The Tangible Benefits of Disability and Accessibility Awareness in Evolutionary Biology College Courses Centered in Universal Design for Learning (UDL)

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ABSTRACT

Universal Design for Learning (UDL) is one method for implementing inclusive education that can have tangible benefits for all learners, increasing educational accessibility. Furthermore, UDL can be used as a vehicle to train majority nondisabled students in methods of inclusive education. We implemented an inclusive education pedagogical framework centered in UDL and tasked undergraduate evolutionary biology students with creating digital science media products throughout semester-long science communication projects. Our goal was to assess student perceptions of accessibility and disability, within the context of science products such as digital media. Student pre–post survey comparisons indicate an increase in ability to define accessibility, consider accessibility in science media, and advocate for access in science. Additionally, postsurvey results suggest that students experience a greater sense of classroom community, inclusion in science, and awareness of disability as diversity. We centered our study in Critical Disability Theory, and we draw on universal design literature and our lived experiences. Evolutionary biology courses inherit a long and troubling history of exclusion and othering through problematic science communication and debunked concepts of human categorization. As biology educators and education researchers, we wish to enact change in our evolutionary biology college classrooms to center our pedagogy in social justice, challenging this history. We encourage future UDL implementation in evolutionary biology and other science courses, where future practitioners of science, medicine, engineering, and other fields can feel empowered by inclusive practices and community experience.

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INTRODUCTION

Inclusive education has been at the forefront of efforts to provide equitable learning for all students, including students with disabilities, as it focuses on transforming the educational environment to meet the needs of all learners (Katz, 2013; Wilson, 2017; García-Campos *et al.*, 2018; Slee, 2018; Karisa, 2023). Universal Design for Learning (UDL), with its roots in universal design in the built environment, is one method of implementing inclusive education (Rose, 2000; Hall *et al.*, 2012; Karisa, 2023) that forges a wide "spectrum of possibility" for student learning (Baglieri *et al.*, 2011). Although UDL has potential to impact all learners, it provides a framework and methodology particularly well-suited for exploring accessibility and disability awareness, by virtue of its flexibility and commitment to removing barriers to education, its use of multiple means of content perception, and its grounding in disability social justice (Hackman and Rauscher, 2004; Wilson, 2017; Hanesworth *et al.*, 2018; Karisa, 2023; CAST, 2024). UDL, in short, seeks to increase educational accessibility and equity. In a U.S. college educational system where faculty, staff, and students hold wide-ranging views and perceptions of accessibility and disability (Houck *et al.*, 1992; Lombardi and Murray, 2011; Baker *et al.*, 2012; Toutain, 2019), we recognize that the implementation of inclusive design such as UDL into pedagogy has the potential to shift these perceptions, especially for those directly doing the implementing. As such, in addition to using UDL guidelines in developing our courses, we guided our students to implement UDL themselves, to develop accurate science communication pieces. We then investigated how student implementation of UDL impacted their perceptions of accessibility and disability while they produced science media content in evolutionary biology.

We chose to focus on disability in conjunction with accessibility because "accessibility" can have many common meanings, such as access to goods and services, but the term "accessibility" is also tied to disability access. It is unclear from the literature how majority nondisabled undergraduate students perceive this word and its relation to disability. Exposure to UDL principles has potential to reframe this concept for students by going beyond broad meanings of accessibility, to "address barriers rooted in biases and systems of exclusion for learners with and without disabilities," as made explicit in the new 3.0 UDL Guidelines (CAST, 2024). In addition to providing new understanding on student perceptions of "accessibility" and "disability" before and after their practice of UDL in evolutionary biology classes, we highlight student reflections on the broader classroom community benefits of UDL practice. In doing so, we assess how UDL can shift students' able-bodied views of the world. We center our work in Critical Disability Studies, and provide new insights on the tangible benefits of UDL implementation in evolutionary biology classrooms, with college students themselves as UDL practitioners.

BACKGROUND AND CONTEXT

College courses centered in evolution are required in a majority of biology majors, and are often taken by nonmajors to fulfill science core requirements. Evolutionary biology courses provide an opportunity to introduce biology students to content topics such as evolution, earth history, human biology, and more. Less commonly included are topics of equity and social justice, often considered the realm of humanities or social sciences, although calls to action have strongly suggested the integration of science and society (Labov *et al.*, 2010; Woodin *et al.*, 2010; AAAS, 2011; Adams *et al.*, 2023). Because many college students take these courses, they provide an opportunity to introduce concepts of equity and social justice to most people who go on to work in biology fields. UDL is one vehicle for these concepts, and it has been shown to have additional benefits within biology course contexts. For example, UDL holds promise in supporting deaf and hard of hearing students in introductory biology courses by creating more inclusive and holistic teacher training environments that highlight Deaf culture (Orndorf *et al.*, 2022), and has been utilized to encourage student engagement in online biology college courses (Wojdak *et al.*, 2024). Furthermore, we agree with DaSilva and Hubbard (2024) in their call for bioscience educators to actively interrogate ableism and structural biases against disabled people in biology classrooms. The benefits of UDL lead our team to a commitment to equitable pedagogical frameworks in evolutionary biology, with students themselves utilizing inclusive or universal design as a framework for sharing science communication.

STUDY PEDAGOGICAL FRAMEWORK

We developed a pedagogical framework of lesson plans that allowed our students to share the science concepts they had learned from reading and digesting academic papers, and to implement components of inclusive design and disabled accessibility founded in UDL guidelines in their final projects, over a span of ∼6 weeks and in four different university courses. Our goal was to investigate the benefits or drawbacks on student conceptualization of access and disability resulting from this pedagogical approach. We implemented our UDL-centered project in four evolutionary biology courses at three separate U.S. universities, where students learned how to practice methods of UDL as a vehicle for equitable science communication. Full lesson plans are available at the Teach the Earth online lesson repository (Hlusko *et al.*, 2025), including text outlines for learning management system module pages, sample activities, and fully customizable science communication project assessments and discussion topics.

This study shares the results of pre–post surveys and student interviews that assessed student experiences with the project and their perceptions on accessibility and disability in science communication media. We also share pertinent reflections from faculty interviews. There are several studies that analyze the impact of UDL on student learning (Lee *et al.*, 2015; Almumen, 2020) and classroom equity (Price *et al.*, 2012; Basham and Marino, 2013; Finnegan and Dieker, 2019), but to our knowledge there are none that look at the impact of university students as practitioners of UDL themselves, especially as it impacts their perceptions of accessibility and disability. There has been recognition of further need to assess the impact of UDL on classroom and departmental culture in college STEM (science, engineering, technology, and math) environments, especially for marginalized groups such as disabled and neurodivergent people (Salvatore *et al.*, 2024). Although instructor and administrator understanding of UDL is important, we wish to add to the literature by including the perspectives of students themselves as UDL practitioners. By emphasizing UDL and disabled equity in evolutionary biology courses across multiple universities, recognizing evolutionary biology's troubled past regarding the use of science to categorize and "other" disabled people (see Discussion), this study not only addresses historical shortcomings in our field related to disabled equity, but also emphasizes the ability of such inclusive pedagogical approaches to foster a sense of community and social responsibility among future STEM practitioners. Science communication projects can be a powerful medium through which students can practice this social responsibility in science courses.

UDL and Science Education

Universal Design for Learning (UDL) has evolved as an inclusive pedagogical framework with significant implications for science education. Initially rooted in the field of architecture to promote accessible design (Mace, 1985), universal design has extended accessibility best practices into educational settings (Hall *et al.*, 2012). The concept of UDL gained traction in response to the need for inclusive practices that accommodate and more fully welcome diverse learners in an inherently inequitable academic environment, and that address various learning modalities, abilities, and backgrounds. Within the context of science education, UDL has been highlighted as a method for equitable STEM K-16 teaching (Price *et al.*, 2012; Basham and Marino, 2013; Finnegan and Dieker, 2019); studied for its effect on science learning globally (Lee *et al.*, 2015; Almumen, 2020); and has been supported within subject-specific endeavors such as introductory biology (Orndorf *et al.*, 2022), evolutionary biology (Harris *et al.*, 2020; Hasley *et al.*, 2024), anatomy (Balta *et al.*, 2021; Dempsey *et al.*, 2023), undergraduate health science (Kumar and Wideman, 2014), nursing school courses (Celestini *et al.*, 2021; Celestini, 2022), and computer science (Israel et al., 2020), among others. The COVID-19 pandemic has also exposed further education-based inequities and led to a refreshed look at UDL as a potential pathway to equitable and inclusive digital learning (Montgomery *et al.*, 2024). One of our four study courses was run entirely online during the COVID-19 lockdowns, and two others had a hybrid online component. The ongoing impact of inclusive digital learning during this span of time will likely be a subject of interest for inclusive biology education researchers.

DEFINITIONS

Defining Inclusive Education

There is no generally agreed upon definition for inclusive education, although typologies have been made to frame various aspects of what "inclusion" means (Göransson and Nilholm, 2014; Krischler *et al.*, 2019). The Salamanca declaration (UNESCO, 1994) and the "Education for All" initiatives (UNESCO, 2000) sought to provide pedagogical and empirical frameworks to insist upon opportunities for the education for all students, including those with disabilities in "mainstream" classes, as a method of inclusion (Göransson and Nilholm, 2014; Nilholm and Göransson, 2017). Inclusive education has come to encompass a global movement formed "in response to the exclusion of students…viewed as different," including but not limited to disabled students (Waitoller and Artiles, 2013), and is an ongoing global process, rather than a singular goal to be easily achieved. Inclusive education is further interpreted within the global contexts and social norms of the societies in which it operates (Cerna *et al.*, 2021). Our study considers inclusive education as encompassing educational opportunities for all students, centered in community-building efforts to engage students as practitioners of inclusive education, through UDL.

Defining Accessibility

Accessibility, most generally, is a term that can be used to encompass equitable societal access for all people, to the greatest extent possible. Accessibility is defined (Merriam–Webster, 2024) as a capability of being reached, understood, used, appreciated, or influenced; in standard use, accessibility can be understood as the ability of a *person* to be capable of these things ("I can access this"), as well as a state of certain *resources* such as goods, services, or knowledge ("This resource is accessible to me"). The fifth definition on the Merriam–Webster list, as of this writing, pertains to disability, where accessibility is defined as ease of use or ease of access for disabled people, or an adaptation for use by disabled people.

These definitions both influence, and are influenced by, societal understandings of disability as related to ease or adaptation. The definitions strikingly omit mention of equity or equality. Therefore, we provide an additional definition of accessibility, specifically related to disability equality and disabled experience. The U.S. Department of Justice and U.S. Department of Education (2010), along with the National Center on Accessible Educational Materials (2023), define accessibility as below. It is the same definition that CAST, the developer of the current UDL resource website, utilizes in its development of UDL materials:

- Accessibility means that an individual with a disability can acquire the same information, engage in the same interactions, and enjoy the same services as an individual without a disability, in an equally integrated and equally effective manner, with substantially equivalent ease of use.

We present both definitions of accessibility to underscore how the meaning of access can change depending upon the context in which it is used, its intended audience, and an understanding of its use as a disability-centered term. Ease of use is present in multiple definitions, and equity is omitted, while equality is implied in the CAST and U.S. Department of Education definition.

Defining Disability

The Americans with Disabilities Act (1990) defines an individual with a disability as:

- A person who has a physical or mental impairment that substantially limits one or more major life activities, a person who has a history or record of such an impairment, or a person who is perceived by others as having such an impairment.

Disability can also be defined in ways that critique the idea of impairment as strictly negative, and that acknowledge the social and political nature of disabled status. Impairment can also be viewed as a difference or divergence that is respected in a diverse society. For example, another definition of disability to which we prescribe is that shared by Cameron (2010; 2011, p. 20; 2014, p. 6) in their reframing of disability and impairment:

- Disability: a personal and social role that simultaneously invalidates the lived experiences of people with impairments, and validates the lived experiences of those considered normal

- Impairment: a physical, sensory, emotional, and cognitive difference, divergent from culturally valued norms of embodiment, to be expected and respected on its own terms in a diverse society

As we document the narratives of student understanding of both accessibility and disability, it is crucial that we recognize the lived experiences and identities that have shaped our understanding of these terms, as researchers. We acknowledge the shifting cultural meanings of these terms. We use "disability" and "disabled" to reflect the use of these concepts within higher education. Some have suggested the visual disruption of the terms, as (dis)ability (Schalk, 2017), dis/ability, and dis/abled, to trouble the idea that disability is fixed and factual. Dis/ability is a way to interrogate an "inability to perform culturally defined, expected tasks (such as learning or walking) that come to define the individual as primarily and generally 'unable' to navigate society" (Annamma *et al.,* 2013, p. 24). We present these visual disruptions specifically to assert that being disabled does *not* represent a lack of ability. We also wish to acknowledge that we use the terms "disabled people" rather than "persons with disabilities," and thus center disability as core identity through identity-first language and the social model of disability; however, there is no consensus in the use or preference of these terms. Other readers may be more familiar with or prefer the use of person-first language.

Ableism and Anti-Ableism

Increasing accessibility and going beyond accessibility in our academic systems through techniques that utilize universal design may allow students and educators to lessen the impact of many forms of othering, including ableism. Leah Smith (n.d.) of the U.S. Center for Disability Rights defines ableism as follows:

- Ableism: a set of beliefs or practices that devalue and discriminate against people with physical, intellectual, or psychiatric disabilities, which often rests on the assumption that disabled people need to be "fixed" in one form or another

Ableism is further intermingled with different forms of systemic othering. Talila "TL" Lewis (n.d.), in community with Disabled Black and other minoritized people, including Dustin Gibson, defines ableism as:

- Ableism: a system that places value on people's bodies and minds, based on societally constructed ideas of normality, intelligence, excellence, desirability, and productivity. These constructed ideas are deeply rooted in anti-Blackness, eugenics, misogyny, colonialism, imperialism, and capitalism. This form of systemic oppression leads to people and society determining who is valuable and worthy based on a person's language, appearance, religion, and/or their ability to satisfactorily [re]produce, excel, and "behave," You do not have to be disabled to experience ableism.

These two definitions of ableism highlight our belief that ableism is inextricably linked to a multitude of oppressive systems, and that in interrogating one such as ableism, we can simultaneously interrogate others such as racism, sexism, and Eurocentric hegemony. In contrast to ableism is anti-ableism, which seeks to recognize, disrupt, and counteract the harms of ableist systems.

POSITIONALITY AND THEORETICAL FRAMEWORK

As researchers, we recognize we are not values-neutral. In an attempt to highlight our qualitative values and add to our study's reflexivity and accountability, we provide reflexive accounts of our positionality below.

The lead author (T.L.) is an insider researcher as a disabled person, yet occupies only small slices of the full diversity of disability, rendering the insider status as situational and conditional. She is autistic/ADHD and has had shifting low-vision issues throughout her life, having been born premature. Trained as an evolutionary biologist and science education researcher, she is currently a postdoctoral fellow in science education equity at a small Midwestern research university, 40+, white, queer, nonbinary, and femme, from a suburban middle-class upbringing with strong cultural roots and practices, including Sicilian and Scottish earth-based folk culture. She became Jewish as an adult and is a first-generation researcher.

L.J.H. is a full professor of biology at a major research university, and now a research scientist at a national research center in Spain. She has been in academia for more than 20 y with strong ties to the discipline of biological anthropology, is 50+, heteronormative, from a rural upper middle-class upbringing in Appalachia with Christian cultural roots.

L.A. is an assessment professional for a health education program at a major research university. She originally was a chemistry graduate student before obtaining her PhD in science education. She is 35+, white, heteronormative, and was the first in her family to obtain a doctorate degree. She grew up in a mid-sized town with a working class family.

T.F. is a PhD candidate studying paleobiology at a major research university. He is 25+, heteronormative, and was raised in a suburban middle class household in the New York metropolitan area with Ashkenazi Jewish cultural roots.

C.A.S. is an associate professor of anthropology, biology, and women's gender and sexuality studies at a research-intensive private university. He has been a member of the biological anthropology community for over 20 y, is 40+, white, gay/queer, nonbinary man married to another man, raised without religion in working class households with housing/financial insecurity in a predominantly Black urban context in the Midwestern U.S.

O.R. is a middle-class Mexican-American man originally from Los Angeles, and now working at a community college in Los Angeles County.

Z.J.T. is an associate professor at a research-intensive public university. He has been a member of the vertebrate paleontology community for nearly 20 y, is 40+, heteronormative, and a first-generation immigrant and academic in the United States with cultural roots in Taiwan and mainland China.

A.B. is a full professor of chemistry and a member of a graduate group in science education at a major research university. She has been in academia for more than 25 y, is 50+, heteronormative, from an upper middle-class upbringing in urban settings. Her work has focused on student learning and experiences for 13 y.

Our central guiding theories are Critical Disability Studies (Vehmas and Watson, 2014; Schalk, 2017; Goodley *et al.*, 2019) and social justice education (Liasidou, 2013). Critical Disability Studies can be viewed as a subject-oriented area of study, studying disabled people; or as a methodology (Schalk, 2017). When taken as methodology, it involves "scrutinizing not bodily or mental impairments but the social norms that define particular attributes as impairments, as well as the social conditions that concentrate stigmatized attributes in particular populations" (Minich, 2016). Minich (2016) further emphasizes the importance of Critical Disability Studies as methodology in the context of teaching, where disabled students in university systems are subjected to the medical model of disability and instructors are strained in properly implementing disabled access. Schalk (2017) also concurs on the importance of teaching Critical Disability Studies as a methodology to help shift students' able-bodied views of the world. We utilize Critical Disability Studies as methodology in a pedagogical context, to assess awareness of disability and accessibility in our science classes, among our largely nondisabled or nonneurodivergent (as of yet) student bodies.

Social justice is a concept that is understood and manifested in many ways. Here, we define it as a way of challenging systems that privilege one group over others (Choules, 2007), leading to a reflexive, conscious process intended to enhance equity, and boost social action (Carlisle *et al.*, 2006). We deliberately chose UDL over other forms of inclusive education such as differentiated practices, because we wished to go beyond "accommodating" disabled students and address systemic barriers in our educational environments and social constructs. In this way, we practice UDL in alignment with social justice and critical disability theory. UDL cannot achieve these goals in isolation or in a few university courses alone, and it is not "universal" for everyone; we emphasize social justice education as a framework and mindset for helping students grapple with multiple forms of social disadvantage and oppression, while engaging in small components of transformative pedagogical action (Liasidou, 2013).

RESEARCH QUESTIONS

Through the critical disability and social justice pedagogical frameworks, we seek to answer the following questions:

- Research Question #1: How does student implementation of inclusive design in a science communication project impact their perceptions of accessibility and disability?
- Research Question #2: What are the community benefits of implementing inclusive design in a science communication project?

MATERIALS AND METHODS

All surveys were conducted under the home university's Committee for the Protection of Human Subjects Institutional Review Board Protocol #2019-10-12589 for Fall 2020, and amendment Protocol #2022-07-15503 to add the Spring 2022 semester courses.

Here, we outline the course learning concepts, study design, survey reliability, and validity. Because we utilize components of qualitative and quantitative research, the results of which informed one another, we conduct a mixed-methods study in a constructivist paradigm. We therefore provided our positionality and reflexivity for the qualitative component, and here provide our reliability and validity for the quantitative component. We created a new survey instrument to test these research questions, and focused specifically on three of the fixed response questions, comparing preproject with postproject survey responses. We also analyzed a set of postsurvey Likert scale questions. Fixed responses were analyzed using either posttest descriptive statistical analysis (Likert questions) or paired pre–post t tests (Guttman Questions 1, 3, and 5). We conducted postcourse semistructured interviews with students and faculty who agreed to participate, selecting four quotes from a total of nine students interviewed in Fall 2020 (HumanBio), and one quote from one student interviewed in Spring 2022 (Dinosaurs). Only students from HumanBio and Dinosaurs agreed to be interviewed. Two of the four instructors were also interviewed, and sample responses are included.

Students completed an online Qualtrics survey at the beginning 2 weeks and the final week of the semester, before and after their communication project intervention. We offered up to five extra credit points for survey completion, and students had an optional alternate assignment of 500 words centered in accessible design, if they did not wish to complete the survey. Survey participation was entirely voluntary.

Biology Concepts and UDL Framing Relevant to Students' Projects

Student projects spanned a range of evolutionary biology content and concepts, but all courses were centered in some aspect of evolutionary biology and offered within a biology or anthropology department (Table 1). We include objectives and scope for the science communication project (Table 2) to provide transparency on what the courses discussed, though these content objectives were not assessed in the study; rather, we assess disability and accessibility perceptions. A full description of how we implemented UDL, based on CAST's recommended UDL reporting practices (Rao *et al.*, 2020), is also provided (Table 3).

Study Design and Course Scope

This study focused on survey results from the Fall 2020 semester of human biological variation (Pilot Course at University #1 taught by L.J.H.), which we title "HumanBio," at a major public university in the United States; the subsequent Spring 2022 semester of life during the age of dinosaurs at the same university (University #1), which we title "Dinosaurs"; and two additional evolution-based courses at private universities external to the first university (Universities #2 and #3), which we title "EvoBio" and "Evolution" for ease of reference, respectively.

Science Communication Project Overview. In each course, the science communication project led students through the process of choosing, reading, and synthesizing an academic research paper, understanding processes of ethical science

TABLE 1. Courses included in this study

Course Designation (University Type and Location)—Short Name	Course Subject (Course Listings)	Enrollment	Course Semester
Pilot Course at University #1 (Public 4-y, West Coast U.S.)—"HumanBio"	Human Biological Variation (Biology, General Education, and American Cultures[a])	675	Fall 2020
University #1 (Public 4-y, West Coast U.S.)—"Dinosaurs"	Life During the Age of Dinosaurs (Biology and General Education)	100	Spring 2022
University #2 (Private 4-y, Northeast Coast U.S.)—"EvoBio"	Evolutionary Biology of Human Variation (Anthropology, General Education, and Women and Gender Studies)	50	Spring 2022
University #3 (Private 4-y, West Coast U.S.)—"Evolution"	Evolution (Biology)	60	Spring 2022

[a]American Cultures at University #1 is a suite of courses that fulfill a requirement for all undergraduate students to have taken a course that engages with race and ethnicity in the United States; modified from Lepore et al. (2025).

communication, and implementing a component of disability accessibility through inclusive design methodologies.

Over the course of several weeks, student groups created final course projects such as videos, podcasts, or social media infographics and infused their pieces of science communication with aspects of UDL. We tailored our lessons to teach students about disabled equity and accessibility, and about practical techniques for implementing accessible options within their final project presentations. Providing examples of disabled voices was key to this process, and our pedagogy team was led and assisted by disabled and/or neurodivergent contributors throughout the process—maintaining a critical sense of "nothing about us without us" (Sarju, 2021). Before and after the student projects, we asked the students to reflect on their understanding of accessibility—a concept that is central to disabled equity—and how strongly they may notice or consider accessibility when interacting specifically with science media products (documentary videos, podcasts, social media posts, etc.) as a form of science communication. The communication project was initially designed by L.J.H. through her participation in the university's Creative Discovery Fellows Program, formerly known as the Adobe Fellows Program. The Fall 2020 HumanBio version of the project was further developed to include aspects of disability accessibility and additional science communication instruction in collaboration with L.J.H. and the graduate instructor team. This version of the project was again implemented in Spring 2022 with minor changes to accommodate course curricular timing.

TABLE 2. Project objectives

Project Objectives	Example
Scientific accuracy	Students received direct instruction on how to identify reliable scientific sources of information.
A frame for understanding the science that does not rely on the scientifically incorrect idea of there being human races; practice talking about human variation in a way that explicitly rejects the framework of racial variation. This will keep your science communication scientifically accurate and consequently, antiracist[a]	Students whose projects specifically addressed human skin pigmentation and the social construct of race practiced more prevalent examples of antiracist science communication through group discussion.
Consideration of your target audience throughout the project framing process	All student groups considered an imagined target audience for their digital product (demographics, location, etc.)
Choosing a media-type that is appropriate for your target audience and the message you are conveying	All student groups chose or were directed to produce a media type appropriate for their audience and message; examples included podcasts, videos, social media mock-up posts, children's books, traditional poster presentations[b]
Considering audience accessibility and inclusion of those with sensory access needs	Access needs were essential to each student project and included closed captioning, audio narration, colorblind palettes, alt text, signed language, etc.
Learn how to effectively communicate science, as well as the difficulties in doing so effectively; gain a critical eye for science presentations, in particular those on the topic of a chosen academic paper centered in an evolutionary biology concept	Each week of the project guided students with examples and challenges of effective science communication, including comparing different examples of science communication; considering audience, accessibility, and narrative; storyboarding; peer-reviewing drafts of digital products; building teamwork skills; and presenting final edited products.

[a]Fall 2020 and University #2 2022, these courses involved specific student exploration of scientific articles on human skin pigmentation and deconstructing any biological schema for the social construct of race.
[b]University #1 in 2022 produced solely poster presentations, each with an aspect of universal design and accessibility such as signed languages, colorblind-friendly palettes, audio narration, etc.

TABLE 3. UDL implementation based on UDL-reporting recommendations (Rao *et al.*, 2020) and modified fromLepore *et al.* (2025)

Area and Criteria	Implementation
1. Learner Variability and Environment	Students were provided with multiple means of accessing course content knowledge in each project unit, including podcasts, text, and video. When implementing UDL in their projects, student groups chose from an array of project presentation media, anchored to an imagined target audience.
a. Participant information	Majority nondisabled and non-neurodivergent, majority intention to enroll in a science, technology, engineering, or math (STEM) major, roughly 50/50 female–male with minority gender nonconforming or nonbinary.
b. Setting	Instruction was conducted online or in-person dependent upon semester, university, and COVID-19 restrictions. Flexible methods for instruction included online drop-in instructor hours for project guidance, website modules with text- and video-based project guidance, and synchronous/asynchronous options for direct instruction.
2. Proactive and Intentional Design	Students created science communication media that reflected an academic science paper or other science topic of their choosing, with guidance from instructors.
a. Addressing Barriers and/or Increasing Access	Students engaged with UDL practice such as implementation of closed captions, colorblind palettes, audio narration, or alt text to reduce or eliminate barriers for disabled, d/Deaf or Hard of Hearing, and/or neurodivergent people in their science media products.
b. Designing to Address Variability	During weekly planning sessions, instructors met to discuss design and implementation. Variability and choice in student media, topic, and target audience was interwoven in the students' UDL hands-on experience from the beginning to end of the project.
c. Application of UDL Guidelines and Checkpoints	Students engaged directly with the following UDL guidelines: • Providing their science communication audience with multiple means of representation Options for Perception ○ 1.2—Offering alternatives for auditory information ○ 1.3—Offering alternatives for visual information Options for Language and Symbols ○ 2.4—Offering multiple languages in their science communication projects, including non-English spoken and signed languages Options for Comprehension ○ 3.1—Students practiced examples of basic narrative structure to engage their science communication audience and to activate or supply audience background knowledge • Providing their science communication audience with multiple means of action and expression Options for Physical Action ○ 4.2 Optimize access to tools and assistive technologies for their science audience Options for Expression and Communication ○ 5.1—Multiple media for communication, in both access of content knowledge and choice of science communication media (podcast, video, etc.) Options for Executive Function ○ 6.1—Students had direct instruction on project goals, but student groups were in charge of appropriate goal setting with low-to-no stakes checkpoints with instructors, and increasing goal autonomy throughout the course of the project (from guided instruction to student peer-review of one another's projects) • Providing their science communication audience with multiple means of engagement Options for Recruiting Interest ○ 7.1—Students were encouraged to practice individual choice and autonomy in the selection of their project topic and media; and, in their science communication media products, students were encouraged to engage their audience
3. Implementation and Outcomes	Each course implemented the following UDL-centered independent work before beginning the project.Each course implemented the following independent work: 1. To engage with and reflect on two inclusive design videos from the Microsoft Inclusive Design website (https://www.microsoft.com/design/inclusive/), specifically Haben Girma's video on community education and accessibility and the short-film titled Inclusive; 2. To read and reflect on the blog post The Evolution of Universal Design: A Win–Win Concept for All (Simmons, 2020), 3. To read and reflect on the Seven Principles of Universal Design (Center for Universal Design, 1997); 4. A preproject assignment asking students to respond in writing with a one benefit and one drawback of four types of science communication, of the instructors' topic choice, including an infographic, a podcast, a popular newspaper or magazine article, and a short video. Students were then guided through the iterative steps of their science communication project over the span of 6 to 8 wk. See description of implementation and practice above, as well as Supplemental Materials. Full outcomes and implications are described in the paper text.

Fall 2020 Implementation. In Fall 2020, HumanBio student enrollment was 665, and the course was implemented entirely online during the COVID-19 lockdowns. The lecture was taught by one of the authors (L.J.H.), with discussion sections taught by T.L. and a team of fellow graduate student instructors. The weekly lectures supplemented the discussion sections through discussion of human biology, while the communication project was conducted over six in-class discussion sections. Students were given a choice of target audience and final project medium, and selected a topic of interest from three academic papers chosen by the teaching team. Each paper focused on refuting the trope of race through biological evidence.

Spring 2022 Implementation. The Spring 2022 dinosaur course at University #1 (Dinosaurs) was newly revised and offered in Spring 2022 after an "age of dinosaurs" course hiatus of several years. The flexibility of the Dinosaurs course revision allowed the communication project to be implemented as a key component of the student experience. The Spring 2022 course at University #1 was implemented in-person, with weekly synchronous lecture components. The lecture was taught by one of the authors (Z.J.T.), with guest lectures and sections taught by the graduate student instructor and co-author (T.F.). The weekly lectures allowed 30 to 90 min of discussion time, with the project conducted over a period of eight in-class work weeks. The Dinosaurs course had an approximate enrollment of 100 students. Students were given a fixed audience of peers, and students selected a dinosaur-themed topic of interest for independent research through primary literature. Projects were presented as digital posters with an accompanying accessibility component.

The two external Spring 2022 courses were evolutionary biology of human variation at University #2, taught by one of the authors (C.A.S.); and evolution at University #3, taught by one of the authors (O.R.).

The course at University #2, EvoBio, was implemented in-person, with weekly synchronous lectures taught by one of the authors (C.A.S.), and a weekly synchronous discussion component taught by a graduate teaching fellow. The weekly discussion allowed up to 50 min of discussion time, with the project conducted over a period of five in-class work weeks. The course had an approximate enrollment of 50 students. Students were given a choice of target audience and final project medium, and selected a topic of interest in a wide range of evolutionary topics from several primary literature sources provided by the instructor.

The course at University #3, Evolution, was implemented in-person, with weekly synchronous lecture and lab discussion components, both taught by the lead instructor, and an asynchronous Zoom lecture was captured as well. The weekly labs allowed up to 2 h of discussion time, with the communication project conducted over a period of six in-class work weeks. The course had an approximate enrollment of 60 students. Students were given a choice of target audience and final project medium, and were guided by the instructor to find a primary literature source in evolution topics that informed their communication project to a target audience.

Research Survey Instrument

The survey comprised a series of paired fixed-response and open-response questions, divided into broad categories that sought to elicit student responses on accessibility and science communication, as well as general perceptions of diversity. Instructionary text prompted students to reflect on their experiences with accessibility and science communication, and student respondents could not move back to change a previous answer. This was important as we first asked students about their confidence in defining accessibility, whereas later questions provided our definition of accessibility. We implemented the full survey in each of the four evolutionary biology courses, from which the subset of fixed-response questions were selected. This subset was chosen for analysis to focus the research around perception of accessibility and disability.

The following Guttman-style questions (Table 4) are addressed within this study. The Guttman-style questions were paired in pre–post surveys to assess the impact of the communication project, while a separate set of Likert scale questions (Table 5) were provided only in the postsurveys. Because the Guttman-style questions were merged to include pre–post pairings, the sample size is smaller for these questions than for the set of Likert scale questions, which were administered postsurvey only.

Survey Reliability and Validity

The goal of the survey was to assess student confidence in defining, thinking about, and valuing the inclusion of accessibility in science media. The question subsets were chosen to reflect this focus on disability and accessibility, whereas the larger survey contained questions related to diversity more broadly. We assessed survey item reliability and validity through a number of correlated methods (Cobern and Adams, 2020), which are described here. Initial survey items and response choices were drafted in Qualtrics by the lead author in consultation with several experts in science education research and disability studies within the College of Chemistry, School of Education, Department of Integrative Biology, and Department of Anthropology at University #1. An expert writer and editor also completed a sample of the survey instrument and provided feedback as an external reviewer. Undergraduate student volunteers unassociated with the study provided think-aloud feedback on individual questions. Any confusing or jargon-based wording in the item questions or response choices was edited for clarity following this process of review. In addition, the initial round of presurveys at University #1 (HumanBio) underwent testing through Item Response Theory (IRT), which allowed further clarification within future versions of the survey.

IRT protocol (Wilson, 2023) was conducted under the guidance of Prof. Mark Wilson and a team of graduate student peer-reviewers familiar with IRT at the University of California Berkeley School of Education. Any unclear or internally inconsistent question response stems were removed accordingly. Specific changes included removing unclear or double-barreled question choices (e.g., [pilot survey] I always think about the accessibility of that medium, and I always or almost always communicate my thoughts to others = [new survey] I always think about the accessibility of that medium). From Pilot University #1 presurvey to postsurvey, double-barreled

TABLE 4. Guttman survey items

Survey Items
Pre–Post Guttman, Question 1 "How well can you define accessibility?" Scale 0 [I cannot define accessibility.] Scale 1 [I can define accessibility in broad terms, but I cannot provide specific explanations or examples.] Scale 2 [I can define accessibility and provide a few (1–2) explanations or examples.] Scale 3 [I can define accessibility and provide many (3 or more) explanations or examples.]
Pre–Post Guttman, Question 3 *Definition of accessibility provided after this point; students could not return to previous questions to edit answers."Accessibility is a concept that results in accommodating a resource or physical place so that it is equitably reached, entered, or utilized by people with disabilities. Imagine you are watching, reading, listening to, or engaging with a piece of science media. How would you respond to the following statement? When interacting with a piece of science media, such as a news article, video, podcast, website, social media post, or infographic about science: Scale 0 [I would never think about the accessibility of that medium for disabled persons.] Scale 1[I would sometimes…] Scale 2 [I would always…]
Pre–Post Guttman, Question 5 Accessibility is a concept that results in accommodating a resource or physical place so that it is equitably reached, entered, or utilized by people with disabilities. How would you respond to the following statement? Accessibility is important to consider when science communicators craft science media. Scale 0 [I believe accessibility is always important to consider when crafting science media.] Scale 1 [I believe accessibility is sometimes important to consider when crafting science media.] Scale 2 [I do not believe accessibility is important to consider when crafting science media.]

question responses were analyzed so that the highest construct map levels (always and almost always) were combined; no significant difference was found when examining the results with or without combining. Both the pilot survey in HumanBio and the new Spring 2022 version of the survey in Dinosaurs, EvoBio, and Evolution maintained the same open response questions, which are the subject of additional forthcoming qualitative work (Lepore *et al.*, *2025*).

With regard to the Likert scale questions, we conducted exploratory factor analysis to assess question groupings into themes of disability awareness and advocacy, and community connection (Table 5). The rotational type utilized was varimax orthogonal rotation, which assumes factors that are independent or uncorrelated with each other (Corner, 2009). We used a four-point Likert scale to remove respondent choice of neutrality (Dixon *et al.*, 2016). The two resulting factors had scree plot and eigenvalues greater than 1, comprising 100% of the variance, and those two factors resulted in factor loading of 0.5 or greater (Figure 1). The Kaiser-Meyer-Olkin measure demonstrated sampling adequacy at KMO = 0.952 (Worthington and Whittaker, 2006; Braun *et al.*, 2017; Field, 2024). Bartlett's test of sphericity, which is sensitive to smaller sample sizes, was highly significant ($p > 0.0001$) (Worthington and Whittaker, 2006).

Response Rate

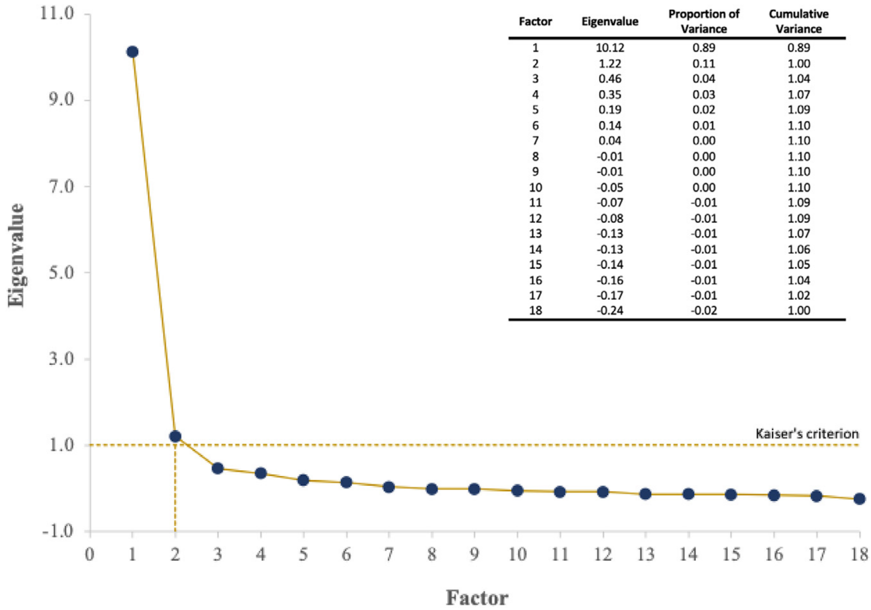
We report the following response rates (Table 6) for the total course responses, as well as consented responses.

Demographics

These demographics (Table 7) represent the Pilot Course in Fall 2020, as well as the combined Spring 2022 courses. Spring 2022 courses are combined due to relatively small sample sizes in each individual course. We report self-reflections of gender identity, ethnicity/race, and sexual orientation. In addition, we combined responses reflecting neurodiversity, disability identity, and for Spring 2022 we report those who shared that they receive disability services on their campuses.

TABLE 5. Likert scale survey items

Theme	Likert Scale Questions
Disability awareness and advocacy	I have grown in my awareness of disability accessibility and accommodation. I am more motivated to advocate for disability accommodation in the future. I now consider disability to be a part of human diversity more than before this project or course.
Community connection	I have a greater connection to other human beings as a part of the human race. As a student, I feel more included in science because of this course or project. I built a greater connection with my peers and instructors as a classroom community. I have made new friends throughout this learning experience.



Factor	Eigenvalue	Proportion of Variance	Cumulative Variance
1	10.12	0.89	0.89
2	1.22	0.11	1.00
3	0.46	0.04	1.04
4	0.35	0.03	1.07
5	0.19	0.02	1.09
6	0.14	0.01	1.10
7	0.04	0.00	1.10
8	-0.01	0.00	1.10
9	-0.01	0.00	1.10
10	-0.05	0.00	1.10
11	-0.07	-0.01	1.09
12	-0.08	-0.01	1.09
13	-0.13	-0.01	1.07
14	-0.13	-0.01	1.06
15	-0.14	-0.01	1.05
16	-0.16	-0.01	1.04
17	-0.17	-0.01	1.02
18	-0.24	-0.02	1.00

FIGURE 1. Scree plot and eigenvalues.

TABLE 6. Survey response rates

Survey Instrument	Timeline	Total Responses	Total Enrollment	Total Response Rate (%)	Consented Responses	Consented Response Rate (%)
Pilot Course University #1 (HumanBio) Presurvey	Fall 2020	597	665	89.77	382	57.44
Pilot Course University #1 (HumanBio) Postsurvey	Fall 2020	560	665	84.21	462	69.47
University #1 (Dinosaurs) Presurvey	Spring 2022	83	107	77.57	79	73.83
University #1 (Dinosaurs) Postsurvey	Spring 2022	89	107	83.18	73	68.22
University #2 (EvoBio) Presurvey	Spring 2022	35	50	70.00	23	46.00
University #2 (EvoBio) Postsurvey	Spring 2022	30	50	60.00	25	50.00
University #3 (Evolution) Presurvey	Spring 2022	49	60	81.67	37	61.67
University #3 (Evolution) Postsurvey	Spring 2022	36	60	60.00	29	48.33

NOTE: Only consented responses are included in the study, with a matching pre- and postsurvey.

TABLE 7. Demographics

Category	Fall 2020	Spring 2022
Gender identity[a]	Female, 110 Male, 88 NB, 1 Prefer not to say, 7	Female, 33 Male, 28 NB, 0 Prefer not to say, 1
Ethnicity/race[b]	American Indian/Alaska Native, 1 Black or African American, 1 East Asian, 94 South Asian, 46 Southeast Asian, 15 Hispanic/Latinx, 15 Pacific Islander, 1 Middle Eastern/Southwest Asian, 2 White, 22 Prefer not to say, 7	American Indian/Alaska Native, 0 Black or African American, 5 East Asian, 20 South Asian, 9 Southeast Asian, 3 Hispanic/Latinx, 10 Pacific Islander, 0 Middle Eastern/Southwest Asian, 4 White, 8 Prefer not to say, 2
Sexual orientation[c]	Heterosexual, 164 Bi/Ace/Queer/Other, 39	Heterosexual, 38 Bi/Ace/Queer/Other, 20
Disabled/neurodivergent	Yes, 14 No, 177 Unsure, 8 Prefer not to say, 7	Yes, 11 No, 49 Unsure, 0 Prefer not to say, 1 – Disabled, 3 – Neurodivergent, 11 – DSP Services?, 2

[a]Students were given the choice of male, female, and nonbinary (NB)/third-gender. In the Spring 2022 survey, students were also asked whether they identified as transgender in a separate question, though none responded yes.
[b]Tabulated from preresponses ($N = 204$, Fall 2020; $N = 61$, Spring 2022); each respondent was given multiple examples of countries and regions potentially corresponding to these categories.
[c]Tabulated from preresponses ($N = 203$, Fall 2020; $N = 58$, Spring 2022); nonheterosexual categories are combined.

In the Spring 2022 courses, 34% of the student total ($N = 61$) identified as nonheterosexual, and 18% identified as disabled, whereas in Fall 2020, 19% of the student total ($N = 203$) identified as nonheterosexual, and 7% identified as disabled.

RESULTS

Taken in sum, we share statistical analyses from the pre–post paired surveys and the postsurvey Likert responses. We also provide sample quotes from the semistructured student and instructor interviews to highlight participant experiences in their own words.

Statistical Analysis

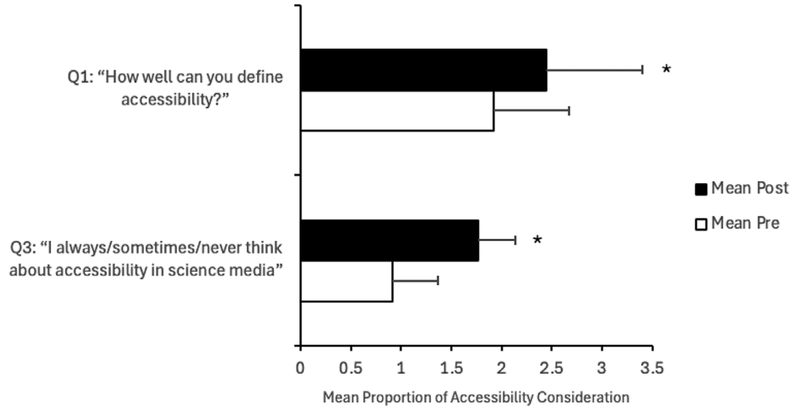
We compare inferential statistics and pre–post t tests for the Fall 2020 (HumanBio) and Spring 2022 (Dinosaurs, EvoBio, and Evolution) (Figure 2) survey cohorts. In addition, there is no statistical significance shown when comparing subsets of STEM major students versus non-STEM major students within the cohorts (Table 8).

Survey Questions 1 and 3—Accessibility Definitions, and Thinking About Accessibility in Science Media. When asked how well they could define accessibility (Question 1), student responses shifted from a mean of 1.92 to 2.45 (Fall 2020) and from 1.83 to 2.08 (Spring 2022 combined). The effect size in Fall 2020 was high enough to indicate a likely effect, at 0.72; however, the effect size in Spring 2022 was much smaller at 0.37. When asked how much they think about accessibility in science media (Question 3), student responses shifted from a mean of 0.91 to 1.77 (Fall 2020) and from 0.82 to 1.11 (Spring 2022 combined). The P values were <0.01 for Fall and Spring in questions 1 and 3.

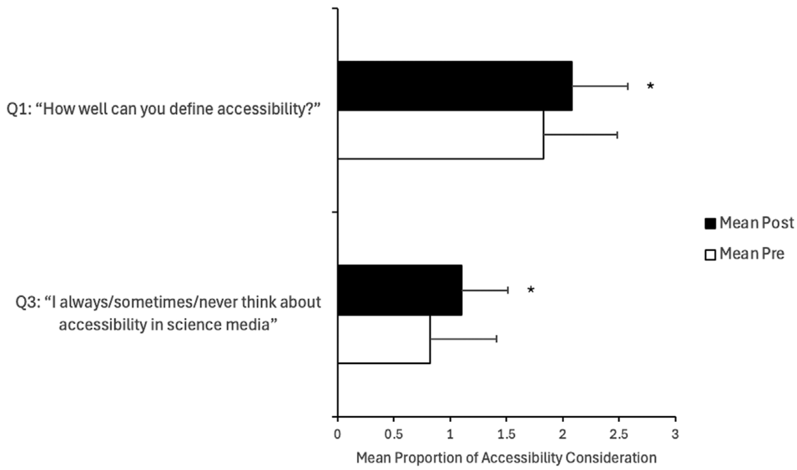
Survey Question 5—Accessibility's Importance in Science Media. When asked whether they agreed that accessibility was important to include in science media, student responses shifted from a mean of 1.75 (pre) to 1.86 (post) in Fall 2020. In the Spring 2022 courses, the shift was slight from "always" to "sometimes" thinking accessibility is important in science media, from 1.87 (pre) to 1.84 (post); this result was not statistically significant, with very low effect size (0.07).

Postsurvey Likert Responses

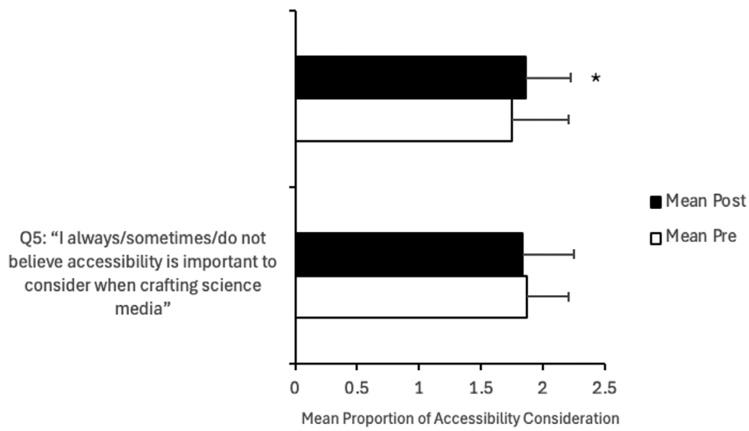
The Likert results were generated from Fall 2020 postsurvey responses ($N = 299$) and the Spring 2022 postsurvey responses ($N = 100$) (Figure 3), with both semesters' responses combined. Bar charts show abbreviations of the survey question, with fixed-response ordinal choices ranging from Strongly Disagree to Strongly Agree. Neutral/No Response was not a respondent option. Aggregate inferential statistics are provided here, indicating the majority of students "agreed" or "strongly agreed" across each question. A total of 78% of students agreed they had made friends during the course project. A total of 86% reported feeling more connected to others' humanity after the course. A total of 81% agreed they had built a greater connection with their peers



a. Fall 2020 (Q1 and Q3)



b. Spring 2022 (Q1 and Q3)



c. Fall 2020 (top) and Spring 2022 (bottom) (Q5)

FIGURE 2. (A) Pretreatment and posttreatment, Fall 2020 HumanBio, $p = 0.001$. Q1 and Q3 are a scale of 0–3; Q5 is a scale of 0–2. *N*-size, degrees of freedom: Q1 $N = 199$ (df = 198), SD Pre = 0.68, SD Post = 0.67, effect size = 0.72; Q3 $N = 205$ (df = 204), SD Pre = 0.75, SD Post = 0.95, effect size = 0.87; Q5 $N = 204$ (df = 203), SD Pre = 0.46, SD Post = 0.37, effect size = 0.23. (B) Pretreatment and posttreatment, Spring 2022 EvoBio, Evolution, Dinosaurs, $p = 0.006$ (Q1), $p = 0.000$ (Q3), $p = 0.568$ (Q5). Q1 and Q3 are a scale of 0–3; Q5 is a scale of 0–2. *N*-size, degrees of freedom: Q1 $N = 59$ (df = 58), SD Pre = 0.65, SD Post = 0.75, effect size = 0.37; Q3 $N = 62$ (df = 61), SD Pre = 0.59, SD Post = 0.50, effect size = 0.47; Q5 $N = 62$ (df = 61), SD Pre = 0.34, SD Post = 0.41, effect size = 0.07.

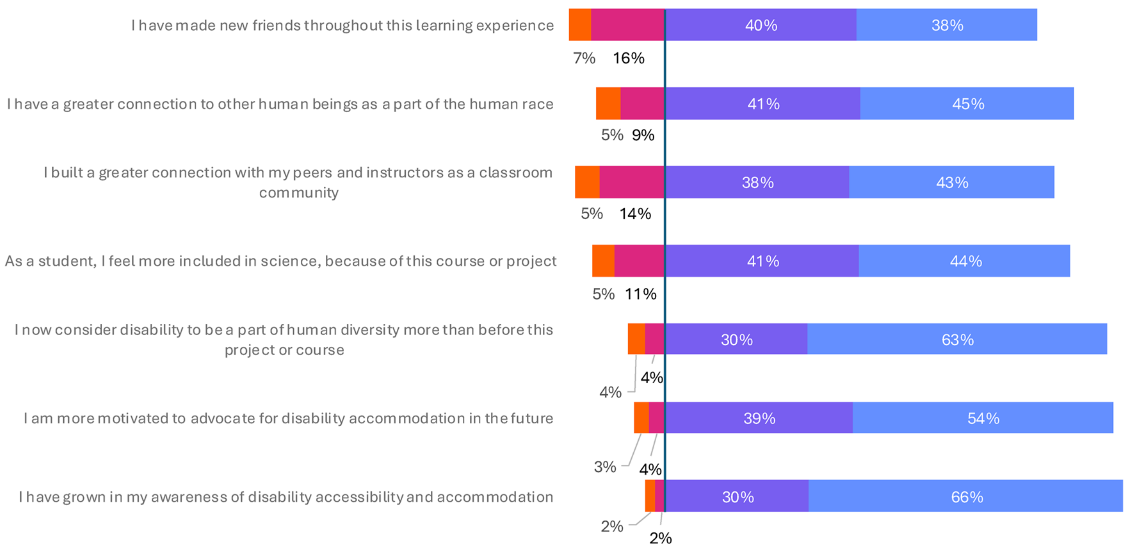


FIGURE 3. Likert postsurvey responses

and instructors. A total of 85% of students felt more included in science as a result of the course or project. Of >93% of students agreed they now considered disability as part of human diversity more than before the course. A total of 96% of students agreed that their sense of disability awareness had grown, and 93% agreed their sense of disability advocacy had increased across all courses.

Sample Quotes

To better understand the context of the science communication project and its impact on our classroom communities alongside the quantitative results, we conducted semistructured postcourse interviews with students and faculty who had agreed to participate. The selected quotes highlight student thinking around accessibility as a focus of the course project, as well as accessibility as a term that incorporates disability. Respondents also reflected more generally on the project experience. The quotes were selected to synthesize a representative sample of student thinking around these concepts.

When asked by the interviewer, *How did you feel about the accessibility focus of the project and why?,* students responded

TABLE 8. STEM versus non-STEM majors—comparison groups

STEM majors vs. non-STEM Majors—Fall 2020 HumanBio					
	MANOVA			Linear Regression	
Question	STEM Major (*N*)	Non-STEM major (*N*)	*p*	R^2	*p*
Q1*: "How well can you define accessibility?"	168	38	0.7526	0.0005	0.7641
Q3*: "I always/sometimes/never think about accessibility in science media."	168	38	0.3071	0.0051	0.3319
Q5+: "I always/sometimes/do not believe accessibility is important to consider when crafting science media."	168	38	0.7928	0.0003	0.7347

STEM Majors vs. non-STEM Majors—Spring 2022 Dinosaurs, EvoBio, and Evolution					
	MANOVA			Linear Regression	
Question	STEM Major (*N*)	Non-STEM major (*N*)	*p*	R^2	*p*
Q1*: "How well can you define accessibility?"	38	23	0.4081	0.0123	0.3850
Q3*: "I always/sometimes/never think about accessibility in science media."	38	23	0.5261	0.0068	0.5296

with thoughts about the social and content learning aspects of the project.

One student [F2020-7, F/South Asian] from the HumanBio course reflected on the social implications of including accessibility, such as building a more inclusive university environment:

> "I actually thought it was really cool, I feel like a lot of classes I'm in don't really make time to make accessibility a factor in the course. I also like how it went along with the material and showed the social implications of the material. I wish more courses would do it because I feel it would help make the school a more inclusive environment."

Another student [S2022-1, F/Latinx-white] from the Dinosaurs course discussed broad accessibility during COVID and the helpfulness of the project in self-assessing learning:

> "There was a big focus on trying to figure out how to make the project accessible in the class. I felt like the class was pretty accessible to people who didn't want to come in because of COVID. Um, so, yeah there was a lot of talk about accessibility and that was really helpful. … I felt like I got a good grasp of what we were learning about."

During the semistructured interview, one student was also asked, *When you think of the word "accessibility," are there definitions that come to mind? Did your definition change, thinking about accessibility as a disability-centered term?* The respondent, the same student from the Dinosaurs course [S2022-1, F/Latinx-white], shared their broadened understanding of disability and accessibility:

> "Um, yeah, I definitely changed my definition over time. So first it was really simple, I just thought of um, like, people who don't have certain abilities, like Deaf uh non-hearing or blind people, and trying to make things accessible to [people categorized within] different races or socioeconomic statuses, but then, there are a lot of things I didn't, like I didn't think about colorblind people, like how certain graphs may be really difficult for them to see. So it really broadened my understanding of like, oh yeah, we need to make things accessible to all these different groups."

The interviewees were also asked a final question, *Do you have any other thoughts about the project?* Because the largest sample of interviewees by far was from HumanBio, all three sample quotes are from this interview cohort:

> [F2020-2, F/South Asian]—"Personally I don't like biology, but I thoroughly enjoyed this class, how considerate everybody was, it's much more than the sciences, it's reaching out and saying there's a place for all of you in this science world."

> [F2020-9, M/East Asian]—"I actually learned quite a lot from the project and I guess for me it strengthened some of the thoughts I had about diversity and accessibility."

> [F2020-6, F/East Asian]—"I have a deeper impression of the skills to help those with [a] disability. And it's also motivated [*sic*] me to do those in the future."

The instructor of the Evolution course (author O.R.) shared thoughts on the project implementation:

> "Despite this being a tough semester with Zoom and the pandemic, I thought this was the best version of this kind of science communication project that I've had.

Thinking about the science and learning about the science is important—but also the other side of it, thinking much more sensitively about how [the students] are communicating about it."—Spring 2022 University #3 Professor (Evolution)

Finally, the instructor of the EvoBio course (author C.A.S.) shared reflections on how they perceived a benefit to students by completing the project:

> "It's a new way of thinking about the science that is really kind of beneficial for [the students]; it forces them not to just memorize the information, but process it in a way that helps them think about themselves as part of a community, and communicate to a community."—Spring 2022 University #2 Professor (EvoBio)

DISCUSSION

In our pedagogical framework, we are curious about the tangible benefits of greater accessibility and disability awareness in evolutionary biology courses. We highlight quantitative and qualitative evidence in the form of Guttman-style pre–post survey questions, Likert scale postsurvey questions, and semistructured interview responses, each providing new information on student perceptions of accessibility and disability, particularly in an evolutionary biology and science setting. Returning to our research questions, we aimed to better understand how student implementation of an inclusive design project, hard-wired with disability and accessibility content knowledge through UDL, would impact student perception of these concepts. We also asked whether there are broader community benefits to students implementing UDL themselves, within our evolutionary biology classrooms.

- *Research Question #1: How does student implementation of inclusive design in a science communication project impact their perceptions of accessibility and disability?*

We share our interpretation of results from Guttman-style questions in a pre–post comparison *t* test, from Likert scale questions, and from select interview quotes from students and instructors. Respondents considered aspects of accessibility's definition, their awareness of accessibility, their sense of accessibility advocacy in science media, community aspects of an accessible course project, and their sense of disability as diversity. In the pre–post comparison, survey questions 1 and 3 sought to understand how students define accessibility, and their readiness to think about accessibility when engaging with science media, while question 5 focused on their perceptions of accessibility's importance in science media.

Guttman Questions (pre–post comparison)

Survey Questions 1 and 3—Accessibility Definitions, and Thinking About Accessibility in Science Media. In both Fall 2020 (Pilot, University #1, HumanBio) and Spring 2022

(Universities #1, #2, #3, Dinosaurs, EvoBio, and Evolution), students agreed that they could define accessibility more confidently, with more examples or explanations of what accessibility means, compared with before the project. This is an interesting measure, which we find important as a baseline for students to reflect on their own knowledge of access. A reflexive qualitative analysis of some of the student written responses can further help us understand when students had a wide range of actual definitions of accessibility, including general access to goods and services rather than disability-specific access; see our related work (Lepore *et al.*, 2025). In addition, some of the student respondents relied on the internet to answer their definition of accessibility, and the definitions generally reflect a sense of ease of access rather than equity for disabled people.

We note that these written responses may not always reflect disabled accessibility, which provides insight into student understanding of the word as used in standard conversation; this also ties to the Merriam–Webster dictionary usage of accessibility as "a capability of being reached, understood, used, appreciated, or influenced." Students reflected on their definition of accessibility before the course and answered accordingly, based upon what they believed to be accurate. Given our direct instruction on accessibility as a disability equity term, and the increase in students' self-reflection of more holistically defining accessibility following the project, we interpret a positive shift in students' conceptualization of accessibility to incorporate more awareness of disabled accessibility. The shift from a mean of 1.92 to 2.45 (Fall 2020) and from 1.83 to 2.08 (Spring 2022 combined) indicates that students came in to the project with a fairly high confidence in their ability to define accessibility, and both cohorts saw increase, while the shift toward more confidence (closer to 3) was greater in Fall 2020. The effect size of 0.72 in Fall 2020 indicates a likely effect of the treatment; however, the effect size in Spring 2022 was much smaller at 0.37. This could be due to numerous factors, including the smaller sample size in Spring 2022, mixed student population samples across three courses, and the slight changes in treatment between courses in Spring 2022, as well as the many other variables at play when considering the magnitude of a treatment's effect. P values were <0.01 for Fall and Spring in questions 1 and 3, indicating a statistically significant shift in both cohorts of students.

Students in both semesters expressed that they think about accessibility in science media more readily after the project. This result indicates the effectiveness of our pedagogical goals to help students build awareness of target audiences that include disabled people and others who have specific access needs. We centered this question on accessibility in science media specifically to prompt students to consider their experiences engaging with science communication products in their day-to-day lives and during their learning experiences at their university. The prompt included text-based description of examples of what we consider to be science media, such as science podcasts, documentaries, and social media posts. If students then create their own equitable science media products, using multiple means of action, representation, and expression through UDL, it appears that the needle is shifted toward more awareness of accessibility in the science communication media that they consume. The shift from a mean of 0.91 to 1.77 (Fall 2020) and from 0.82 to 1.11 (Spring 2022 combined) indicates that students increased their self-reflected awareness of accessibility in science media, with a greater shift toward always thinking about accessibility (closer to 2) in Fall 2020.

To further delineate student experiences regarding accessibility definitions or accessibility in science media, we revisit sample quotes shared by students in the postsurvey interviews. Student F2020-9 shared about their increased awareness of diversity and accessibility, while Student F2020-6 shared that they now had a greater sense of the skills needed to "help those with [a] disability," and felt motivated to do more in the future. We note that the sense of helping disabled people may be founded in ableist ideas of disability as a limitation, although it is encouraging to see students sharing their sense of skill building in disabled access and awareness. Student S2022-1 further reflected on their increased understanding of different disabled identities such as colorblindness, and their increased awareness of a wider variety of disabled access needs. These narratives are important to document as these students will potentially stay motivated to bring their awareness of disabled equity and accessibility to future endeavors. Critical Disability Studies as methodology invites us to shift nondisabled students' ableist views of the world (Schalk, 2017), and as educators, we take on this role in our evolutionary biology courses.

Survey Question 5—Accessibility's Importance in Science Media. There was a significant increase in believing accessibility is always important to consider when crafting science media, from 1.75 to 1.86 in Fall 2020, though the initial mean of 1.75 was already quite high. This may have been due to a strong belief coming into the course that accessibility is always important in science media. In Spring 2022, there was a very slight decrease from "always" to "sometimes" thinking accessibility is important in science media, from 1.87 (pre) to 1.84 (post); this result was not statistically significant, with very low effect size (0.07). Taken together, we emphasize the difference between students acknowledging the importance of accessibility when asked about it in the presurvey, and continued belief in its importance after having actively engaged with UDL. Student interviews provided occasional reflections on accessibility's importance, though reflections specific to science media were less common. Student S2022-1 reflected in the postsurvey on the course's increased accessibility during COVID lockdown, and as well as the importance of accessibility in the course project at large. With an increasing trend toward digital learning, utilizing UDL as a method of inclusive design may continue to benefit students in multiple classroom settings, particularly post–COVID-19 (Montgomery *et al.*, 2024).

Likert Questions

Regarding disabled awareness and advocacy, >93% of students agreed they had increased their sense of disability awareness and sense of disability advocacy across all courses. When asked about their sense of disability as a part of human diversity, 93% of students agreed they now considered disability as part of human diversity more than before the course. Although singular implementations are not enough to change the perception of disability and wholly promote ongoing disabled advocacy, these results are encouraging and signal the potential for more disability and accessibility awareness if projects such as these are implemented in science courses.

- *Research Question #2: What are the community benefits of implementing inclusive design in a science communication project?*

Past studies have recognized that students benefit from inclusive community building (Elliott *et al.*, 2016; Walker *et al.*, 2024) and collaborative learning (Cabrera *et al.*, 2001), with pedagogical implementations that include group work with clear goals, knowing one another's names, and genuine dialogue (Gordon, 2011) that encourages openness and safety. Our inclusive instructional practices and direct teaching about UDL encouraged all of these aspects of community building, and we sought to understand student narratives around their sense of community, friendship, and inclusion. Students also practiced UDL themselves, as science communication project designers. When considering Likert scale questions centered on classroom community, building friendships, a sense of inclusion in science, and student sense of connections to one another, our respondents substantially agreed that these aspects of connection increased as a result of the project or course. This is especially true with respect to a sense of feeling more included in science, with 85% agreeing, and student connections to one another, with 86% agreeing. These findings underscore the broad community benefits of implementing inclusive design, especially in a science communication project, and within an evolutionary biology course.

Classroom community and sense of inclusion or connection were also documented through selected student and instructor interview quotes. Student S2020-7 reflected upon the inclusive quality of the science course, and how more courses could implement accessibility as part of a pedagogical framework. In addition, Student F2020-2 shared that they do not like biology, but enjoyed the course and the "considerate" nature of the course community. This student shared how crucial it was to reach out and make a place for all in science, which ties to our questions surrounding a sense of inclusion in science and connections to one another in a classroom community setting.

Instructors also shared their sense of a tough semester with online teaching and the COVID pandemic, while simultaneously feeling enthusiastic about implementing a science project that emphasizes inclusive pedagogy. Student-to-instructor informal reflections included not just thinking about science and learning science, but thinking more sensitively about communicating science, especially while considering themselves as part of a community. With a growing literature of inclusive pedagogy implementation in evolutionary biology college courses (Harris *et al.*, 2020; Hasley *et al.*, 2024) and discussion of ableism in biology (DaSilva and Hubbard, 2024), we add to this ongoing conversation on science communication best practices through UDL and social justice in our evolution-based classrooms. We suggest that this combination offers a unique way to empower students to actively consider who is represented in science, and in doing so, it may indirectly impact students' own sense of science identity. When students consider how they, themselves, can expand science accessibility to a group with whom they largely do not identify, students are directly placed in a position of prosocial awareness that may extend beyond the classroom space. We encourage future consideration of whether this focus on ensuring someone else's right to participate fully in science can be achieved also subtly activates students' own expectations for themselves in science.

In general, we were interested in the ideas that students and, to an extent, faculty have about accessibility and disability. We find that student respondents are more readily reflecting on sensory disabilities or more noticeable disabilities, such as wheelchair ramps, signed languages, braille, and closed captioning. These access needs are also tied to our pedagogy, as student projects most often implemented multiple means of representation such as closed captioning, audio narration, alt text, and/or colorblind palettes, centered in their own UDL practice. We agree with Reinholz and Ridgway (2021) in that a discussion of access needs and accessibility in STEM classes "allows us to talk about disability and ableism, which is necessary for dismantling these often-invisible systems of oppression." Even nondisabled people can benefit from acknowledging access needs, which "create a more inclusive and humanizing space" for all students (Reinholz and Ridgway, 2021). Building on this enhanced awareness, we also encourage future work on invisible or nonapparent disabilities, such as mental health and learning disabilities, anxiety and depression, vertigo, fatigue, chronic pain or autoimmune disabilities, and so on. Collecting data on the frequency of different UDL guideline implementations could also be beneficial. As advocates for disabled and neurodivergent awareness, we know that more work is needed to underscore student awareness and cocreation of community that is welcoming and inclusive for all learners. Future studies on the implementation of UDL-based course projects and modules should take into account these additional dimensions of disability.

WHY PRACTICE UDL IN EVOLUTIONARY BIOLOGY COURSES?

We believe practicing UDL and inclusive science communication is especially important in evolutionary biology courses, and we underscore our position within a field that has caused harm to disabled people. Disabled and neurodivergent people have been historically cast off and othered by evolutionary science (Vaahtera, 2016; Branch *et al.*, 2022). Evolutionary biology has a long history of problematic science communication, which has contributed to systematic othering. Although concepts behind the notion of "survival of the fittest" predate Charles Darwin and his scientific articulation of evolution-by-natural-selection (Malthus in 1798, [1986]), the publication of *On the Origin of Species* (Darwin, 1859) provided the illusion of biological validity for harsh philosophical notions of how society could or should operate, based on those who are "fit" or "unfit" (Claeys, 2000). For many influential social leaders, "Darwinian evolution" applied to humans has long provided justification for exclusionary, racist, and ableist practices (Dennis, 1995; Fuentes, 2021), with effects that stretch across a very wide spectrum, from bias in STEM disciplines to the Nazi justification for genocide during World War II

(O'Mathúna, 2006; Bergman, 2014, p.13). The social concept of Darwinian evolution includes scientifically debunked but incredibly pervasive notions of human racial categorization (Morning, 2008; Yudell, 2014). The eugenics movement (Allen, 2011) also relies on many of these same concepts to justify the marginalization, sterilization, and oppression of people deemed nonwhite and aberrant from the so-called normal (Dyett and Thomas, 2019; Cronin *et al.,* 2021).

The ways in which evolutionary biology has been communicated within the scientific community still contains echoes of this history, which has broad implications for the general public's understanding of societal diversity and fitness or normality. For example, some of the terms and narratives traditionally used in evolutionary science are laced with ableist meaning and undertones, such as "we could swim before we could walk"—assuming all can walk—and terms such as "wild-type" and "mutant" that subtly emphasize a spectrum of normality in nature (Vaahtera, 2016; Branch *et al.*, 2022; Packer and Lambert, 2022). Academic systems continue to be rife with oppressive practices (Patton, 2004; Settles *et al.*, 2021; Bhopal, 2022), and simultaneously, efforts to counter the exclusion of minoritized groups have been made (Draffan *et al.*, 2017; Lafferty *et al.*, 2023). These more diverse, inclusive, justice-based, and equitable efforts are under attack by the political landscape in the United States in 2025. As science educators and evolutionary biology researchers, it is essential that we take a hard look at this history and current practice of exclusion (Reese, 2023), and here, we focused on disabled equity based upon our experiences as disabled researchers and allies. One small way to begin to reckon with this history is to implement tangible pedagogical changes such as UDL that give instructors and students alike the tools to communicate science in an equitable manner, acknowledging this troubling history and teaching our students that there is a more equitable path forward for all who wish to learn about and contribute to science. This is especially important in evolutionary biology courses, which by the nature of their subject matter are connected to this history.

EVOLUTIONARY BIOLOGY AS A FORUM FOR SCIENCE COMMUNICATION

The way that science is communicated to our students, and how students approach their own science communication, clearly matters. Evolutionary biology courses provide an opportunity to create a structural change in the education and perspectives of scientists. We did not assess specific evolutionary biology concept learning or learning about eugenics within this study, but rather, assessed how UDL woven into evolutionary biology courses could impact our student perceptions of accessibility and disability. The practice of UDL seeks to explicitly address barriers rooted in biases and exclusionary systems of learning, including for disabled people (CAST, 2024), and it has its roots in disability accessibility (Mace, 1985).

As graduate student-teaching assistants and faculty lead instructors, we wished to create evolutionary biology courses with a social justice mindset that expects our students to become practitioners of equity-centered science communication. We were particularly interested in awareness of concepts such as accessibility and disability, based on the lived experiences of the lead author and other broad experiences of our research group. Inclusive science education is one way in which this awareness can be realized, through reflexivity and intentionally inclusive practices, as has been recognized by dedicated efforts in inclusive science communication (Canfield and Menezes, 2020). It is important to investigate the tangible benefits of disabled equity awareness in evolutionary biology courses on our university students—whether self-identified as disabled or nondisabled—and to teach students what to do with this awareness. In this way, we can develop best practices for teaching students to recognize and produce inclusive science. Evidence of the effectiveness of equity-centered science communication will inform continued practice of inclusive science education pedagogy in college science classrooms, uniting subject-matter pedagogy with inclusive pedagogy for intended the benefit of all (Stinken-Rösner *et al.*, 2020). Furthermore, as discipline-based education researchers, we share our instructional best practices to recognize the cultural and organizational norms of our departments and institutions, and "address those norms that pose barriers to change in teaching practice" (National Research Council, 2012, p. 195), especially in the context of disability perception.

STRENGTHS AND LIMITATIONS

All studies have strengths and limitations, and we highlight ours here. Our survey instrument was not a replicate of a statistically or internally validated instrument, though we conducted intensive validation through the expert reviews, think-aloud, and IRT. Our Likert scale questions were limited in the nature of data collection without paired open responses. We recognize that these courses were based in Carnegie R1 research universities in the United States, which limits the global generalizability of the results. However, we also share results from multiple universities and student populations within a single country.

UDL is not a checklist that, when completed, would resolve all classroom equity concerns. It is a methodology for implementing a form of inclusive education, and an imperfect one at that. UDL has been critiqued as complex, having limitations in empirical measurement of its implementation (Basham *et al.*, 2020; Murphy, 2021; Boysen, 2024). It has been called out as ignorant of the Global South, only beneficial for those students who already have significant social capital (Song, 2017), and ambiguous in its application of "multiple means" of expression (Smith *et al.*, 2019; Baglieri, 2020). We are aware of the potential limitations of the guidelines based on their Western cultural context, and that it may also be extended and intertwined, or "cross-pollinated," with culturally sustaining pedagogy to reposition and empower marginalized leaders (Waitoller and King Thorius, 2016), such as disabled students themselves.

Certain courses may have primed students in different ways; for example, the Fall 2020 pilot course had both a biology and humanities designation. Students may have enrolled expecting to be made aware of societal disparities, and therefore may have come into the project experience with greater knowledge of accessibility and disability as multifaceted. Similarly, the EvoBio course was colisted within anthropology and women's/gender/sexuality studies, which may have attracted students with greater knowledge or understanding of disabled equity due to the subject matter often covered in these types of courses and the perception that these disciplines may be more welcoming to minoritized identities (Forbes, 2020; Friedensen *et al.*, 2021). The lived experiences of our students likely influenced the ways in which students responded, and we note that during the first 2 y of the COVID-19 pandemic from late 2019 to 2022, students may have grown in their own awareness of self-identifying factors such as queerness and/or disability. In addition to personal awareness of disability, COVID-19 has been identified as a mass disabling event (Roberts *et al.*, 2022) with persistent long-term symptoms occurring (Del Rio *et al.*, 2020). Although we did not ask students about their COVID-19 experiences or symptoms, these factors are important to consider for future work.

Social Justice and Undergraduate Equity

To create more equitable educational environments, we believe that it is essential to build awareness within our undergraduate student populations of the educational disparities that exist around them. This includes awareness of disparities that exist within the disabled and/or neurodivergent communities. We highly encourage weaving social justice concepts and practice into science courses in general, and evolutionary biology courses in particular. Evolutionary biologists have a particularly salient obligation to counter the prejudices that our discipline attempted to justify in American and global society. By reflecting on the limitations and unique qualities of their own individual experiences, our students may become more aware of their biases, which in turn may help improve classroom climate for *all* students. Engaging in this type of social justice learning can help students start to consider matters of justice in their daily lives (Leonardo, 2010; Waitoller and Artiles, 2013).

Faculty perceptions of equity have been shown in some cases to range from confusion with equality, or devoid of concepts of justice, which can lead to ineffective pedagogy practices and potentially maintain rather than deconstruct educational barriers (Russo-Tait, 2023). Providing opportunities for faculty to practice equity and confront their biases alongside their students, using methods such as UDL, may help foster classroom equity. In case studies, faculty have indicated that exposure to UDL practices has increased their confidence in implementing inclusive pedagogy (Izzo *et al.*, 2008). Additionally, educator reflections on their experiences with disabled students and inclusive education indicate a need for further dialogue and support surrounding inclusive education (Kochung, 2011; Smith and Tyler, 2011; Nketsia and Salovita, 2013; AlMahdi and Bukamal, 2019; Makoelle and Burmistrova, 2021; Goodwin *et al.*, 2024).

Disabled students have themselves advocated for more faculty awareness of inclusive design principles and general knowledge of disabled experience (Black *et al.*, 2015). In addition, effective course design should make the purposes behind our pedagogical decisions clear to our students, which universal design insists on doing. Disabled and neurodivergent people are experts on their own experiences in STEM and other fields (Kingsbury *et al.*, 2020), and in sharing reflections of majority nondisabled students, our findings highlight equitable community-building efforts that can support, rather than supplant, the perspectives and experiences of these medicalized and marginalized disabled and/or neurodivergent groups. This is important because majority nondisabled students can have very different perceptions of accessibility and disability from those of disabled students, which can influence overall perspectives on disabled community at large.

CONCLUSION

UDL is an effective method of implementing flexible pedagogy, with the goal of building a more inclusive classroom environment. We share evidence from pre–post survey comparisons that indicate projects where students learn about *and* implement UDL make a difference in student sense of defining and advocating for accessibility in science, through direct practice learning about accessibility, engaging with disabled voices, and crafting accessible science media. Student and instructor quotes provide context for the fixed response analysis, which also indicate a statistically significant shift in accessibility definition and advocating for accessibility. Likert questions demonstrate broad agreement on an increase in various community and personal benefits for students, such as a sense of inclusion in science community as well as disabled advocacy. Despite its demonstrated effectiveness, UDL is not a fix-all method for classroom inequities, and a larger culture shift in how we build inclusive and culturally relevant pedagogy into our curriculum, and how we assess our students with rigid summative exams may be part of this equation. However, providing students with the tools and awareness of accessibility and disability in science, through flexible methods such as UDL, can create a classroom environment that instills inclusive teaching and learning and a social justice mindset. Moreover, nondisabled students and instructors can become more conscientious about accessibility when teaching and conducting their science across formats beyond the classroom, such as conference talks, designing figures, and so on. Evolutionary biology still has a long way to go in order to create welcoming spaces, given its extremely fraught history of upholding and supporting bias. We advocate for greater awareness and appreciation of disabled voices in evolutionary biology and other science courses, and in doing so, we aspire to help students and instructors cocreate class environments where all students feel they are represented, listened to, and can thrive. In future work, we aspire to continue building inclusive education into our pedagogical frameworks in evolutionary biology and related science fields, interrogating the inequitable academic systems in which we operate and to which science has contributed, through tangible and evidence-based action in our teaching and empowerment of our students.

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