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Education Article

Astrobiology Undergraduate Education: Students' Knowledge and Perceptions of the Field

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Abstract

With the field of astrobiology continually evolving, it has become increasingly important to develop and maintain an educational infrastructure for the next generation of astrobiologists. In addition to developing more courses and programs for students, it is essential to monitor the learning experiences and progress of students taking these astrobiology courses. At the University of Florida, a new pilot course in astrobiology was developed that targeted undergraduate students with a wide range of scientific backgrounds. Pre- and post-course surveys along with knowledge assessments were used to evaluate the students' perceived and actual learning experiences. The class incorporated a hybrid teaching platform that included traditional in-person and distance learning technologies. Results indicate that undergraduate students have little prior knowledge of key astrobiology concepts; however, post-course testing demonstrated significant improvements in the students' comprehension of astrobiology. Improvements were not limited to astrobiology knowledge. Assessments revealed that students developed confidence in science writing as well as reading and understanding astrobiology primary literature. Overall, student knowledge of and attitudes toward astrobiological research dramatically increased during this course, which demonstrates the ongoing need for additional astrobiology education programs as well as periodic evaluations of those programs currently underway. Together, these approaches serve to improve the overall learning experiences and perceptions of future astrobiology researchers. Key Words: Astrobiology—Education—Undergraduate—Distance learning. Astrobiology 9, xxx–xxx.

Introduction

Astrobiology has emerged as a multidisciplinary field rooted in the sciences of astronomy, chemistry, biology, and geology. The success of astrobiology as a new discipline lies in the interactions and collaborations of researchers in each of these seemingly disparate fields. Educators of astrobiology are challenged to coalesce these diverse fields and present to students an integrated program that spans the entirety of astrobiology. Over the past decade, multiple academic institutions have developed more than a dozen new undergraduate courses nationwide (http://nai.nasa.gov/college_courses/faculty_forum.cfm). As astrobiology undergraduate education continually expands, it is increasingly important to monitor educational progress by examining students' perceived and actual learning experiences.

In the past, astrobiology education studies have focused primarily on issues associated with bridging the gap between disciplines and increasing interfield communication among working professional researchers (Offerdahl *et al.*, 2005). One of the major tools facilitating this effort has been the Astrobiology Primer (Mix *et al.*, 2006). Although not designed as a textbook, the Primer has served as a reference guide that makes the many subdisciplines of astrobiology accessible to all. Other astrobiology education studies have focused on developing educator curriculums for high school and undergraduate students (Carrapiço *et al.*, 2001; Tarter *et al.*, 2002). While the focus on bridging the gap between disciplines and interfield communication is essential to the field of astrobiology education, it is also critical that we expand these studies so as to monitor the progress of these high school and undergraduate educational programs and document the astrobiology classroom experience.

At the University of Florida (UF), in the Department of Microbiology and Cell Science, a new Astrobiology course was offered in the spring semester of 2007 to any

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undergraduate who had completed at least one year of introductory science classes. The objectives of this intermediate-level course were to expose and familiarize students to the fundamentals of astrobiology and its application. By the end of this course, students were expected to have developed critical science writing and reading skills as well as an understanding of important concepts and experimental approaches in astrobiology. The class was developed as a hybrid teaching course that utilized traditional in-person lecturing with distance learning and online course management technology. Organization of the course material was based on the Astrobiology Primer (Mix *et al.*, 2006) such that lectures were characterized by one of the seven key categories of astrobiological research. The Primer was not used as a textbook but merely as a reference guide for initial course development.

In this study, we examined the undergraduate learning experience in the UF pilot Astrobiology course by assessing both knowledge gains and student perception. Specifically, the goals of this study were to (1) examine pre- and post-course student knowledge of different areas of astrobiological research and correlate that with student self-perceptions of the field, (2) determine students' perceived abilities regarding science writing skills and reading the primary literature, (3) evaluate the usefulness of a hybrid teaching method that couples traditional and distance learning platforms, and (4) evaluate students' long-term goals of research careers in astrobiology.

The results of this study reveal that, despite the growing field of astrobiological research and related educational programs, more than 75% of students in this class were unfamiliar with the discipline of astrobiology and its related research areas prior to this class. After participation in the course, however, students' knowledge and perceptions of astrobiology significantly improved, which reinforces the need for more undergraduate-specific courses. These results provide a framework for future course development and assessments of the student learning experience in astrobiology.

Materials and Methods

Class structure and description

The class Astrobiology was a new course developed in the spring of 2007 for UF undergraduate science and engineering students who had completed at least one year of introductory science classes. Enrollment into the class was limited to 25 students, as the class was held in a computer lab so that every individual student had access to a computer. The class lectures were structured into two categories: traditional and distance learning. Each of the 40 lectures took approximately 8–10 h of preparation, which included background research, slide construction, and question preparation. Traditional in-person lectures accounted for two thirds of the Astrobiology lectures, while the remaining lectures were given via distance learning technology. The distance learning lectures consisted of a PowerPoint (Microsoft, Seattle, WA) slide presentation coupled with a Polycom VSX 5000 Video conferencing unit (Polycom, Pleasanton, CA). Distance learning lectures were given from the Space Life Sciences Lab at the Kennedy Space Center and transmitted to the UF Department of Microbiology and Cell Science. Course materials for all lectures (*i.e.*, slides, assignments, and assessments) were provided to the students via the WebCT Vista 3 (Blackboard, Washington, DC) internet course management system. At the beginning of each class, students downloaded the slides for the day's lecture and were able to take lecture notes on the computer. The textbooks used to supplement lectures included *An Introduction to Astrobiology* (Gilmour and Sephton, 2003) and *Life in the Universe* (Bennett and Shostak, 2007). In addition to these textbooks, supplemental primary literature was assigned to complement each lecture topic. The course was divided into several key areas, including stellar formation and evolution, planetary formation and evolution, astrobiogeochemistry and the origin of life, evolution of life through time, planet detection and characterization, diversity of life, and science in space. A detailed syllabus of the lecture topics and the correlating Astrobiology Primer sections is listed in Table S1.

Four assessment tools were used to monitor the progress of each student's learning experience. These tools included biweekly quizzes, written reviews of primary literature, oral presentations, and essay exams. The quizzes consisted of online multiple-choice questions given via the WebCT Vista management software. The quizzes were designed for a rapid assessment of student progress and understanding of the astrobiology course material. The writing assignments were critical to the assessment and development of each student's ability to understand the scientific primary literature. Specifically, the assignments were designed to improve a student's understanding of the purpose of primary literature as well as to assess the quality of its content. There were no teaching assistants available for this course; therefore, the instructor graded all writing assignments, which thus made the grading uniform and consistent. Grading of the one-page primary literature summaries took approximately 8 h for each assignment, based on a classroom size of 25 students, and included comments to the students on how to improve their writing. Students were also asked to give two 10-minute oral presentations on astrobiology topics of their choosing. To enhance classwide participation, assessment of the oral presentations included a graded, peer-reviewed comment evaluation sheet as well as the instructor's summation. Finally, midterm and final examinations consisted of short and long essay questions, which took approximately 10–12 h to grade. These essays were essential in that they helped to evaluate whether students were able to integrate the seemingly disparate components of the astrobiology course.

Self-assessments and knowledge surveys

In addition to the knowledge assessments made throughout the Astrobiology course, anonymous surveys were conducted to evaluate the students' perception of astrobiology as well as their critical thinking and writing skills. These surveys also compared student perceptions of the traditional in-person lectures with those given by way of distance learning technology. The surveys were given pre- and post-course, and students were asked the degree to which they agreed or disagreed with a particular statement by way of Likert scaling (Likert, 1932). The Likert scale ranged from: strongly agree (5), somewhat agree (4), neither agree nor disagree (3), somewhat disagree (2), and strongly disagree (1). The surveys were analyzed by either examining the shifts in the means of the Likert scale responses or in the percentage of student responses for a particular score. The means of student responses in the pre- and post-course surveys were also statistically compared via a Student's *t*-test. The percentage shifts in the Likert scale during pre- and post-course surveys were statistically compared via a Fisher's exact test, two-sided analysis.

To assess astrobiology knowledge pre- and post-course, students were given a multiple-choice quiz that contained questions from various disciplines of astrobiology. The quiz was administered anonymously via the online WebCT Vista program. The percentages of correct answers pre- and post-course were compared via Fisher's exact test.

Results

Student self-assessment in astrobiology knowledge

Students were asked to self-assess their own individual knowledge of astrobiology by indicating the extent to which they agreed that they could (1) describe three subdisciplines of astrobiology, (2) describe mechanisms by which an extremophilic microbe survives in its environment, (3) understand Darwinian evolution, and (4) describe solar and planetary formation (Fig. 1). For all statements, there was a statistically significant increase in the students' comfort level with each topic area in the post-course surveys. For the first question, the pre-course Likert scale mean was 2.6 versus a post-course mean of 4.6 ($P < 0.0001$), which indicates a significant improvement in their fundamental awareness of the multidisciplinary nature of astrobiology. The means of the second and third questions, which examined their knowledge of mechanisms of extremophile adaptation (2.7 pre-course, 4.5 post-course) and Darwinian evolution (4.1 pre-course, 4.6 post-course), also significantly improved with P values of <0.0001 and <0.01, respectively. The largest shift in students' self-confidence pertained to their perceived understanding of stellar and planetary formation. The means of student agreement for this knowledge area changed dramatically from 1.8 in the pre-course survey to 4.1 in the post-survey ($P < 0.0001$).

Knowledge assessment of student learning

To complement the students' self-assessment of their familiarity with astrobiology, a knowledge test was given as a multiple-choice online quiz. The quiz consisted of questions that paralleled the seven major sections of the Astrobiology Primer (Mix *et al.,* 2006). Students were asked at least two questions in each of the seven Astrobiology Primer categories during a pre- and post-course quiz. Most of the questions

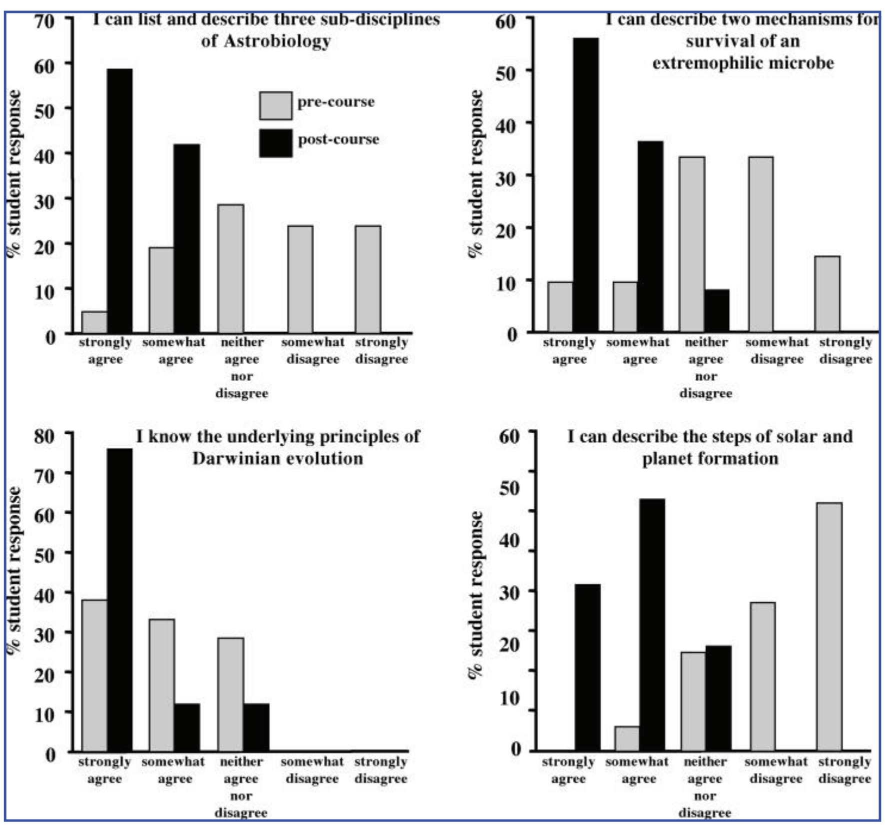

FIG. 1. Students' self-assessment of their knowledge of astrobiology. Students were asked their level of agreement with four statements associated with different aspects of astrobiology in pre-course (gray bars) and post-course (black bars) surveys. In all four statements, students demonstrated a significant increase in astrobiology knowledge in post-course surveys ($P < 0.01$) as determined by the increase of the mean response on a Likert scale in the pre- versus post-course surveys.

Table 1. Astrobiology Knowledge Assessment for Undergraduates

Knowledge area[1]	% correct responses		P values
	Pre-course[2]	Post-course[3]	
1. The universe is approximately 13.7 billion years old.	27.8	73.0	0.003
2. An astronomical unit is the distance between the Earth and the Sun.	72.2	76.9	0.49
3. Stellar parallax is the apparent shift in position of nearby stars as the Earth moves around the Sun.	44.4	57.7	0.30
4. The faint young sun paradox suggests that the Sun was 30% less luminous in the past.	61.1	84.6	0.08
5. When a sedimentary rock is completely melted it will re-solidify into an igneous rock.	44.4	50.0	0.50
6. The carbon cycle can't easily correct for increasing levels of CO_2 because the cycle operates far too slowly.	72.2	73.1	0.60
7. Severe long-term global cooling periods during Earth's history are known as Snowball Earth.	0.0	76.9	<0.0001
8. The molecular building blocks of life have been found on the Earth, in interstellar clouds, and in meteorites.	33.3	65.4	0.04
9. The search for life in the Solar System is essentially a search for liquid water.	33.3	61.5	0.06
10. The Cambrian Explosion began approximately 545 million years ago.	11.1	65.4	0.0004
11. A chemoautotroph is an organism that obtains its energy from chemical reactions and its carbon from the environment.	83.3	84.6	0.60
12. Most of the extrasolar planets detected to date are found very close to their parent star.	33.3	53.9	0.15
13. Current data suggests that the north pole of Mars is made up of CO_2 ice overlaying water ice.	33.3	65.4	0.04
14. Liquid water cannot exist for very long on the surface of Mars because its atmosphere is too thin.	44.4	57.7	0.30
15. The Search for Extraterrestrial Intelligence (SETI) program currently involves listening for signals broadcasted by extraterrestrial civilizations.	33.3	69.2	0.02

[1]Survey was conducted in a multiple-choice format in which students had four possible choices to choose from.
[2]Pre-course assessment was conducted with 18 students.
[3]Post-course assessment was conducted with 25 students.

asked in the pre-course survey were answered correctly by less than 50% of the students; in fact, only 4 of the 15 astrobiology-related questions were answered correctly by the majority of students in the pre-course quiz (Table 1). In the post-course quiz, all the questions had a correct response percentage greater than 50%, which indicates a significant improvement in student knowledge of these tested areas. The most dramatic improvement by the students involved the concept of Snowball Earth. In the pre-course quiz, none of the students answered the question correctly, whereas after the course, 76% of the students answered the Snowball Earth questions correctly ($P < 0.0001$; Fisher's exact test).

Qualitative assessment of integration of astrobiology subdisciplines and knowledge

To assess the students' capacity to integrate the Astrobiology course material into comprehensive and inclusive answers, long-answer essay questions were used. An example of one of the Astrobiology course essay questions is listed in Table 2 as well as excerpts from three student essays. To grade these essays, a simple rubric was used, in which student responses were compared directly to a detailed outline generated by the instructor prior to the exam. Grading was based on the students' ability to (1) make arguments for the role of climate in the evolution of life that reflect the various subdisciplines of astrobiology, (2) provide examples of research supporting their arguments, and (3) develop comprehensive answers in the time allotted to them (2 h for the entire exam). Review of these essays indicated that, though the students possessed a wide range of writing skills, most were able to combine geological, biochemical, and morphological evidence into a single cohesive response.

Student self-assessment of critical science communication skills

To provide experience in scientific interpretation and communication, students were asked to write reviews of four astrobiology primary literature papers that were analyzed during group discussions. The students' writing abilities as well as their familiarity with the purpose and content of primary literature was self-assessed with pre-course and post-course surveys (Fig. 2). Students were also screened for their ability to

Table 2. Examples of Essay Question and Unedited Student Responses

Essay Question: Discuss the role of climate (*e.g.,* carbon cycle, effective temperature, Snowball Earth) in the evolution of life. Give examples of evidence that supports your statement whenever possible.

Student 1: "About 540 mya, after the last snowball earth, oxygen rose in the atmosphere to about 20% and there was a huge increase in diversity and disparity known as the Cambrian explosion. Evidence for this rise in oxygen includes biomarkers, like steranes from eukaryotic cells, and hopanoids from aerobic photosynthetic cyanobacteria"

Student 2: "There is no geological evidence before 2.5 Ga that the Earth was frozen suggesting some mechanisms, like greenhouse gasses, to raise the effective temperature of Earth. One of the major greenhouse gases on ancient earth would have been methane. Methanogenesis is an ancient form of metabolism and early life might have used the high concentrations of methane as a energy source. The redox state of greenhouse gases such as methane would have provided an ideal energy source for early life"

Student 3: "The global and localized freeze events appear to have had an enormous effect on the evolution and diversity of organisms particularly the multicellular eukaryotes and the rapid expansion of animal body plans that is called the Cambrian explosion 550 million years ago … the Cambrian explosion could have been because HOX genes, which led to segmentation and hard body plans and body parts, evolved creating diverse organisms."

Student responses were taken as excerpts from larger essays that ranged from 0.5–2 pages.

read primary literature in the field of astrobiology. In all three of the areas examined, there was a significant difference between the pre- and post-course surveys. In the area of science writing, 92% of the students in the post-course survey "strongly agreed" or "somewhat agreed" that they had developed science writing skills as opposed to 50% of students in the pre-course survey ($P < 0.0007$). A similar result was observed when students were asked about the purpose and content of the primary literature. Only 67% of undergraduate students (mean = 3.6) agreed that they understood the primary literature, whereas 92% of the students agreed in the post-survey ($P < 0.0002$). The students experienced the strongest improvement in the area of astrobiology literature. Eighty-eight percent (mean = 4.6) of the students agreed that they experienced an increase in their comfort with astrobiology literature in the post-course survey, whereas only 28% of the students (mean = 2.9) agreed in the pre-course survey ($P < 0.0001$).

Comparison of traditional and distance learning approaches

Due to the geographical distance between the Kennedy Space Center and the University of Florida, one third of all lectures were given via distance learning technology. Since none of the Astrobiology students had previously participated in a distance learning course, it was important to assess the actual and perceived impact of distance education technologies on student learning. No statistical differences were observed in the grades of those short-answer essay questions that were based on distance learning lectures to those questions derived from in-person lectures (data not shown). Despite the lack of difference in the objective knowledge assessments, students were asked to assess their own learning experiences during traditional in-person lectures and during lectures with a Polycom video conferencing system as they followed an online slide presentation (Fig. 3). When queried about whether they actively followed the lectures (*i.e.,* do they comprehend the material), the mean response was 4.2 for in-person lectures and 3.7 for distance learning lectures, a significant decrease ($P < 0.02$) at the 95% confidence level. Another disparity between in-person lectures versus distance lectures was observed in the comfort level of students in asking questions during class. The mean response for the in-person lectures was 4.5, whereas the mean response for the distance learning lectures was 4.0 ($P < 0.04$). No significant change was observed in mean student response to their participation levels (*i.e.,* do they feel they have contributed to the class discussions) between in-person (3.8) versus distance learning (3.3) ($P < 0.09$).

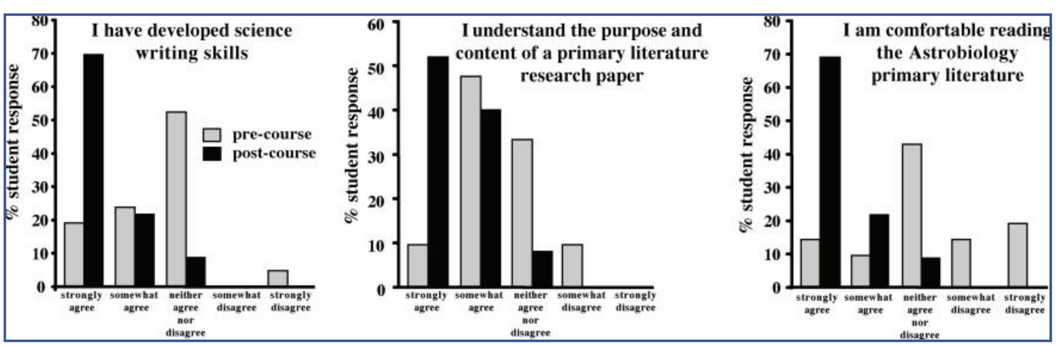

FIG. 2. Assessment of student scientific writing and reading of primary literature skills. In both pre-course (gray bars) and post-course (black bars) surveys, students were asked to indicate their level of agreement with the different statements regarding their individual skill sets. In all cases, results suggest a dramatic improvement in scientific writing ($P < 0.0007$) and reading skills in the primary literature ($P < 0.0002$). Students showed the largest improvement in their understanding of the astrobiology literature with a shift from 28% to 88% ($P < 0.0001$).

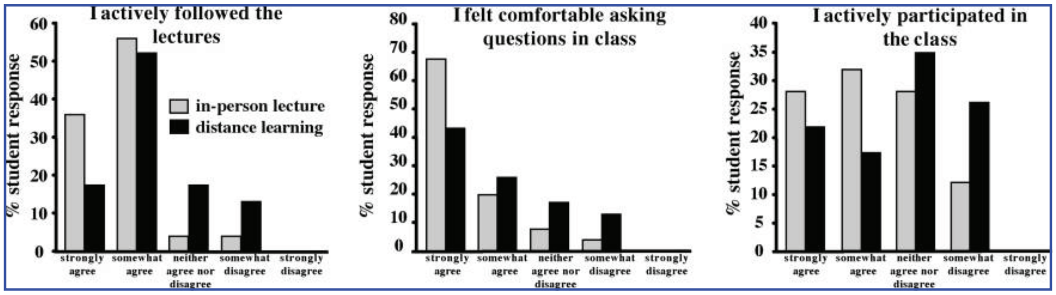

FIG. 3. Comparison of student in-person and distance learning experiences from course surveys. Results suggest that students were slightly less comfortable with distance learning (black bars) lectures than with in-person (gray bars) lectures when it came to actively following the lectures (84% in-person versus 70% distance learning, $P < 0.02$) and asking questions in class (96% in-person versus 70% distance learning, $P < 0.04$), whereas there was no difference in student self-perceived participation levels (60% in-person versus 40% distance learning, $P < 0.09$).

Student overall assessment of course and astrobiological research

Upon completion of the course, an additional survey was conducted to evaluate the students' perceptions of the various assessment methodologies (*i.e.,* quizzes, essays, oral presentations, and writing assignments) as well as their overall satisfaction with the Astrobiology course (Table 3). Of the different assessment tools, students "strongly agreed" or "somewhat agreed" that oral presentations (88%) and writing assignments (80%) greatly enhanced the course, whereas only 36% of the students strongly or somewhat agreed that the multiple-choice quizzes enhanced the course. Interestingly, 65% of students thought the course would be improved by offering more than two essay exams. A majority of the students appear to have been satisfied with this course (96% strongly or somewhat agreed) and would recommend (81% strongly or somewhat agreed) this Astrobiology course to their peers.

To assess whether student satisfaction with the Astrobiology course translated into a possible future career path in research, students were asked pre- and post-course whether they were interested in a biological or astrobiological research career (Fig. 4). Although there was a significant shift in the percentage of students interested in pursuing a biological research career after taking Astrobiology ($P < 0.009$), there was no significant shift in those students interested in an astrobiology-specific research career ($P < 0.22$). Despite the lack of classwide statistical significance, there was a 3% increase in the number of students that "strongly agreed" that they were interested in a career in astrobiological research after taking this course.

Discussion

One of the major objectives of this new course was to expose undergraduate students to the emerging and expansive field of astrobiology. By using pre- and post-course surveys, we evaluated the students' prior knowledge and perceptions about astrobiological research. This study also complemented student self-assessments of learning gains with objective assessments of knowledge gains to monitor the actual learning

Table 3. Final Post-Course Survey Results[1]

Student self-assessment statement	*Strongly agree*	*Agree somewhat*	*Neither agree nor disagree*	*Disagree somewhat*	*Strongly disagree*
I am satisfied with what I learned in this course.	60	36	4	0	0
This class exceeded my expectations.	40	28	32	0	0
I thought the journal article discussions and writing assignments increased my critical thinking skills.	56	24	16	0	0
Student oral presentations enhanced this course.	52	36	12	0	0
Student oral presentations gave me a greater appreciation and understanding of astrobiology.	40	32	16	8	4
I think that quizzes enhanced my learning experience.	8	28	40	20	4
I think this course would benefit from more than 2 exams.	40	24	20	4	12
I think that guest lectures enhanced the course.	32	40	28	0	0
Based on in-person lectures I would recommend this course.	72	24	0	4	0
Based on distance learning lectures only I would recommend this course.[2]	52	35	13	0	0
Overall, I would recommend this astrobiology course.	48	33	0	8	0

[1]Results are percentages of 25 students who completed the course.
[2]Results are percentages of 23 students who participated in the distance learning component of the course. Two students participated only in in-person lectures.

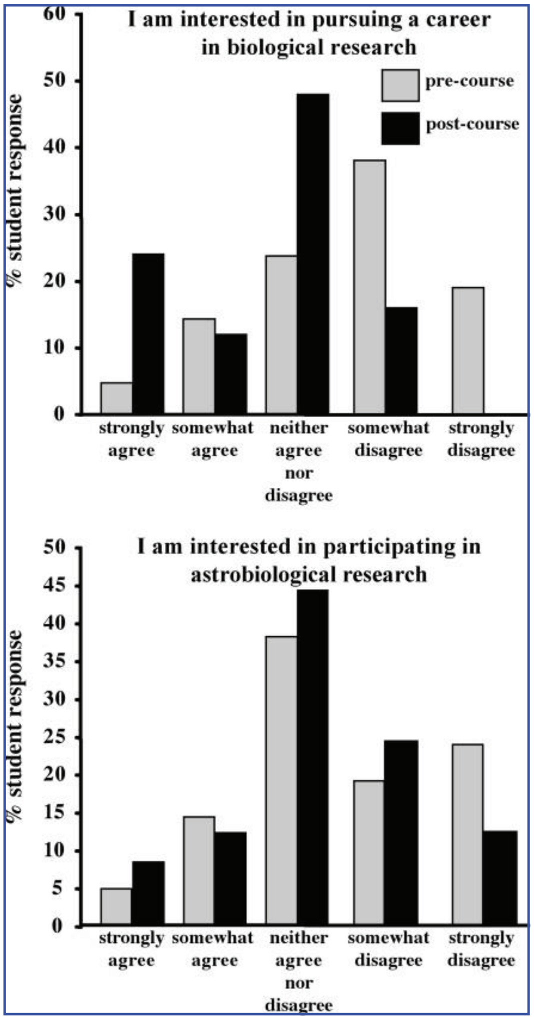

FIG. 4. Student assessment of long-term interest in a scientific research career. Based on pre-course (gray bars) and post-course surveys (black bars), students demonstrated a significant increase in pursuing a biological research career path ($P < 0.009$). However, students interested in a career path in astrobiological research did not significantly differ before or after the course ($P < 0.22$). These results were measured by the percentage of students who strongly or somewhat agreed with the statements on the pre-course assessments versus the post-course assessments.

experience. The results of these assessments indicated that, though students demonstrated little prior knowledge of astrobiological research, significant improvements were made via this introductory course. The results also suggest that despite technological advances with distance leaning, students were more comfortable with in-person lectures.

To encapsulate the broad, multidisciplinary nature of astrobiology into a format that would be accessible to undergraduates with a limited prior knowledge of the field, the Astrobiology Primer (Mix *et al.*, 2006) was used as a guideline. Although originally intended as a resource for working astrobiologists and not a textbook, the organization of the Astrobiology Primer made it an excellent template to develop into an introductory astrobiology course. As in the Primer, the course was divided into several key areas, including stellar formation and evolution, planetary formation and evolution, astrobiogeochemistry and the origin of life, evolution of life through time, planet detection and characterization, diversity of life, and science in space (Table S1). Lectures from each area were given throughout the semester, and questions from each category were included in the pre- and post-course assessments.

In the initial assessments of student knowledge, there was a definitive lack of familiarity with astrobiology such that only 28% of students were able to describe three subdisciplines of the field (*e.g.*, geology, astronomy, chemistry). Although 100% of the students felt capable of describing various astrobiology subdisciplines by the end of the course, the initial student perceptions suggest the need for more undergraduate and high school programs for students and educators alike. Although it is encouraging that one fourth of the students were familiar with astrobiology prior to taking the course, it is clear that much more progress needs to be made. The students' perceptions were reinforced by their objective knowledge assessments. The majority of students answered only 26% of the objectively scored knowledge questions correctly. The students did best on those questions associated with microbiology and the diversity of life. Although this course contained a broad range of science majors, including those in psychology and mechanical engineering, more than half the students were pre-med Microbiology and Cell Science majors, which may have skewed the pre-course results in those target areas. Despite this potential caveat, the Astrobiology course provided an opportunity for students who may not otherwise have taken a course in the various subdisciplines of astrobiology (*e.g.*, geology, astronomy) to be exposed to a broad range of topics. Although the challenge of integrating seemingly disparate ideas is not limited to courses in astrobiology or its subdisciplines, the Astrobiology course offered an ideal platform to reinforce to students the integrative nature of science as a whole. It is important in all science courses to convey the idea that the molecular and genetic processes within an organism must be ultimately correlated with the geological or biochemical influence of its surrounding environment.

The pre-course surveys targeted two other key facets of the course as potential problem areas: lack of critical writing skills and unfamiliarity with the primary literature, particularly in astrobiology. Before taking this course, only 50% of the students strongly or somewhat agreed that they had developed science-writing skills, and only 67% felt they understood the content and purpose of a primary literature (28% for astrobiology primary literature). By incorporating writing exercises, essays, and discussions of astrobiological research papers in the course, the students indicated greater confidence in the areas of science writing (96%), understanding general primary literature (92%), and astrobiology primary literature (88%) in the post-course self-assessment. Together, these results suggest a perpetual need for the ongoing development of critical thinking and writing skills in other science courses. Writing assignments and discussions are particularly critical for astrobiology education, as it is essential for students to integrate the research areas of several different fields. Although the questionnaire was targeted toward the field of astrobiology, these assessment methodologies can be easily adapted for courses in the various subdisciplines of astrobiology.

Although the course was designed for a small classroom size of 25, the framework of this course could easily be adapted to classes of larger sizes (50–100 students). For those institutes where teaching assistants are available, rubrics could be developed to facilitate a consistent grading scheme for all essays and discussion assessments. If no teaching assistants were available for large classes, adaptations to the course structure could include more group projects and presentations or modifications of the literature reviews. For example, instead of one-page written summaries, students working in groups could be asked to write two or three questions on the primary literature article. The questions could be exchanged within the group, and the students would be required to research and write a short answer to their peer's question on the literature article. Such adaptations would be limited only by the creativity of the instructor.

Prior to this course, none of the students had participated in any form of distance learning and, to their credit, quickly accepted this novel form of hybrid teaching. As it is difficult to expect instructors to be familiar with all areas of astrobiological research, distance learning enables the participation of guest lecturers with specific expertise from all over the world. In this pilot course, three lectures were taught by outside speakers from the Kennedy Space Center. In all three of these cases, the majority of the students (64%) strongly or somewhat agreed that these outside lecturers enhanced the Astrobiology course. Because this was a pilot course, it was also essential to monitor the students' perception of their learning experience in this relatively new form of hybrid teaching. Although no statistical difference was detected in the short-answer essay questions that were given based on distance and in-person lectures, there was a significant difference in student perceptions of their lecture experience. Interestingly, students felt less comfortable asking questions in class and thought it was more difficult for them to follow video conferencing lectures versus in-person lectures, though no statistical difference was detected in students' perception of their class participation. Previous research has shown no statistical differences in knowledge assessment in distance learning science classes (Berge and Mrozowski, 2001; Maushak and Chen, 2001; Koch, 2006); however, few, if any, have assessed the students' perceived learning experience via a hybrid teaching approach. The decreases in student comfort levels during distance learning may reflect the novelty of the teaching form for many of the students as well as the instructor. More breaks for questions and student absorption of the material may be essential for distance learning lectures. Distance learning, however, remains an integral means by which to broaden student education by including off-campus students, faculty, and guest lecturers into the learning experience. Therefore, it continues to be essential to monitor and assess effective use of distance learning technology.

Overall, students' interest in the field of astrobiology dramatically increased over the course of the semester with over 81% of the class strongly agreeing or somewhat agreeing with the statement that they would recommend this course to others. Interestingly, 96% of the class would recommend the course based on in-person lectures only, and 87% would recommend the class based on the distance learning lectures only, yet the overall course recommendation percentage was only 81%. The discrepancies between the lecture-only values and the overall course recommendation percentage could reflect the student views of course assignments, methods of assessment, or the wording of the questionnaire. Despite these discrepancies, the students overwhelmingly expressed positive attitudes about the course and the field astrobiology. These positive attitudes did not, however, translate into major changes in student long-term career plans in astrobiology. One of the long-term goals of this Astrobiology course was to fuel student interest in astrobiological research careers. Although it is not surprising that a single course did not change the long-term goals of the class overall, reaching the few individuals that may be open to future astrobiological research is critical. At the beginning of this class, only one of the students strongly agreed that they were interested in pursuing an astrobiological research career. By the end of the class, two students had expressed a strong interest in an astrobiological career path. While only a 3% increase, this reinforces the need for additional courses to expose more undergraduates to the field and potentially foster a long-term interest in astrobiological research. Only by creating a well-established undergraduate infrastructure in astrobiology can we perpetuate the pool of young scientists who will actively participate in astrobiological research well into the future.

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Abbreviation

UF, University of Florida.

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