the paired control questions was notably higher than the 13–18% differences observed for the other case studies (Fig. 1).

Case study teaching increases student perception of learning gains related to core course objectives

Student learning gains were assessed using a modified version of the SALG course evaluation tool (Appendix 2). To determine whether completing case studies was more effective at increasing student perceptions of learning gains than completing textbook readings or participating in class discussions, perceptions of student learning gains for each were compared. In response to the question "Overall, how much did each of the following aspects of the class help your learning?" 82% of students responded that case studies helped a "good" or "great" amount, compared with 70% for participating in class discussions and 58% for completing textbook reading; only 4% of students responded that case

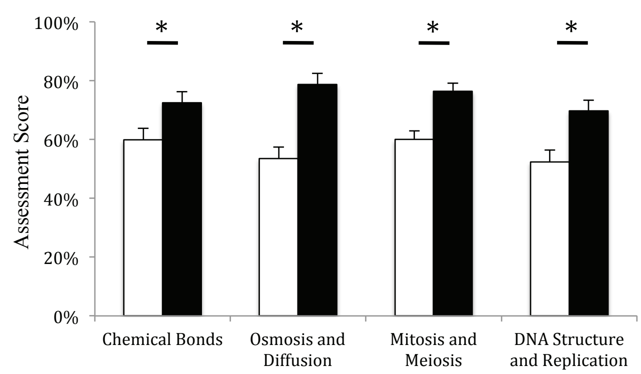

FIGURE 1. Case study teaching method increases student performance on examination questions. Mean score on a set of examination questions related to lessons covered by case studies (black bars) and paired control questions of similar format and difficulty about an unrelated topic (white bars). Chemical bonds, n = 54; Osmosis and diffusion, n = 54; Mitosis and meiosis, n = 51; DNA structure and replication, n = 50. Error bars represent the standard error of the mean (SEM). Asterisk indicates $p < 0.05$.

studies helped a "small amount" or "provided no help," compared with 2% for class discussions and 22% for textbook reading (Fig. 2A). The differences in reported learning gains derived from the use of case studies compared with class discussion and textbook readings were statistically significant, while the difference in learning gains associated with class discussion compared with textbook reading was not statistically significant by a narrow margin ($p = 0.051$).

To elucidate the effectiveness of case studies at promoting learning gains related to specific course learning objectives compared with class discussions and textbook reading, students were asked how much each of these methods of content delivery specifically helped improve skills that were integral to fulfilling three main course objectives. When students were asked how much each of the methods helped "improve your ability to communicate knowledge of scientific concepts in writing," 81% of students responded that case studies help a "good" or "great" amount, compared with 63% for class discussions and 59% for textbook reading; only 6% of students responded that case studies helped a "small amount" or "provided no help," compared with 8% for class discussions and 21% for textbook reading (Fig. 2B). When the same question was posed about the ability to communicate orally, 81% of students responded that case studies help a "good" or "great" amount, compared with 68% for class discussions and 50% for textbook reading, while the respective response rates for helped a "small amount" or "provided no help," were 4%, 6%, and 25% (Fig. 2C). The differences in learning gains associated with both written and oral communication were statistically significant when completion of case studies was compared with either participation in class discussion or completion of textbook readings. Compared with textbook reading, class discussions led to a statistically significant increase in oral but not written communication skills.

Students were then asked how much each of the methods helped them "understand the connections between scientific concepts and other aspects of your everyday life." A total of 79% of respondents declared that case studies help a "good" or "great" amount, compared with 70% for class discussions and 57% for textbook reading (Fig. 2D). Only 4% stated that case studies and class discussions helped a "small amount" or "provided no help," compared with 21% for textbook reading (Fig. 2D). Similar to overall learning gains, the use of case studies significantly increased the ability to understand the relevance of science to everyday life

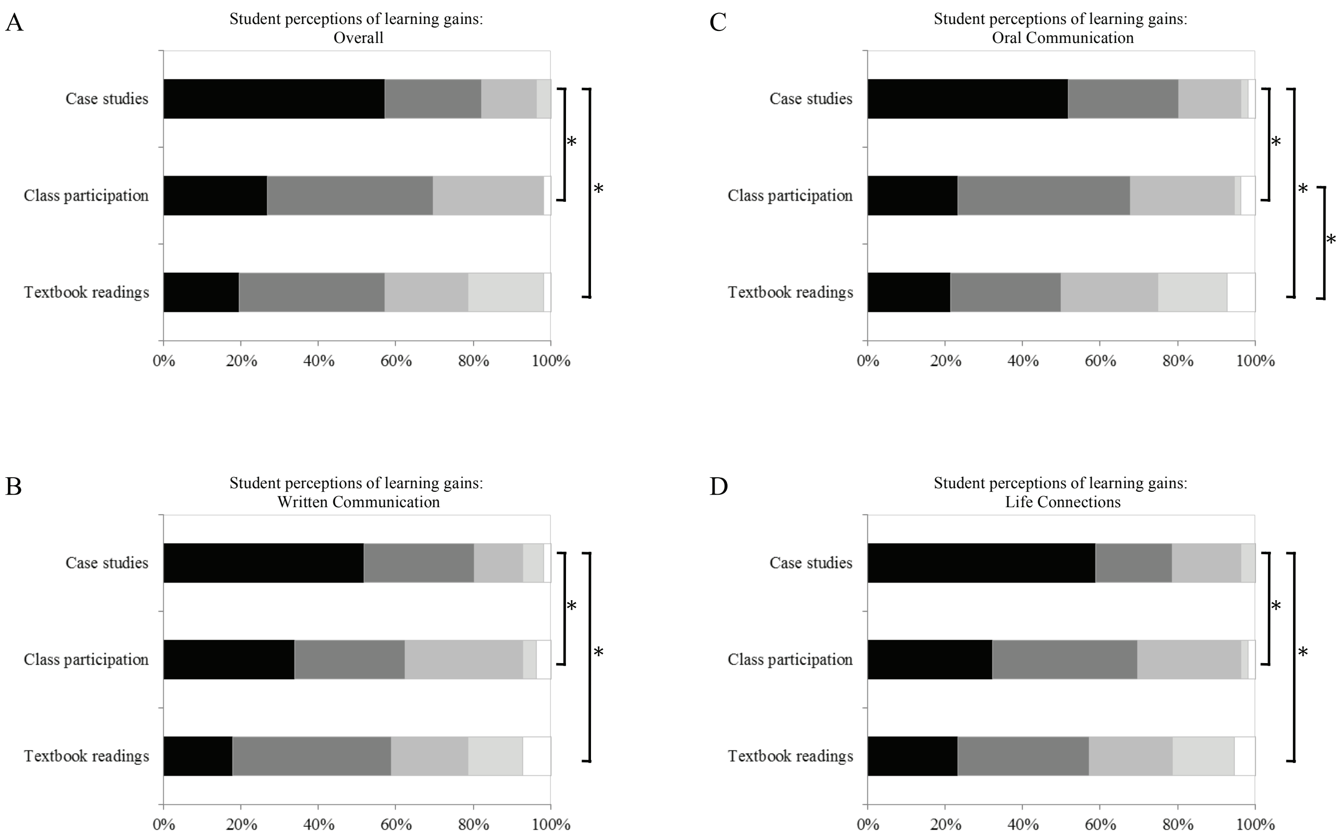

FIGURE 2. The case study teaching method increases student perceptions of learning gains. Student perceptions of learning gains are indicated by plotting responses to the question "How much did each of the following activities: (A) Help your learning overall? (B) Improve your ability to communicate your knowledge of scientific concepts in writing? (C) Improve your ability to communicate your knowledge of scientific concepts orally? (D) Help you understand the connections between scientific concepts and other aspects of your everyday life?" Reponses are represented as follows: Helped a great amount (black bars); Helped a good amount (dark gray bars); Helped a moderate amount (medium gray bars); Helped a small amount (light gray bars); Provided no help (white bars). Asterisk indicates $p < 0.05$.

compared with class discussion and textbook readings, while the difference in learning gains associated with participation in class discussion compared with textbook reading was not statistically significant ($p = 0.054$).

Student perceptions of learning gains resulting from case study teaching are positively correlated to increased performance on examinations, but independent of case study author

To test the hypothesis that case studies produced specifically for this course by the instructor were more effective at promoting learning gains than topically relevant case studies published by authors not associated with this course, perceptions of learning gains were compared for each of the case studies. For both of the case studies produced by the instructor of the course, 87% of students indicated that the case study provided a "good" or "great" amount of help to their learning, and 2% indicated that the case studies provided "little" or "no" help (Table 1). In comparison, an average of 85% of students indicated that the case studies produced by an unaffiliated instructor provided a "good" or "great" amount of help to their learning, and 4% indicated that the case studies provided "little" or "no" help (Table 1). The instructor-produced case studies yielded both the highest and lowest percentage of students reporting the highest level of learning gains (a "great" amount), while case studies produced by unaffiliated instructors yielded intermediate values. Therefore, it can be concluded that the effectiveness of case studies at promoting learning gains is not significantly affected by whether or not the course instructor authored the case study.

Finally, to determine whether performance on examination questions accurately predicts student perceptions of learning gains, mean scores on examination questions related to case studies were compared with reported perceptions of learning gains for those case studies (Fig. 3). The coefficient of determination (R^2 value) was 0.81, indicating a strong, but not definitive, positive correlation between perceptions of learning gains and performance on examinations, suggesting that student perception of learning gains is a valid tool for assessing the effectiveness of case studies (Fig. 3). This correlation was independent of case study author.

DISCUSSION

The purpose of this study was to test the hypothesis that teaching with case studies produced by the instructor of a course is more effective at promoting learning gains than using case studies produced by unaffiliated instructors. This study also tested the hypothesis that the case study teaching method is more effective than class discussions and textbook reading at promoting learning gains associated with four of the most commonly taught topics in undergraduate general biology courses: chemical bonds, osmosis and diffusion, mitosis and meiosis, and DNA structure and replication. In addition to assessing content-based learning gains, development of written and oral communication skills and the ability to connect scientific topics with real-world applications was also assessed, because these skills were overarching learning objectives of this course, and classroom activities related to both case studies and control lessons were designed to provide opportunities for students to develop these skills. Finally, data were analyzed to determine whether performance on examination questions is positively correlated to student perceptions of learning gains resulting from case study teaching.

Compared with equivalent control questions about topics of similar complexity taught using class discussions and textbook readings, all four case studies produced statistically significant increases in the mean score on examination questions (Fig. 1). This indicates that case studies are more effective than more commonly used, traditional methods of content delivery at promoting learning of a variety of core concepts covered in general biology courses. The average increase in score on each test item was equivalent to nearly two letter grades, which is substantial enough to elevate the average student performance on test items from the unsatisfactory/failing range to the satisfactory/passing range. The finding that there was no statistical difference between case studies in terms of performance on examination questions suggests that case studies are equally effective at promoting

TABLE 1.
Case studies positively affect student perceptions of learning gains about various biological topics.

Case Study Topic	Case Study Author	Provided a Great Amount of Help	Provided a Good Amount of Help	Provided a Moderate Amount of Help	Provided a Small Amount of Help	Provided No Help
Chemical bonds	Yee and Bonney (25)	37%	50%	11%	2%	0%
Osmosis and diffusion	Bonney (2)	62%	25%	11%	2%	0%
Mitosis and meiosis	Herreid (10)	52%	39%	5%	4%	0%
DNA structure and replication	Pals-Rylaarsdam (18)	55%	23%	18%	2%	2%

learning of disparate topics in biology. The observations that students did not perform significantly less well on the first case study presented (chemical bonds) compared with the other case studies and that performance on examination questions did not progressively increase with each successive case study suggests that the effectiveness of case studies is not directly related to the amount of experience students have using case studies. Furthermore, anecdotal evidence from previous semesters of this course suggests that, of the four topics addressed by cases in this study, DNA structure and function and osmosis and diffusion are the first and second most difficult for students to grasp. The lack of a statistical difference between case studies therefore suggests that the effectiveness of a case study at promoting learning gains is not directly proportional to the difficulty of the concept covered. However, the finding that use of the osmosis and diffusion case study resulted in the greatest increase in examination performance compared with control questions and also produced the highest student perceptions of learning gains is noteworthy and could be attributed to the fact that it was the only case study evaluated that included a hands-on experiment. Because the inclusion of a hands-on kinetic activity may synergistically enhance student engagement and learning and result in an even greater increase in learning gains than case studies that lack this type of activity, it is recommended that case studies that incorporate this type of activity be preferentially utilized.

Student perceptions of learning gains are strongly motivating factors for engagement in the classroom and academic performance, so it is important to assess the effect of any teaching method in this context (19, 24). A modified version of the SALG course evaluation tool was used to assess student perceptions of learning gains because it has been previously validated as an efficacious tool (Appendix 2) (20). Using the SALG tool, case study teaching was demonstrated to significantly increase student perceptions of overall learning gains compared with class discussions and textbook reading (Fig. 2A). Case studies were shown to be particularly useful for promoting perceived development of written and oral communication skills and for demonstrating connections between scientific topics and real-world issues and applications (Figs. 2B–2D). Further, student perceptions of "great" learning gains positively correlated with increased performance on examination questions, indicating that assessment of learning gains using the SALG tool is both valid and useful in this course setting (Fig. 3). These findings also suggest that case study teaching could be used to increase student motivation and engagement in classroom activities and thus promote learning and performance on assessments. The finding that textbook reading yielded the lowest student perceptions of learning gains was not unexpected, since reading facilitates passive learning while the class discussions and case studies were both designed to promote active learning.

Importantly, there was no statistical difference in student performance on examinations attributed to the two case studies produced by the instructor of the course compared with the two case studies produced by unaffiliated instructors. The average difference between the two instructor-produced case studies and the two case studies published by unaffiliated instructors was only 3% in terms of both the average score on examination questions (76% compared with 73%) and the average increase in score compared with paired control items (14% compared with 17%) (Fig. 1). Even when considering the inherent qualitative differences of course grades, these differences are negligible. Similarly, the effectiveness of case studies at promoting learning gains was not significantly affected by the origin of the case study, as evidenced by similar percentages of students reporting "good" and "great" learning gains regardless of whether the case study was produced by the course instructor or an unaffiliated instructor (Table 1).

The observation that case studies published by unaffiliated instructors are just as effective as those produced by the instructor of a course suggests that instructors can reasonably rely on the use of pre-published case studies relevant to their class rather than investing the considerable time and effort required to produce a novel case study. Case studies covering a wide range of topics in the sciences are available from a number of sources, and many of them are free access. The National Center for Case Study Teaching in Science (NCCSTS) database (http://sciencecases.lib.buffalo.edu/cs/) contains over 500 case studies that are freely available to instructors, and are accompanied by teaching notes that provide logistical advice and additional resources for implementing the case study, as well as a set of assessment questions with a

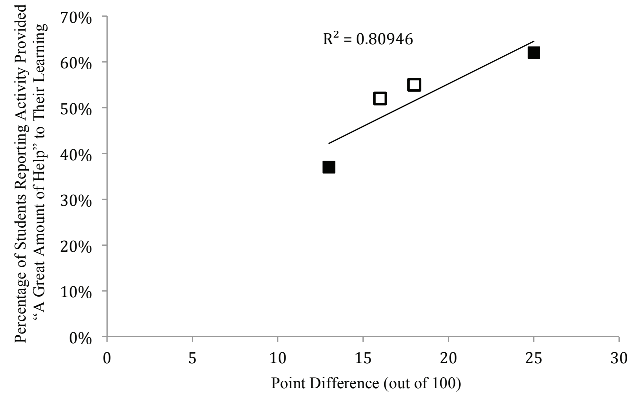

FIGURE 3. Perception of learning gains but not author of case study is positively correlated to score on related examination questions. Percentage of students reporting that each specific case study provided "a great amount of help" to their learning was plotted against the point difference between mean score on examination questions related to that case study and mean score on paired control questions. Positive point differences indicate how much higher the mean scores on case study-related questions were than the mean scores on paired control questions. Black squares represent case studies produced by the instructor of the course; white squares represent case studies produced by unaffiliated instructors. R^2 value indicates the coefficient of determination.

password-protected answer key. Case study repositories are also maintained by BioQUEST Curriculum Consortium (http://www.bioquest.org/icbl/cases.php) and the Science Case Network (http://sciencecasenet.org); both are available for use by instructors from outside institutions.

It should be noted that all case studies used in this study were rigorously peer-reviewed and accepted for publication by the NCCSTS prior to the completion of this study (2, 10, 18, 25); the conclusions of this study may not apply to case studies that were not developed in accordance with similar standards. Because case study teaching involves skills such as creative writing and management of dynamic group discussion in a way that is not commonly integrated into many other teaching methods, it is recommended that novice case study teachers seek training or guidance before writing their first case study or implementing the method. The lack of a difference observed in the use of case studies from different sources should be interpreted with some degree of caution since only two sources were represented in this study, and each by only two cases. Furthermore, in an educational setting, quantitative differences in test scores might produce meaningful qualitative differences in course grades even in the absence of a p value that is statistically significant. For example, there is a meaningful qualitative difference between test scores that result in an average grade of C- and test scores that result in an average grade of C+, even if there is no statistically significant difference between the two sets of scores.

In the future, it could be informative to confirm these findings using a larger cohort, by repeating the study at different institutions with different instructors, by evaluating different case studies, and by directly comparing the effectiveness of the case studying teaching method with additional forms of instruction, such as traditional chalkboard and slide-based lecturing, and laboratory-based activities. It may also be informative to examine whether demographic factors such as student age and gender modulate the effectiveness of the case study teaching method, and whether case studies work equally well for non-science majors taking a science course compared with those majoring in the subject. Since the topical material used in this study is often included in other classes in both high school and undergraduate education, such as cell biology, genetics, and chemistry, the conclusions of this study are directly applicable to a broad range of courses. Presently, it is recommended that the use of case studies in teaching undergraduate general biology and other science courses be expanded, especially for the teaching of capacious issues with real-world applications and in classes where development of written and oral communication skills are key objectives. The use of case studies that involve hands-on activities should be emphasized to maximize the benefit of this teaching method. Importantly, instructors can be confident in the use of pre-published case studies to promote learning, as there is no indication that the effectiveness of the case study teaching method is reliant on the production of novel, customized case studies for each course.

SUPPLEMENTAL MATERIALS

Appendix 1: Example assessment questions used to assess the effectiveness of case studies at promoting learning

Appendix 2: Student learning gains were assessed using a modified version of the SALG course evaluation tool

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