Online courses are a large and growing part of the undergraduate education landscape, but many biology instructors are skeptical about the effectiveness of online instruction. We reviewed studies comparing the effectiveness of online and face-to-face (F2F) undergraduate biology courses. Five studies compared student performance in multiple course sections at community colleges, while eight were smaller scale and compared student performance in particular biology courses at a variety of types of institutions. Of the larger-scale studies, two found that students in F2F sections outperformed students in online sections, and three found no significant difference; it should be noted, however, that these studies reported little information about course design. Of the eight smaller scale studies, six found no significant difference in student performance between the F2F and online sections, while two found that the online sections outperformed the F2F sections. In alignment with general findings about online teaching and learning, these results suggest that well-designed online biology courses can be effective at promoting student learning. Three recommendations for effective online instruction in biology are given: the inclusion of an online orientation to acclimate students to the online classroom; student-instructor and student-student interactions facilitated through synchronous and asynchronous communication; and elements that prompt student reflection and self-assessment. We conclude that well-designed online biology courses can be as effective as their traditional counterparts, but that more research is needed to elucidate specific course elements and structures that can maximize online students’ learning of key biology skills and concepts.

INTRODUCTION

The advent of the Internet and related tools for digital communication and global connectivity has changed the way information is stored, communicated, and shared, removing the barriers of time and location. Not surprisingly, this development has caused many in the world of academia to rethink how courses could be taught, considering approaches that lessen barriers and increase access for many potential students. These ideas have deep roots—before the Internet, distance education was conducted through the mail and was well established by the late 1800s (12)—but are reaching new heights as digital communication tools mature. Today most distance education is conducted via the Internet, and it touches millions of students each year. For example, in 2014, over 5.8 million students participated in online classrooms, with more than half of them concurrently enrolled in online courses and on-campus courses (2).

Online and blended courses allow for greater flexibility and convenience in timing and location for the both the instructor and student. However, convenience and accessibility are only valuable if courses effectively facilitate student learning. Several meta-analyses have tackled this question, largely concluding that well-designed online courses do facilitate student learning. The US Department of Education found that in 43 of 50 studies of online courses, students did “modestly better, on average, than those learning the same material through traditional, face to face instruction” but noted that their results “do not demonstrate that online learning is superior as a medium...It was the combination of elements in the treatment conditions (which was likely to have included additional learning time and materials as well as additional opportunities for collaboration) that produced the observed learning advantages” (emphasis in original) (13). Siemens, Gašević, and Dawson reported similar results in Preparing for The Digital University: A Review of the History and Current State of Distance, Blended and Online Learning (20). The authors concluded that well-designed courses are crucial for further adoption of online learning. While these results reflect positively on online and blended learning in general, they do not examine online and blended learning outcomes in science courses, specifically those at the undergraduate level.
METHODS

To answer the question of whether the positive outcomes of online courses extend to undergraduate biology courses, the references cited in Siemens et al. (20) were reviewed and the biology-specific courses were identified. Studies comparing online with traditional face-to-face (F2F) biology courses were also identified through searching the ProQuest version of the ERIC database using the search terms “online or electronic” and “biol*”. Studies were also identified from the reference lists of those found through the database searches.

The studies included were those that compared performance in multiple sections of online and F2F biology courses taught at community colleges. The remaining eight were smaller studies examining a particular biology course at a variety of institution types.

The results for the larger studies are summarized in Table 1. Rosenzweig considered the final grades for more than 6,000 students over 14 semesters in four community college biology courses: General Biology I (GBI), Microbiology of Human Pathogens (MHP), Human Anatomy and Physiology I (HAPI), and Human Anatomy and Physiology II (HAPII) (18). Student grades were higher in the F2F sections than online sections of MHP and HAPI, but exhibited no difference in F2F versus online sections of GBI or HAPII. Importantly, the report does not indicate whether a lab was included as an integral part of the courses. The author makes the distinction that all of the courses were taught by different instructors, and just as this can play a role in the efficacy of F2F traditional lectures, it also can affect the learning outcomes in virtual classrooms. She also says that investments in up-to-date technology, student computer usage and online course competency, and instructor training could close the gap seen between online and on-campus courses.

Garman performed a somewhat similar study, comparing lecture grades, lab grades, and final course grades for students in biology courses over six semesters at a community college (5). She found that all of these measures were higher in F2F sections than in online sections, although effect sizes were small (η² = 0.02 for lecture grades and lab grades; η² < 0.01 for overall grades). Interestingly, when Garman considered traditional age students (25 years old), she observed no difference in grades for F2F and online courses, while students older than 24 exhibited better performance in F2F classes.

Similarly, Riggins examined performance of students in six sections of General Biology I with lab at a community college, comparing performance on unit tests and on an entrance exam for a more advanced course for students in three online and three F2F sections of the course (17). She saw no significant difference in student performance on either type of measure, although she did find that students in the online sections had significantly higher interactions with the instructor.

Hauser also compared online and F2F versions of an introductory biology class including lab (BIO 101) taught at community colleges, using student performance in F2F BIO 102 as the measure (7). More specifically, the study examined the BIO 102 performance of about 5,000 nonscience major students who completed BIO 101 (F2F or online) at one of 23 Virginia community colleges and also completed BIO 102 (F2F) at a Virginia community college within 1.5 years. Mode of instruction in BIO 101 was not predictive of success in BIO 102, although the study did find that male students who completed BIO 101 F2F were more likely to be successful in BIO 102.

Hill examined pretest/posttest gains in students taking introductory biology in online (12 sections; 75 participating students) or F2F (3 sections; 65 participating students) format at three community colleges in Missouri (8). She observed no difference in pretest/posttest gains in students taking the course in different formats. She did observe, however, a significantly different distribution of grades in online and F2F formats, with online students earning fewer high grades and more failing grades.

Thus, results from multi-section comparisons at community colleges do not provide a consistent answer to the question of whether online biology courses can be effective. It is worth noting that none of the studies considered the design of either the F2F or the online courses, for instance whether the design included evidence-based good practices such as active learning approaches or activities to promote student-student and student-instructor interaction.

We also identified eight studies that compared a particular course taught in two different formats. Six of these found no difference in student performance in the F2F and online formats, while two found that students in the online course had better learning outcomes (see Table 2).

Barbeau and colleagues compared grades for students taking a microscopic anatomy laboratory class in either a F2F or online format at a research university (3). Online students watched a pre-lab lecture, then completed microscopic analyses online. The authors found no significant difference in student performance on any of the measures, which included laboratory assignments, quizzes, practical examinations, and multiple-choice exams. Notably, the design of both the F2F and online courses included elements intended to promote student-instructor interaction.
Collins also observed no significant difference in student course grades in sections of a nonmajors biology course taught F2F and online at a large research university (4). The online course in this study included elements to promote student self-assessment and included mechanisms for feedback and student-instructor interaction.

Lunsford and Bolton compared student performance in F2F and online sections of an introductory biology course for nonmajors taught at a community college, observing no difference in student performance on an end-of-course exam (11). The online course included simple lab activities for students to complete at home as well as activities requiring library or Internet research.

Somenarain and colleagues compared student perception and student performance in F2F and online sections of Medical Terminology at an urban community college, observing no difference in either measure (22). The online class included several components designed to promote student engagement, including weekly quizzes and discussion boards.

Similarly, King and Hildreth observed no significant difference in test performance of students taking an introductory biology course either online or F2F at a liberal arts college (10). The online course was modified from the F2F course to include tools for student self-assessment as well as weekly assignments to increase student accountability and student-instructor interactions.

Johnson also observed no significant difference in grades, pretest/posttest gains, or gains in scientific reasoning for students taking a nonmajors biology class either online or F2F at a community college (9). The course included a lab, which online students completed online. The online course included elements intended to promote student engagement.

### Table 1

<table>
<thead>
<tr>
<th>Study</th>
<th>Course(s) Compared</th>
<th>Scope of Study</th>
<th>Measure Used</th>
<th>Results Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garman (5)</td>
<td>A biology course (lecture and lab; course name not provided)</td>
<td>170 F2F sections, 127 online sections</td>
<td>Lecture grades, Lab grades, Final course grades</td>
<td>All measures were higher in F2F sections. When students &lt;25 yo were considered as a separate group, however, there was no significant difference between F2F and online students using these measures.</td>
</tr>
<tr>
<td>Rosensweig (18)</td>
<td>General Biology I (GBI) Microbiology of Human Pathogens (MHP) Human Anatomy and Physiology I (HAPI) Human Anatomy and Physiology II (HAPII)</td>
<td>14 semesters</td>
<td>Final course grades</td>
<td>Grades were higher in F2F sections of MHP and HAPI. Grades were not different in GBI and HAPII.</td>
</tr>
<tr>
<td>Hill (8)</td>
<td>Introductory biology</td>
<td>3 F2F sections (77 students), 12 online sections (212 students)</td>
<td>Pre-/posttest scores, Final grades</td>
<td>No significant difference in pre-/posttest gains. Students in online sections earned significantly lower final course grades.</td>
</tr>
<tr>
<td>Hauser (7)</td>
<td>Introductory biology with lab (Biology 101)</td>
<td>2 semesters; 4,959 students</td>
<td>Grades in follow-up course (Biology 102; F2F)</td>
<td>No significant difference when males were considered as a separate group, however, males who completed Biology 101 online were significantly less likely to be successful in F2F Biology 102.</td>
</tr>
<tr>
<td>Riggins (17)</td>
<td>General Biology I with lab</td>
<td>3 F2F sections, 3 online sections</td>
<td>Grades on unit tests, Entrance exam scores for subsequent biology course</td>
<td>No significant difference</td>
</tr>
</tbody>
</table>

F2T = face to face; yo = years old.

a The description of the scope for each study differs due to study design and information given in the reports.

b Pre-/post-course assessments were completed by 65 students in the F2F sections and 75 students in online sections.

c Final grades were assigned for 73 students in F2F sections and 167 students in online sections.
engagement, accountability, and self-assessment, as well as student-instructor interaction.

Schoenfeld-Tacher and colleagues compared student pretest/posttest gains as well as student-instructor interactions in an upper-level histology course (with lab) taught F2F and online at a large land-grant university (19). The online course was structured to promote student-content interaction, student-instructor interaction, and student-student interaction. They observed that online students performed significantly better on the posttest and demonstrated a significantly greater pre-/posttest gain than the F2F students, with a small to medium effect size ($\eta^2 = 0.192$). Further, Schoenfeld-Tacher and colleagues observed greater levels of student-instructor interaction and more student-initiated interactions in the online course.

Reuter also observed stronger student performance in an online section of a course compared with a F2F section (16). Specifically, students took Sustainable Ecosystems, a course with both lecture and lab components that is designed to promote a biological science general education requirement at a comprehensive university. Students taking the course in both formats received the same lecture materials and performed similar lab and field exercises. The online course was structured to facilitate student-student and student-instructor interaction by including three required discussion boards and additional optional discussion boards for student questions and review. Students who took the course online performed significantly better on the post-course assessment and demonstrated significantly greater gains from pre- to post-course assessment. There was no difference in lab assignment grades or final course grades for the two groups.

Thus these studies suggest that online biology courses that are designed to promote desired student activities and interactions can be at least as effective as F2F sections of the course. What, then, are the design elements that help students in online biology courses reach the desired learning outcomes?

**Implications for teaching biology online**

A variety of resources provide guidelines for effective teaching practices in online education, including the Institute for Higher Education Policy report *Quality on the Line: Benchmarks for Success in Internet-Based Distance Education* (15); the Department of Education report on evidence-based practices in online learning (13); Pallloff and Pratt's *Lessons from the Virtual Classroom* (14); and Siemen et al.'s report

### TABLE 2.
Smaller-scale studies comparing effectiveness of F2F and online delivery for specific biology courses.

<table>
<thead>
<tr>
<th>Study</th>
<th>Course Compared</th>
<th>Type of Institution</th>
<th>Measure Used</th>
<th>Results Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collins (4)</td>
<td>Nonmajors biology</td>
<td>Research university</td>
<td>Final course grades</td>
<td>No significant difference</td>
</tr>
<tr>
<td>King and Hildreth (10)</td>
<td>Introductory biology course</td>
<td>Liberal arts college</td>
<td>Course exam grades</td>
<td>No significant difference</td>
</tr>
<tr>
<td>Schoenfeld-Tacher, McConnell, and Graham (19)</td>
<td>Histology with lab</td>
<td>Research university</td>
<td>Pre-/posttest scores</td>
<td>Online students demonstrated higher posttest scores and greater pre-/posttest gains</td>
</tr>
<tr>
<td>Johnson (9)</td>
<td>Nonmajors biology with lab</td>
<td>Community college</td>
<td>Final course grades Pre-/posttest gains Modified Lawson Classroom Test of Scientific Reasoning</td>
<td>No significant difference</td>
</tr>
<tr>
<td>Lunsford and Bolton (11)</td>
<td>Nonmajors biology</td>
<td>Community college</td>
<td>End-of-course exam</td>
<td>No significant difference</td>
</tr>
<tr>
<td>Reuter (16)</td>
<td>Sustainable Ecosystems with field/lab component</td>
<td>Comprehensive university</td>
<td>Pre-/posttest scores Grades on lab assignments Final course grades</td>
<td>Online students demonstrated higher posttest scores and greater pre-/posttest gains. No significant difference in lab assignment grades or final course grades.</td>
</tr>
<tr>
<td>Somenarain, Akkaraju, and Gharbaran (22)</td>
<td>Medical terminology</td>
<td>Community college</td>
<td>Final course grades</td>
<td>No significant difference</td>
</tr>
<tr>
<td>Barbeau, Johnson, Gibson, and Rogers (3)</td>
<td>Microscopic anatomy laboratory course</td>
<td>Research university</td>
<td>Grades on lab assignments, quizzes, practical exams, and multiple choice exams</td>
<td>No significant difference</td>
</tr>
</tbody>
</table>
1. Before instruction begins, students should be involved in an online orientation to transition them into the online learning environment. Palloff and Pratt stress the importance of an online orientation and development of the learning community in *Lessons from the Virtual Classroom*, saying that students need to be trained on how to learn in an online classroom. Course site navigation training, discussion and expectations for participation, and frequently asked questions can all help students feel comfortable and ready to learn in the online environment (14). Garman echoed the need for this type of orientation in her study of multiple sections of a biology course at a community college, suggesting that the addition of online orientation activities to help students become accustomed to the online classroom helps combat the higher attrition rate seen in the online sections (5).

2. As instruction occurs, instructors should facilitate student-student and student-instructor interactions in online classrooms to maximize student success. Phipps and Merisotis (15) suggest that these interactions should be facilitated in a variety of formats including discussions, activities, and e-mail. Palloff and Pratt also support the necessity of interaction, adding that both synchronous and asynchronous interactions should be used in online classrooms, as synchronous communication allows students to ask questions as they occur, while asynchronous communication allows students to respond when they have time and use research and critical analysis in their conversations. The type of communication and technology used should be selected based on learning outcomes desired (14). Siemens adds that asynchronous communication "results in new engagement and learning patterns" (20). Many of the studies on specific courses mentioned here reported placing special attention on elements that facilitated these kinds of interactions (3, 4, 22, 9, 16, 19, 10). It is worth adding that Palloff and Pratt identify peer collaboration as a particularly valuable form of student-student interaction to include in online instruction (14) and that both collaboration and cooperation are listed in the "significant factors that frame educational experiences in online settings" in *Preparing for the Digital University* (20). While none of the studies reported explicitly describe this type of student-student interaction, instructors should consider collaborative assignments during course design.

3. Multiple sources also identify course design that promotes student reflection and self-assessment as an element of effective online instruction. Means et al. reported that ten studies considered in their meta-analysis found that offering students triggers for self-reflection on understanding provided advantages for student learning (13). Siemens et al. also report the Means' finding, classifying these interactions as a form of asynchronous discussion (20). Student reflection as an element of effective online teaching practice is also supported by Palloff and Pratt, who encourage the use of open-ended questions to stimulate reflection and evaluation (14). While none of the studies reported here specifically included prompts to encourage student reflection, several of them did include opportunities for student self-assessment (4, 22, 10, 9).

**CONCLUSION**

Our review of the literature identified relatively few studies comparing student performance in online and F2F undergraduate biology courses. Of the thirteen studies we examined, however, nine found no significant difference in student performance across the two formats. In the remaining four studies, the two large studies that examined student grades across sections and teachers found that students in F2F sections outperformed students in online sections. Notably, however, these studies did not consider course design elements that could potentially influence student learning in either format. The remaining two smaller studies that did describe course design elements found one or more measures on which online students outperformed F2F students. We therefore conclude that well-designed online biology courses can be at least as effective for student learning as F2F courses. This result mirrors results observed for larger meta-analyses that consider online courses in all disciplines (13, 20). Further, the design elements that were found to be predictive of success in these meta-analyses and in other sources (e.g., 14) were also found in the design of many of the effective online biology courses examined here.

This literature review does not address other important considerations for student performance in online education. One vital element to consider is student attrition; the results we report derive from students who completed the courses, but do not consider the number of students who dropped the course. In many cases, this fraction can be significant (e.g., 5). In addition, we do not consider student characteristics that can predict success within online courses, a question raised by recent findings about massive open online courses (MOOC) access and completion rates (6). Further, we limited our review to "online" courses, or courses in which 80% or more of the content and course communication is delivered over the Internet; many interesting and potentially transformative course designs include more fluid use of F2F and online interaction. Additionally, there is difficulty parsing out students' actual learning gains.
when course objectives and activities vary across different courses and institutions. One potential solution to this issue is the implementation of pre- and posttest concept inventories to more accurately compare gains across institutions (21). While our conclusions suggest course design choices that can increase student learning in online biology courses, more research is needed to elucidate specific course elements and structures that can maximize students’ learning of biology skills and concepts in this context.

ACKNOWLEDGMENTS

The authors declare that there are no conflicts of interest.

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