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Still a private universe? Community college students' understanding of evolution

Meredith A. Dorner[1*], Philip Sadler[2] and Brian Alters[3]

Abstract

Background: Measuring what students know and retain about evolution is essential to improving our understanding of how students learn evolution. The literature shows that college students appear to have a poor understanding of evolution, answering questions on various instruments correctly only about half of the time. There is little research regarding evolution understanding among community college students and so this study examines if those students who are enrolled in life science classes, who are assessed using questions based on grade eight standards, show a better understanding of evolutionary principles than younger students and if there are differences in knowledge based on course enrollment. The authors utilized a survey of 41 items of the Life Sciences Concept Inventory that were specifically designed to measure knowledge about various aspects of evolution that relate to the 5–8 grade science standards on evolution. They administered it to 191 adult students who were enrolled in nine sections across five life sciences courses at one community college in Southern California.

Results: Results indicated that the students in this study possessed a fair understanding of evolution, averaging scores of nearly 70%, higher than what other researchers have found (using different instruments). Students enrolled in biology major classes scored significantly higher than those enrolled in non/mixed-major courses. There was a strong relationship between item difficulty and discrimination as well as difficulty and misconception strength. When compared with the 5–8 grade student data, the community college students showed a lower level of difficulty and higher levels of item discrimination, but the proportion choosing the most popular wrong answer (the dominant misconception), was comparable. College students showed similar patterns to the grade 5–8 students in terms of which questions and which material were the most challenging, despite performing better overall.

Conclusions: In this study, students possessed fair understanding of evolution. However, they were assessed with an instrument designed for 5th through 8th grade students. The results of this study support the need for more research into how community college students understand evolution and which factors impact that understanding.

Keywords: Evolution understanding, Evolution education, Community college

Background

Measuring what students know and what they retain about key scientific principles is essential to improving our understanding of how students learn science and science education pedagogy. Not all ideas that are presented to students during their education are necessarily understood or, even if initially learned, maintained to a later time. The film, "A Private Universe" (Schneps and Sadler 1987) paints a picture of a surprising lack of understanding of basic science knowledge of college students, in spite of being taught these concepts earlier in their education. In one scenario, on graduation day at Harvard University, students, faculty and alumni are asked to explain why their summers are warmer than their winters and the reason for the moon's monthly change in appearance. In the U.S., most students cover this content in

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middle school (grades 5–8) and this knowledge is drawn upon later when learning about ellipses in mathematics, orbital motion in physics, and seasonal variation in biology. Shockingly, only two out of the 23 graduates, faculty, and alumni were able to give the scientifically correct explanation when asked.[1] Most held a common misconception: that seasons are caused by the changing distance of the Earth to the sun (despite the fact that the earth is closest in January) or that the moon's shape changes due to moving into the shadow of the earth (a lunar eclipse).

The film then goes on to offer additional examples of basic science concepts that students have never understood and the misconceptions to which they cling. High school students held the same misconceptions as the Harvard participants and none were able to do so without revealing their own "private universes" or misconceptions. Even when probed that "some people say" (i.e., scientists holding the correct view), students will deny that they were ever exposed to the presented idea or reject it outright.

One area not addressed in the film, is that of evolution education. Evolution is the fundamental, underlying principle in biology providing a robust a framework for examining the diversity of life on the planet, i.e., "Nothing in biology makes sense except in the light of evolution" (Dobzhansky 1973). Both the National Science Education Standards (NSES) from the National Research Council (NRC 1996) and the subsequent Next Generation Science Standards (NGSS) (NGSS Lead States 2013), based on the NRC Framework for K-12 Science Education (NRC 2012), include standards about evolution including diversity, adaptation, and extinction at the elementary, middle school, and high school levels. In fact, within the NGSS, evolution is the core idea of the life sciences. This means, when a student attends public school in the United States, by the time they reach the college level, they likely have been exposed to this concept and their understanding assessed at minimum of two or three times (often through class tests and statewide standardized testing). One might think this would lead to a fairly high or at least moderate degree of understanding of the principles of evolution.

In "A Private Universe" (Schneps and Sadler 1987), the overwhelming majority of graduating Harvard seniors had not mastered concepts even though they had been exposed to them early in their education. This phenomenon of being taught simple concepts in astronomy, but never fully acquiring them, piqued our interest in determining whether community college students follow the same pattern with the foundational principle of evolution.

[1] That the tilt of the Earth's axis with respect to its orbital plan around the sun, changes the amount of sunlight impinging on different locations. This was understood by the geocentric ancients as simply the path of the sun is lower and shorter in the winter than the summer, a good place to start with young students.

Understanding of evolution among college students

The research literature includes several studies that have examined how well college students understand evolution. Much of the published data is from studies that are either focused on developing an instrument to measure knowledge and understanding of evolution or are looking at the effects of a specific pedagogical strategy on the understanding of evolution. In many cases, the studies are concerned with exploring relationships between the understanding and acceptance of evolution and often raw data regarding understanding are not reported. There are few peer-reviewed studies on the state of evolution understanding in community college students. This review focuses primarily on understanding, not acceptance, among college students and relevant results from studies employing quantitative instruments are summarized in Table 1. Here we will focus on the subset of those studies that were conducted with community college students.

Several researchers have worked to develop instruments to assess the understanding or knowledge of evolution among college students (Mead et al. 2019). Researchers have reported varying levels of understanding, typically ranging from poor (answering half of the questions correctly) (e.g., Anderson et al. 2002; Beggrow and Sbeglia 2019; Laidlaw 2020; Moore et al. 2011; Nadelson and Southerland 2010a; Tran et al. 2014) to passable (answering 70% of questions correctly) (e.g., Barnes et al. 2017; Nadelson and Southerland 2010a; Partin et al. 2013). Often, students that are biology majors or enrolled in upper level courses show a greater level of understanding than nonmajor students.

One of the most frequently used instruments, the Concept Inventory of Natural Selection (CINS) was developed with community college students who achieved approximately 50% accuracy (Anderson et al. 2002). The CINS is interesting because it was designed specifically to identify whether students understand the concept of natural selection or hold a popular, well-documented misconception. This is important as evolution understanding is likely not binary, instead, many individuals may understand parts of evolution while simultaneously holding misconceptions (Bishop and Anderson 1990). When the CINS was administered to another group of community college students enrolled in a nonmajor biology class before they had received instruction on natural selection, they also answered approximately 50% of the questions accurately (Anderson et al. 2002).

Table 1 Summary of relevant studies with quantitative assessment of the understanding of evolution in college students

Citations	Assessment	Assessment source	Course enrollment	Sample size *= community college	Pre course mean ± SD	Post course mean SD	Statistically significant change?
Nadelson and Southerland (2010a)	Measure of Understanding Macroevolution (MUM)	Nadelson and Southerland (2010a)	Introductory biology	667	11.97 ± 5.49 out of 27 (44%)	–	–
			Evolutionary biology	Pre 74/post 54	19.90 ± 30.1 (74%)	21.04 ± 3.03 (78%)	Pre vs. post
Nadelson and Southerland (2010b)	MUM	Nadelson and Southerland (2010a)	Introductory biology	~600	Not reported	–	–
			Evolutionary biology	74	Not reported	Not reported	Pre vs. post
Anderson et al. (2002)	Conceptual Inventory of Natural Selection (CINS)	Anderson et al. (2002)	Nonmajor biology	3 groups of ~100*	Average 50%; group 1: 2.54 ± 1.35, group 2: 2.36 ± 1.46, group 3: 2.12 ± 1.15 out of 5	–	–
			Nonmajor biology	110 and 96*	Two sections: 8.21 ± 3.07 (41%) and 10.42 ± 3.31 (52%)	–	–
Partin et al. (2013)	CINS	Anderson et al. (2002)	Nonmajor biology	149	14.5 ± 3.96 out of 20 (72.5%)	–	Major vs. nonmajor
			Major biology	52	9.54 ± 3.23 out of 20 (47.7%)	–	–
Fowler and Zeidler (2016)	CINS	Anderson et al. (2002)	Upper level major and nonmajor	52	Reported as both 13.61 ± 4.19 (68%) AND 13.38 ± 4.16 (67%)	–	–
Barnes et al. (2017)	CINS	Anderson et al. (2002)	Evolutionary medicine	182	Reported as both 13.90 ± 3.5 (70%) AND 14.09 ± 3.53 (70%)	16.41 ± 3.13 (82%)	Pre vs. post
Beggrow and Sbeglia (2019)	CINS	Anderson et al. (2002)	Introductory biology course	260	13.6 ± 0.12 (SE) (68%)	-	Anthropology vs. biology
			Introductory anthropology course	208	10.68 ± 0.14 (SE) (53%)	–	–
Green (2019)	CINS	Anderson et al. (2002)	Nonmajor biology	29 and 34	Of 9.12 ± 3.06 and 9.13 ± 3.35 out of 20 (approximately 46% correct)	11.92 ± 3.70 and 11.38 ± 4.80 (approximately 60% correct)	Not reported
Kalinowski et al. (2016)	Conceptual Assessment of Natural Selection (CANS)	Kalinowski et al. (2016)	Introductory biology	218	47% (median 11 out of 24)	77% (median 18)	Pre vs. post
Fiedler et al. (2019)	CANS and CINS	Anderson et al. (2002); Kalinowski et al. (2016)	Introductory biology	468	15.46 ± 3.78 (out of 24) (64%) and 15.73 ± 5.03 (out of 20) (79%)	–	–

Table 1 (continued)

Citations	Assessment	Assessment source	Course enrollment	Sample size *= community college	Pre course mean ± SD	Post course mean SD	Statistically significant change?
Hawley et al. (2011)	Evolutionary Attitudes and Literacy Survey (EALS)- Evolutionary Knowledge Subscale (EKS)	Hawley et al. (2011)	Child and social psychology	371	5.02 ± 0.86 out of 7 (72%)[1]	–	–
Short and Hawley (2012)	EALS short form (EALS-SF) (EKS)	Short and Hawley (2012)	Introductory biology course	526	4.91 ± 0.89 out of 5 (98%)[1]	–	–
Short and Hawley (2015)	EALS (EKS)	Hawley et al. (2011)	Introduction to organismal biology, evolutionary psychology and political science	868	Ranged from 4.87 ± 1.03 (70%) to 5.81 ± 0.81out of 7 (83%)[1]	4.97 ± 1.09 (71%) to 6.16 ± 0.79 out of 7 (88%)	Pre vs. post for non-biology students only
O'Brien et al. (2009)	EALS- beta version (EKS)	Hawley and Parkinson (2008)	Introductory biology	121	5.42 ± 1.81 out of 7 (77%)[1]	Not reported	Pre vs. post
Dunk and Wiles (2018)	EALS-SF (EKS)	Short and Hawley (2012)	Introductory biology course for major and nonmajor	656	Of 26.98 ± 3.69 out of 35 (77% correct) [1]	Not reported	Not reported
Barnes et al. (2022)	EALS (EKS)	Hawley et al. (2011)	Introductory major and nonmajor biology	202* and 2088	Not reported but community college students 8% lower than university		Community college vs. university
Dunk et al. (2017)	Familiarity with Evolutionary Terms	Barone et al. (2014)	Anatomy and physiology	284	15.947 ± 4.167 (56.7%)	–	–
Moore et al. (2011)	Knowledge of Evolution Exam (KEE)	Moore et al. (2011)	Introductory biology course	179	5.3 ± 2.2 (53%)	–	–
Laidlaw (2020)	KEE	Moore et al. (2011)	Introductory biology course	351	5.49 to 5.76 out of 10 (~55% correct; SD not reported)	Not reported	None
Brown (2015)	KEE	Moore et al. (2011)	Introductory biology	373*	45.90%	–	–
Brown and Scott (2016)	KEE	Moore et al. (2011)	Major biology	372*	~45.96 out of 100	–	–
Sinatra et al. (2003)	Understanding Biological Change (UBC)	Settlage and Jensen (1996)	Nonmajor biology	93	Not reported	–	–
Price et al. (2016)	Genetic Drift Inventory (GeDI)	Price et al. (2014)	Major and non-major upper and lower division biology	825	Overall: 0.58 (SD 0.09); experimental 0.60 (SE 0.02)	Experimental group: 0.70 (SE 0.30)	In the experimental group only
Dorner (2016)	5–8 Life Sciences Concept Inventory (LSCI)	Sadler et al. (2013)	Many major and non-major courses	867*	5.05 ± 2.45 (out of 10) (51%)	–	–

Table 1 (continued)

Citations	Assessment	Assessment source	Course enrollment	Sample size *= community college	Pre course mean ± SD	Post course mean SD	Statistically significant change?
Sbeglia and Nehm (2022)	Assessment of COn-textual Reasoning about Natural Selection (ACORNS)[2]	Nehm et al. (2012)	Introductory biology	1434	Not specifically reported but appear to be ~ 25/%	Not specifically reported but appear to be ~ 60–70%	Not reported
Fiedler et al. (2017)	Open Response Assess-ment- Germany	Nehm and Reilly (2007)	Biology major and preservice teachers	140	0.55 ± 0.31 (out of 1); bio: 0.60 ± 0.04 (SEM); preservice teachers 0.46 ± 0.04 (SEM)	–	Biology major vs. preser-vice teachers
Lan (2017)	Open Response Ques-tionnaire (ORQ), which was derived from the CINS	–	Math, chemistry and physics courses	21	Poor to moderate understanding	–	–
Tran et al. (2014)	Open Response original instrument	–	Environmental physiol-ogy	66	Overall < 50%. 4.35 to 6.42 out of 10 (SD not reported)	–	–
Speth et al. (2014)	Course exams using modeling	–	Major biology	170	Midterm: 2.78 ± 1.85 out of 5 (50% on their models)	Final: 3.62 ± 1.92, (70%)	Midterm vs. final
Heitz et al. (2010)	Evolution speciation test- original	–	Major biology students (3 groups)	283	51 ± 8.4, 48.6 ± 10.4, 52.3 ± 8.0	57.5 ± 11.1, 58.4 ± 11.3, 59.0 ± 11.4	Pre vs. post in all three groups

[1] These instruments (EALS and EASL-SF) differ from the others in that they are composed of statements that students agree or disagree with by choosing a score on a Likert scale. When these instruments are employed, students typically report higher scores

[2] Although the ACORNS assessment is not specifically quantitative it has been utilized to produce quantitative scores so is it included here

Similarly, Brown and Scott (2016) surveyed undergraduate biology major students at five community colleges in Texas using the Knowledge of Evolution Exam (KEE; Moore et al. 2011). Their results confirmed previous findings that students enter college with a poor understanding of evolution (Moore et al. 2011) as the participants in Brown and Scott's study only correctly answered an average of 45.9% questions about evolution.

Other than Anderson et al. (2002) few studies have been conducted with community college students specifically. In one case, McKeachie et al. (2002) explored the effects of learning biology on student beliefs about evolution. They found that students who accepted evolution also earned higher grades in the course than those who did not; however, firm creationist students did pass the class with the grade of C and believed that they had a fair understanding of the theory of evolution. But because the sample size of the study was so small and the focus was more on beliefs than understanding, the study offers limited insight into community college student understanding.

A few recent dissertations have examined understanding of evolution in community college students with similar results. Butler (2008) found poor results among introductory biology students at a community college who answered a third of the CINS questions correctly before instruction. However, that number increased dramatically after instruction (especially in understanding the nature of science) to approximately 75%. Green (2019) surveyed community college students enrolled in non-major introductory biology classes who also scored approximately 46% correct on the CINS (Anderson et al. 2002). Similarly, Dorner (2016) analyzed survey data from 10 questions about evolution derived from the grade 5–8 Life Sciences Concept Inventory (LSCI; Sadler et al. 2013) to determine their understanding of evolution. Community college students enrolled in life sciences classes earned a mean score on the LSCI items was approximately 50%. The data here align with the published literature on college students; however, their generalizability is limited due to the lack of peer review.

In summary, community college students appear to have a poor understanding of evolution, answering questions on various instruments correctly only about half of the time. Dorner (2016) reported a 50.5% correctness rate which aligns well with previous studies that have used a different measure, in which scores ranged from 45.95% among community college students majoring in biology (Brown and Scott 2016) to 54% and 53% among university introductory biology students (Moore et al. 2011; Moore et al. 2009), 46–60% among nonmajor biology community college students (Green 2019). Additionally, when a third measure was employed (the CINS), nonmajor biology students scored at 50% or less (Anderson et al. 2002).

There appears to be a limited understanding of community college student knowledge of evolution. One limitation is due to the fact that many of the studies exploring this topic with community college students are reported in dissertations and therefore have not yet the full peer review required for journal publication. Additionally, most of these studies have relatively small sample sizes. Given these limitations and the range in understanding of evolution observed in four-year college and university students, it is essential to conduct further research to understand community college student knowledge of evolution, especially in light of the important, if often overlooked, role of community colleges in higher education.

Significance

Our research is important and will add to the existing body of knowledge. First, most previous studies have not examined the level of understanding of evolution among community college students in a quantifiable way that allows us to compare understanding with younger students. This gap in the literature is significant because community college students represent a relatively understudied population with regard to evolution and understanding more about their views may provide insight into the views of the general public who have low understanding and acceptance of evolution (Weisberg et al. 2018). Using university student population samples and generalizing their results to the general population is problematic (Hanel and Vione 2016). Specifically, in regard to evolution understanding, students enrolled in community college have reported lower levels of understanding than those enrolled in a four-year university (Barnes et al. 2022). It may be that community college students are more representative of the general public than four-year college students as they are often representative of a broader range of ages. There were nearly 12 million students enrolled in the 1044 community colleges across the nation in 2019 (American Association of Community Colleges 2021) compared to 14 million students in 4-year institutions in 2019 (NCES 2021) and the community college students range beyond the traditional college age, as nearly 36% of students are between the ages of 22 and 39 (American Association of Community Colleges 2021).

Second, because community college serves as continuing education or possibly the beginning of the college career, these students may enter with a lower level of preparation and may have very different ranges of scholastic preparation. For example, over half of students in community college are continuing students, and in 2020, over 11% already possessed degrees while nearly 2% had not graduated from high school (Education Status Summary Report 2020). We may find that community college students represent a broad enough range of the general population such that their understanding of evolution reflects that of the general population more accurately rather than that of four-year college students.

Finally, understanding evolution is essential to understanding the biological sciences. The understanding of evolution (and evolution acceptance) is critical to scientific literacy and our research speaks to this. Surveys have shown that 52% of Americans don't agree that humans evolved from earlier species (National Science Board 2016) and 38% identify as creationists (Swift 2017). The US ranks well behind other developed countries in terms of evolution acceptance (Funk et al. 2020; Miller et al. 2006).

Weisberg et al., (2018) administered a survey to 1100 Americans who were determined to be demographically representative of the United States. They found that 32% of their respondents accepted naturalistic evolution and 68% of their participants scored less than 60% on the evolution knowledge portion of the survey. Among the American public, both the acceptance and knowledge of evolution are low. This is in stark opposition to the scientific community, which overwhelmingly supports evolution (Alters and Alters 2001; Pew Research Center 2015; Wiles 2011). This disconnect in evolution understanding and acceptance of evolution between scientists and the public is a strong argument for improving scientific literacy.

There is some controversy in the field of education regarding the relationship between acceptance and understanding. Smith (1994) contended that developing the understanding of a construct in science can be hindered by the failure to accept that construct. Some researchers have argued that it is essential to address the idea of student acceptance of evolution before students will be able to learn about the construct (Cobern 1994; Jackson 2000; Meadows et al. 2000; Scharmann 1990; Smith 1994). Alternatively, other researchers have proposed that acceptance of the theory is predicated on understanding it (Lawson and Weser 1990; Lawson and Worsnop 1992). Lawson and Worsnop (1992) found that, in general, individuals who were better skilled at reasoning were also more likely to accept and be committed to evolutionary statements.

While the aforementioned researchers suggest a relatively straightforward connection between knowledge and acceptance, other findings have indicated the relationship is not as clear. Several studies did not find any relationship between understanding of evolution and student acceptance of evolution (Bishop and Anderson, 1990; Demastes-Southerland et al. 1995; Lord and Marino 1993). In addition, researchers have found that students with creationist views can demonstrate a solid understanding of evolution and students who identify themselves as evolutionists may in turn demonstrate a poor understanding of evolutionary theory (Demastes-Southerland et al. 1995; Hermann 2016). Another study also showed that understanding and acceptance can be related to each other in some college students but less so in others (Barnes et al. 2022). It is, however, unclear exactly how knowledge and acceptance influence each other (Dunk et al. 2019).

Slater et al. (2019) discussed the importance of transitioning from understanding scientific literacy as knowledge, to understanding science as a process, particularly when considering the importance of the public's trust in science. They noted that scientific issues, especially when politicized, are challenging the public's trust in science. This is particularly worrisome for the scientific community during a time when public health is dependent on public acceptance and trust of the scientific community (e.g., covid vaccines).

Regardless, it is very clear that understanding of evolution is one of the goals of education in the United States and the factors connected to the low rates of understanding should be explored. Additionally, it would be useful if scientists and science educators would come to a consensus on whether increasing student acceptance of evolution should be the goal of evolution education (Barnes and Brownell 2016; Dunk et al. 2019).

This leads us to our question: will community college students who are enrolled in life science classes, who are assessed using questions based on grade 8 standards, show a better understanding of evolutionary principles or as in a Private Universe, will they also still accept common misconceptions?

Research questions

1. How well do community college students enrolled in life sciences classes understand evolution?
2. Do students enrolled in major biology classes understand evolution at a different level than those enrolled in mixed major courses?
3. How does this compare to the understanding of pre-college, 5–8th grade students, assessed using the same questions?

Methods

Choice of instrument

To assess the understanding of evolution, we employed a tool that is highly useful: a distractor-driven multiple-choice (DDMC) test (Sadler 1998). Much of science education is based on the theoretical framework of constructivism: that people construct their realities based on their interactions with the world (Piaget 1937). Thus, learning is an interactive and ongoing process with the world, including the social environment. The social environment is particularly important for children (Piaget 1971). Because the ideas of children can be different than those of adults (Driver and Easley 1978), identifying student misconceptions is an important part of the education and assessment processes. When students are offered multiple-choice assessments lacking choices that reflect common misconceptions, they may choose the correct answer for a particular item because it is the only one that makes sense to them or that they have heard previously (from teachers or others). When faced with the answer options, they will choose the one that appeals to them most, but they may not actually believe. In contrast, a DDMC item (and a collection of them on a test) provides distractors that often more closely match exactly what their ideas are, even if they are inaccurate or scientifically invalid. Administering such assessments to students can help educators identify those who know the material as opposed to those who think they know the material by distinguishing between preconceived notions and those accepted by scientists.

Sadler et al. (2013) developed the Life Sciences Concept Inventory (LSCI) as part of the Misconception-Orientated Standards-based Assessment Resources for Teachers project (MOSART) to assess understanding of science standards at the K–4 grade level and the 5–8 grade level. In order to develop an effective DDMC assessment, the authors undertook a long and involved process of identifying student misconceptions for each science standard, having experts evaluate questions, piloting questions across different groups and eventually deploying the assessment nationally to over 30,000 students. Their results revealed that students had challenges mastering certain standards (even when their teachers were confident that they had mastered them). The standard that had the lowest level of mastery is that of standard VB: species diversity results from evolution. On average, grade 5–8 students answered those questions correctly only 36% of the time. Of the pool of 7476 questions that were developed, tested and validated for inclusion in the LSCI, 58 questions assess evolution understanding. Students averaged 36–76% correct depending on the standard the questions covered.

It can be tempting to think that this lack of understanding would be remedied by more exposure to the concepts during schooling; however, research suggests the misconceptions can persist over time (Kuschmierz et al. 2020; Sadler et al. 2013). Therefore, administering this same well-tested instrument with community college students may allow us to examine this indirectly (even though we are not conducting a longitudinal study). Although life sciences standards change every several years, and can vary by state, they generally cover comparable material. By using questions based on science standards to which students should have been exposed earlier in their education, we hoped to measure a basic understanding of evolution.

These LSCI items were developed by Sadler et al. (2013) at Harvard University at great expense and thus could only be used following strict protocols. Thus, this article includes not the full survey but only examples of four items (Additional file 1), available for public use, that are representative of the 41 items that were included in the full survey.

Participants

The authors administered a survey of 41 items of the LSCI that relate to the science standards on evolution to a group of 191 adult students who were enrolled in nine sections across five life sciences courses at one community college in Southern California. Courses included two sections of introductory major biology, two mixed/nonmajor biology lectures and three labs, one human physiology, and one cell biology course. The school is mid-size, with approximately 14,000 students enrolled (Facts and Figures 2015). The study was conducted through in-person class visits in which students were provided with consent information. Data were collected in the second half of the semester (April 2015). Different courses presented the material covered in the LSCI at different times in the semester, but students should have been exposed to the main ideas by this point. The community college students were assessed earlier in the year when compared to the middle and high school students in the original study using the LSCI (Sadler et al. 2013).

Participation in the study was voluntary and optional. In addition, as basic proficiency in English is required to enroll in a life sciences course, all students are considered English-speaking. Surveys were administered in the following way: students were asked at the beginning of a class period if they wish to participate. If they did, they were given an informed consent form, and offered the chance to ask questions. Students were the given a Scantron form and the survey to complete anonymously.

Of the 191 students surveyed who participated in answering the 41-item survey, 83 were enrolled in major biology classes and 108 were enrolled in classes of mixed major and nonmajor students, historically comprised primarily of nonmajor students. Unfortunately, demographic data were not specifically collected however, based on data available from the school, students in the courses that were surveyed had the following characteristics: 51% of students identified as male and 49% identified as female (Education Status Summary Report 2020). The majority of students were between the ages of 18 and 21 (48%), with most of the remainder aged 22–29 (33%), and the rest were 30 or over, with the exception of 4% of students who were under 18 (these were not included in this study) (Education Status Summary Report 2020).

In the life sciences program, as a whole, of the 1,729 students enrolled, nearly half were female (48%), and the vast majority are between the ages of 18 and 21 (66%), with the next highest age frequency being 22–29 years old (24%) (Inform Data Warehouse, 2015). We do not have data on the ethnic background of the student population within life sciences; however, at the college, as of spring 2020, the three largest ethnicities represented on campus were Asian (35%), White Non-Hispanic (31%), and Hispanic (19%) (Education Status Summary Report 2020).

Data collection and analysis

Data were collected using Scantron forms and contained no personally identifiable information. Data were manually entered into Excel by the first author and analyzed to determine how many of the surveys were missing answers to one or more questions. Of the 191 surveys, 21 surveys were missing one or more answers to questions but were still included in the analysis (missing answers were marked as incorrect). All computer files of data and data analysis were stored on a password-protected computer in the home of the researcher.

Survey data were analyzed using Microsoft Excel to calculate standard central tendency measures (means and standard deviations) for the scores, including separating the scores into those from students enrolled in major classes and those from mixed/nonmajor classes. Statistical analyses were employed to determine whether there were any relationships between understanding of evolution and whether students were in biology major courses or not. Data were evaluated for normality and the nonparametric statistic (Mann–Whitney U test) was used to explore the difference in scores between students enrolled in majors and mixed major classes. Reliability of the instrument was also assessed using the Cronbach alpha coefficient, which was 0.906 indicating high internal consistency.

Additionally, in an effort to compare data from this study with the 5–8 graders' data on the same questions (Sadler et al. 2013), three additional classical test theory measures were calculated for each item: difficulty, discrimination, and misconception strength. The difficulty of an item is the proportion of correct answers, while the discrimination of an item is defined as the correlation between the participant's total score on the survey and the score on the specific item (Sadler et al. 2013). The third measure, misconception strength, is calculated as number of students who chose the most popular incorrect distractor answer divided by one minus the total number of students who chose the correct answer (Sadler et al. 2013). This gives a measure prevalence of the most popular wrong answer of all the students who chose a wrong answer.

Results

The mean score on the survey was 28.25 ± 0.61 (SE) (a score of 68.90% correct answers). Figure 1 shows a histogram of the scores from all students surveyed. Negative skewness reveals cluster of scores at high end; however, the 5% trimmed mean was 28.61 (almost the same as the overall mean of 28.25) indicating that the extreme scores did not have a large effect on the data. The dataset is available in Additional file 2.

The mean score for students enrolled in major courses was 29.71 ± 0.94 (SE) (72.46% correct), whereas the mean score for students enrolled in the mixed/nonmajor courses was 27.13 ± 0.78 (SE) (66.17% correct). Figure 2 shows a histogram of each of these groups, indicating a somewhat similar distribution of scores.

In comparison, the grade 5–8 middle school students answered an average of 50% (SE 0.03) of the questions correctly (Sadler et al. 2013), less than the overall average of college students (68.9%), the average of those students enrolled in mixed/nonmajor courses (66.17%), and the average of those students enrolled in major courses (72.46%). Figure 3 displays the average proportion of answers correct (with standard error) for the three groups of students: middle school, mixed/nonmajor, and major and shows a noticeable difference in scores between the two age groups.

A Kolmogorov Smirnov test (0.106, df = 191, sig. = 0.000) showed that the distribution of all of the scores violates assumptions of normality. Therefore, a Mann–Whitney U test was employed to compare the scores of students in the major classes and the mixed classes. The Mann–Whitney U test revealed a significant difference between the scores for students enrolled in major courses ($Md = 32$, $n = 83$) and the students enrolled in courses that are mixed major and nonmajor ($Md = 29$, $n = 108$), $U = 3563.50$, $z = -2.47$, $p = 0.015$, $r = -0.1787$). The r score indicated a small effect (Cohen 1988).

As described above, each survey item has three parameters that characterize how effective it is at evaluating understanding. For example, item 329 reads.

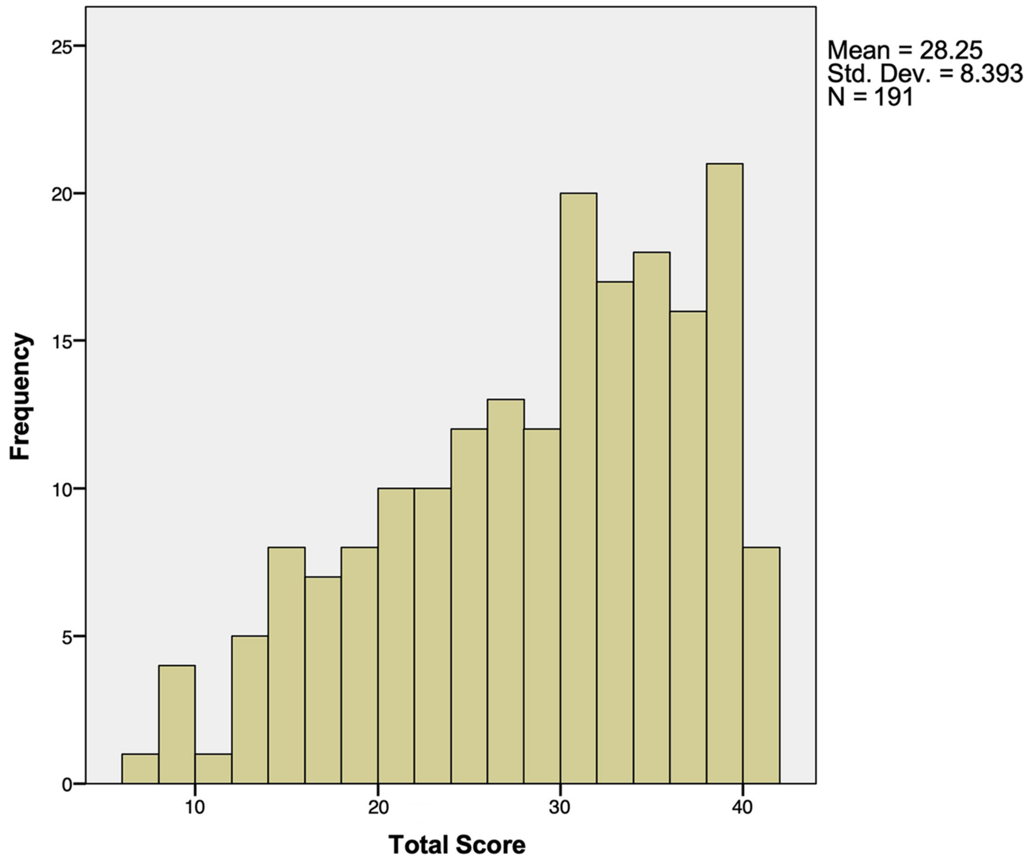

Fig. 1 Histogram of all college students' scores on the assessment

"How would a scientist explain the presence of the hard, outer shell in lobsters? Lobsters:

a. Inherit their shell, which evolved over many generations.
b. Learn to grow an outer shell from their parents.
c. Discovered how to grow an outer shell and passed that on to their offspring.
d. Grow an outer shell in response to predators.
e. Prefer an outer shell to an internal skeleton."

The correct answer is choice "a" and the most common misconception answer is choice "d." This item has a moderate level of difficulty at 0.46 with a moderate level of discrimination at 0.43. The misconception strength is very high at 0.8, which means that of all the students who chose a wrong answer (i.e., a, b, c, e), 82% chose answer "d." If they were choosing wrong answers at random, the misconception strength would be 0.25. A misconception strength above 0.50 is considered "high."

The test items in this survey can be further explored by examining the relationship between difficulty and discrimination. Figure 4 displays the relationship between these parameters and shows that when students chose the correct response for any given item, they usually scored higher on the entire survey.

Figure 5 shows the relationship between the misconception strength and the item difficulty, which is the portion of students who chose the most popular incorrect answer out of the total number of students who answered incorrectly. Thirteen of the 41 items have a single distractor answer choice that more than half of the students that answered incorrectly chose (meaning the misconception strength is more than 0.5).

Table 2 shows a comparison of the overall average scores for difficulty, discrimination, and misconception strength among the community college student data as well as the grades 5–8 student data (Sadler et al. 2013). The average difficulty and discrimination were higher among college students but the misconception strength was similar. Additionally, the range of each item among the college students was smaller or very similar to the grade 5–8 students.

There were 11 questions that over 40% of the college students missed (difficulty ranging from 0.43 to

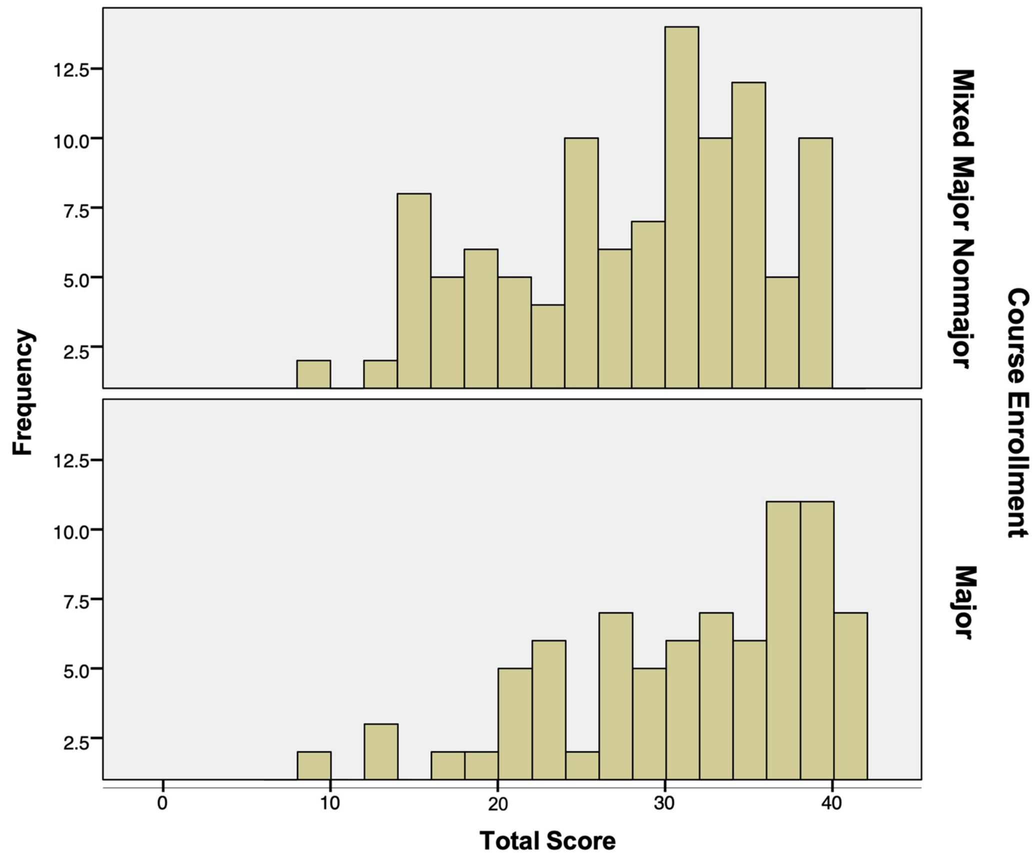

Fig. 2 Histograms of collegestudents' scores on the assessment, separated by enrollment in major biology ormixed major/nonmajor biology courses

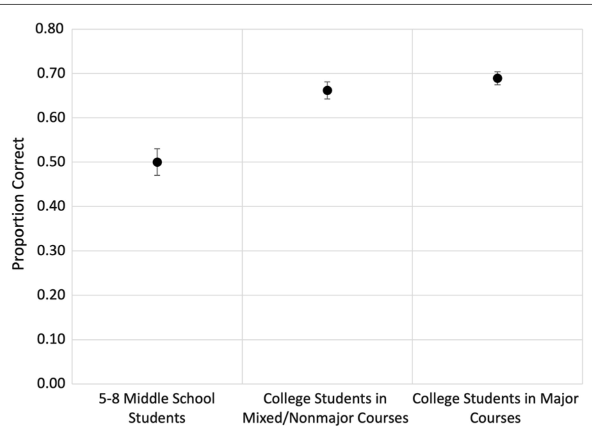

Fig. 3 Mean scores withstandard error of the grade 5–8 middle school students (Sadler et al. 2013) and collegestudents enrolled in mixed/nonmajors courses or major courses

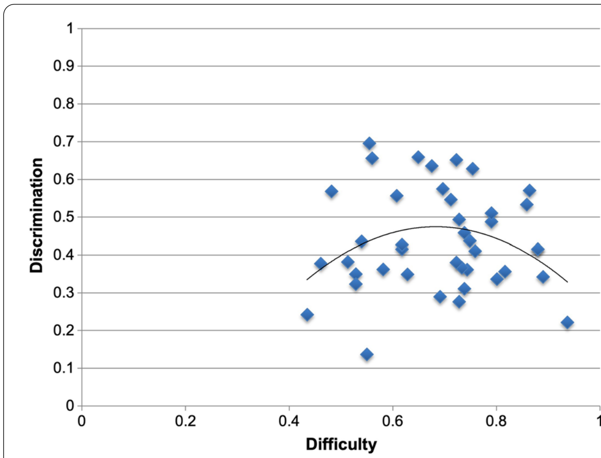

Fig. 4 Discriminationgraphed against difficulty of each item on the assessment

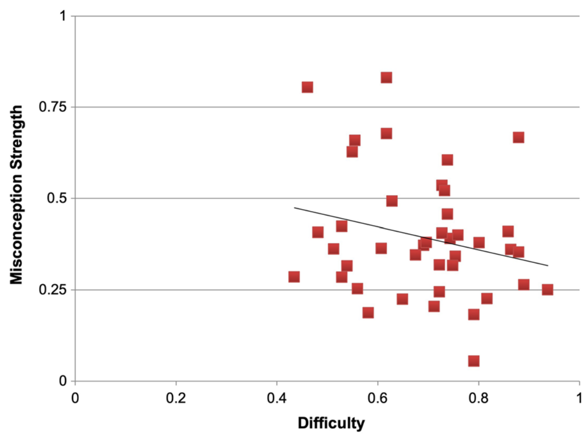

Fig. 5 Misconceptionstrength graphed against difficulty of each item on the assessment

0.58). Among these questions, misconception strength ranged from 0.33 to 0.82 (mean ± SE = 0.50 ± 0.046) and discrimination ranged from 0.13 to 0.68 (mean ± SE = 0.42 ± 0.049). Of those items, eight are also in the top 11 hardest questions of the LSCI grade 5–8 pool.

For the top 11 hardest questions among the grade 5–8 students, the students found them to be more difficult (mean ± SE = 0.26 ± 0.011, range = 0.19–0.29). Furthermore, discrimination ranged from 0.14 to 0.39 (mean ± SE = 0.23 ± 0.022) and misconception strength ranged from 0.34 to 0.56 (mean ± SE = 0.42 ± 0.022). Interestingly, the single hardest question for the grade 5–8 students, which less than 20% of students answered correctly, was not in the top 11 most challenging questions for the college students.

Of the top eight hardest questions shared by both groups, four of the questions had a different distractor answer across groups. This is interesting as the most common misconception was not consistent across age groups for half of these shared items. Overall, out of the 41 items, 17 had different distractor answers than the grade 5–8 student data.

There were 11 questions that were exceptionally easy for the college students: difficulty ranged from 0.76 to 0.94 (mean ± SE = 0.84 ± 0.016), meaning the majority of students answered these correctly. Discrimination ranged from 0.29 to 0.55 (mean ± SE = 0.47 ± 0.025) and misconception strength ranged from 0.33 to 0.65 (mean ± SE = 0.46 ± 0.034).

Of these items, seven of them were in the eleven easiest grade 5–8 student question list. Overall, the grade 5–8 students found these seven to be harder than the college students, difficulty ranged from 0.71 to 0.85 (mean ± SE = 0.77 ± 0.022), which is expected. Discrimination ranged from 0.44 to 0.55 (mean ± SE = 0.48 ± 0.014) and misconception strength ranged from 0.35 to 0.56 (mean ± SE = 0.43 ± 0.026). Both groups of students found the same question to be the easiest. Additionally, of the 7 questions they shared, 4 of those had different distractor answers.

Finally, performance on the assessment can be compared by looking specifically at the science standards these questions were designed to address. Table 3 shows the average difficulty, discrimination, and misconception strength across standards. Standard VA (that millions of species are alive now and share common ancestry) was

Table 2 Average (Mean ± SE) difficulty, discrimination and misconception strength in this study compared with grade 5–8 student data (Sadler et al. 2013)

	Difficulty		Discrimination		Misconception strength	
	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range
College students	0.69 ± 0.02	0.43–0.94	0.46 ± 0.02	0.13–0.69	0.46 ± 0.01	0.31–0.84
Grade 5–8 students	0.50 ± 0.03	0.19–0.85	0.34 ± 0.02	0.13–0.55	0.47 ± 0.02	0.29–0.82

Table 3 Average (Mean ± SE) difficulty, discrimination, and misconception strength of the 41 LSCI items across standards for community college students and grade 5–8 students (Sadler et al. 2013)

Standard	Difficulty		Discrimination		Misconception strength	
	College	Grade 5–8	College	Grade 5–8	College	Grade 5–8
VA	0.71 ± 0.04	0.60 ± 0.07	0.34 ± 0.03	0.39 ± 0.03	0.54 ± 0.04	0.46 ± 0.04
VB	0.68 ± 0.04	0.47 ± 0.05	0.43 ± 0.02	0.37 ± 0.03	0.50 ± 0.04	0.47 ± 0.03
VC	0.68 ± 0.02	0.46 ± 0.05	0.57 ± 0.02	0.28 ± 0.03	0.39 ± 0.02	0.47 ± 0.03

easier for both groups of students whereas standards VB and VC (species diversity arises from evolution and extinction occurred and continues to occur, respectively) were slightly harder for college students and relatively more difficult for the grade 5–8 students. Misconception strength was comparable in both groups and the college students displayed a greater range of discrimination.

Discussion

In this paper, we sought to explore community college life sciences students' knowledge and understanding of evolution. We measured this using the Life Sciences Concept Inventory (LSCI) (Sadler et al. 2013) that targets material covered in grades 5–8 standards on evolution. Our first research question asked how well community college students enrolled in life sciences classes understand evolution. Although there is no set rubric for determining the level of understanding on the LSCI, a typical college class requires a student to earn of score of at least 70% passing to earn the grade of C (National Center for Educational Statistics 2011). Based on this, the results of this study indicated that the students in this study possessed a fair understanding of evolution. The students in this study earned an average score of 68.9%, which is higher than what other researchers have found (using different instruments) other than Fiedler et al. (2019) who found understanding on the CANS (Kalinowski et al. 2016) and the CINS (Anderson et al. 2002) around 70%. Dorner (2016) used only 10 of the most difficult LSCI items and found an average score of approximately 50%, which is fairly common among the literature (see Table 1). There was a strong relationship between item difficulty and discrimination as well as difficulty and misconception strength. Additionally, the average difficulty level among the grade 5–8 students was 50%, similar to that found by Anderson et al. (2002) whereas the college level of 69% is higher (meaning that more students answered correctly, i.e., it was easier for them).

Our second research question asked whether students enrolled in major biology classes understand evolution at a different level than those enrolled in mixed major courses. We found that students enrolled in biology major classes scored significantly higher than those enrolled in non/mixed major courses. The average score of major students in this study was 72%, much higher than other previously reported scores. For example, Brown (2015) reported scores of 46% on the KEE (Moore et al. 2011) among community college students majoring in biology. Furthermore, non/mixed major students in the current study answered an average of 66% of questions accurately compared to other studies with non-major community college students that employed other instruments (see Table 1) whose scores ranged from 46 to 60% (Green 2019) and 50% (Anderson et al. 2002).

The third research question sought to compare the understanding of pre-college, 5–8th grade students, to college students when assessed using the same questions. When compared with the 5–8 grade student data (Sadler et al., 2013), the community college students showed a lower level of difficulty and higher levels of discrimination but the misconception strength was comparable. College students found the questions derived from Standards VB and VC to be more difficult than VA, as did the grade 5–8 students, however, the average scores were higher for the community college students. It was expected that community college students would perform better than fifth through eighth grade students but it is interesting that they displayed the same patterns in terms of which standards were more challenging for them. The most challenging standards, VB and VC, focus on species diversity arising from evolution and extinction occurring in the past and present continually.

The literature indicates that students often find topics relating to macroevolution (and human evolution) more challenging to accept or understand than those relating to microevolution (e.g., Barnes et al. 2019; Dorner 2016; Sbeglia and Nehm 2020; Schlieth 2017). It is possible that the questions that focused on standards VB and VC are more macro in nature which could have challenged students. Given the documented (although inconsistently) direct relationship between evolution understanding and acceptance (Dorner 2016; Dunk et al. 2017; Dunk and Wiles 2018; Dunk et al. 2019; Tavares and Bobrowski 2018), lower acceptance of macroevolution might contribute to reduced understanding of material on standards focused on macroevolution. The major biology students in introductory biology earned an average of 44% on the MUM in one study (Nadelson and Southerland 2010a) while nonmajor students earned 50% on the CINS in another (Anderson et al. 2002). Given that the MUM is centered around macroevolution whereas the CINS focuses on natural selection, the fact that major students scored lower on the MUM than the nonmajor students on the CINS may support the idea that understanding of macroevolution topics is more challenging than other topics in evolution.

There are some additional factors that may account for the fair performance on the LSCI assessment. First, students in the current study scored higher than those previously reported the literature (see Table 1). One explanation for this may be that the study was conducted in April of a typical semester which means students were more than halfway through the material. It is logical to assume that students enrolled in a variety of biology courses would have already encountered evolution by that point in the course. Other studies, as seen in Table 1, primarily surveyed students before a course began or at the very beginning of the course when they would presumably have less knowledge about evolution. For example, students who took the CANS before their course scored below 50% but at the end of the semester, their scores increased by 30% (Kalinowski et al. 2016).

Another possible explanation could have to do with the level of preparedness in the city in which the community college is located. The region possesses several highly ranked high schools (U.S. News 2021) that feed into this community college so it is reasonable to think that those students may have had either more exposure or more meaningful engagement with material about evolution in high school biology classes. Additionally, the LSCI was targeted towards 5–8 grade student whereas the other instruments in the literature are aimed at college students. Therefore, it is expected that college students might perform better on an assessment written for younger students.

Third, even though students in the current study scored higher than previously reported, their scores are still just below a 'passing' grade. Perhaps high school-level instruction in evolutionary biology is flawed (Rutledge and Mitchell 2002) as this appears to be true in high school students as well. Miller-Friedman et al. (2019) examined evolution education in middle and high school using assessment tools that were developed as part of the larger MOSART project (the same project produced the assessment tool used in the current study). Near the end of the school year, over 16,000 middle school students completed the assessment and nearly 10,000 high school students completed the high school level assessment. The average score for the portion of the assessment based on evolution standards was 0.29 for middle school students and 0.42 for high school students (out of 1.0). Both scores indicated that students were answering less than half of the questions correctly. The authors interpreted their results to mean that students as a whole in the United States are not meeting expectations for evolution learning.

Given the low scores of the grade 5–8 students (Sadler et al. 2013), and the high school students (Miller-Friedman et al., 2019), it is possible that both middle school and high school evolution education are lacking. In one study of community college students in Texas, the students reported only having learned evolution for five hours or less in high school and many reported that they were taught creationism (Brown and Scott 2016). Additionally, a survey of 71 AP biology teachers in Alabama found that the understanding of evolution in teachers was low, with average scores just over 50% (Glaze and Goldston 2019). Research suggests that understanding of evolution is positively correlated with positive high school experiences with evolution (O'Brien et al. 2009). If college students tend to do better learning evolution when they have previous experience with it (Barnes et al. 2017) and have positive attitudes towards it, effective high school preparation is essential (Carter et al. 2015).

However, there are bright spots that suggest evolution education at the high school level has improved over the last decade. Plutzer et al. (2020) compared data from 2007 to 2019 regarding how evolution is taught in high school biology classrooms in the US. They found that although the number of teachers who do not teach evolution at all increased a bit, over 95% of teachers reported teaching evolution. Additionally, the number of hours spent on human evolution increased by 60% and general evolution increased by 25%. More teachers agreed with the consensus that evolution is a fact and the number of teachers who disagreed dropped by 9%.

Unfortunately, in a similar study Branch et al. (2021) examined data from 678 middle school science teachers, from a national survey in 2019 regarding their coverage and views on evolution. When compared to data from the previous study of high school biology teachers (Plutzer et al. 2020), middle school teachers felt that they were less prepared to teach evolution, or less likely to take a definitive stand on the science of evolution versus creationism, and spent less time in class on evolution. Clearly, teacher preparedness is still an important issue for evolution education.

Limitations and future research

There are several limitations to this study that suggest directions for future research. Perhaps the most glaring limitation is that no other data were collected from the students. Given the interesting relationships between evolution acceptance and other variables (educational goals, demographics, etc.) it would have been useful to have those data in order to explore correlates of these students' understanding. Previous research has shown a connection between evolution understanding and evolution acceptance (Dorner 2016), as well as understanding of evolution with the understanding of the nature of science (Dorner 2016). The current study represents a missed opportunity to look at correlations between the understanding of evolution and religiosity, educational goals and experience, and demographic characteristics.

Another limitation is the timing of the survey. Given that it was administered to students in the middle of the semester, across multiple courses, it is difficult to know how much exposure to evolution the students had already experienced in their classes. It would have been valuable to be able to administer the survey as both a pre-course and post-course assessment. This, combined with information about the number of biology courses previously taken, might provide insight into the impact of taking courses on the understanding of evolution.

Our data are also limited by the fact that they were collected at only one college. Evidence suggests that attitudes towards and about evolution, including evolution acceptance, can vary with geography, so collecting data from more than one geographic region (e.g., Kelly et al. 2016) could provide more insight into community college students' understanding of evolution. Additionally, a larger sample size might allow for more generalizability.

Additionally, although we obtained a high reliability score for this assessment with this population, the LSCI (Sadler et al. 2013) has not been previously validated with college-level students, only students in grades five through eight. It would be interesting to administer the LSCI along with a well validated measure such as the CINS (Anderson et al. 2002) and compare the results. Previous work has shown, college students typically do not perform very well on the CINS (see Table 1). Given the lack of research correlating the LSCI with the other popular instruments, it is challenging to make comparisons between our data and previous research. However, we chose this instrument because there was published data on younger students' performance on the LSCI, thus allowing us to make comparisons to students earlier in their education. Furthermore, due to the secure nature of the LSCI, we are not able to publish question specific data, such as which distractor answers were most commonly chosen. This information could be of use to other researchers. Researchers can gain access the LSCI by submitting a request though the Project MOSART homepage (https://waps.cfa.harvard.edu/mosart/).

Finally, after the current study had already been conducted, a LSCI was developed for high school-age students (Miller-Friedman et al. 2019). The average score for the portion of the assessment based on evolution standards was 0.42 for high school students (Miller-Friedman et al. 2019), which is significantly worse than how community college students performed on the grade 5–8 LSCI assessment. It would be interesting to see how community college students perform on that compared to their high school counterparts.

Conclusion

This study demonstrated that students enrolled in Life Sciences courses at a community college have a fair understanding of evolution, constituting a good, but not masterful understand of concepts at the middle school level. Students enrolled in major biology courses earned higher scores on average than those enrolled in mixed/nonmajor courses. Additionally, college students performed better on average than the grade 5–8 students who completed the same assessment but, showed the similar patterns in terms of misconceptions and which material was the most challenging. Unfortunately, since no other data were collected from the students, it is hard to know what accounts for these results and therefore, future research should consider collecting more data and measuring evolution understanding at different times in the semester. Regardless, the generally poor performance of college students on assessments of evolution understanding in the literature, suggest that more research into why and which factors impact understanding is necessary. The major implication for college instructors is that while incoming students have some conceptual mastery of biological evolution concepts taught earlier, many students will carry the same misconceptions held by middle school students. Since college-level content is typically built upon much simpler pre-college ideas, instructors would do well to survey their incoming students to reveal their pre-conceptions and attempt to ameliorate non-scientific misconceptions before moving on to teach more sophisticated ideas. Given that teachers who know their students' ideas are much more successful in having their students learn new concepts (Sadler et al. 2013; Chen et al. 2020), the time and energy required may help to increase conceptual understanding in college-level introductory biology courses.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12052-022-00178-y.

Additional file 1: Sample survey questions.

Additional file 2: Dataset of college student answers for each item on the assessment.

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Author contributions
Conceptualization: MAD and BA. Methodology: MAD, BA, and PS. Data collection: MAD. Data analysis: MAD and PS. Writing- original draft: MAD. Writing-review and editing: MAD, PS, and BA. All authors read and approved the final manuscript.

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Availability of data and materials
The dataset supporting the conclusions of this article is included within the article (in its additional file). Additional file 2 contains the college student answer for each item on the assessment.

Declarations

Competing interests
There are no competing interests although the third author is on the board of Evolution: Education and Outreach.

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