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Evaluating Universal Design for Learning and Active Learning Strategies in Biology Open Educational Resources (OERs)

ABSTRACT

With the onset of COVID-19, colleges and universities moved to emergency remote teaching, and instructors immediately adjusted their curricula. Many instructors adapted or developed new online lessons that they subsequently published as Open Educational Resources (OERs). While much has been examined related to how entire course designs evolved during this period, the same attention has not been paid to how individual lessons were structured to meet online learners' needs. As such, we evaluated OER lessons for the integration of universal design for learning (UDL) guidelines and active learning strategies. We evaluated OER lessons published in *CourseSource,* which is an open-access, peer-reviewed journal that focuses on biology lessons implemented in undergraduate classrooms and provides the necessary details and supporting materials to replicate the lesson. We found that biology instructors used a variety of UDL guidelines and active learning strategies to encourage student learning and engagement in online teaching environments. This study also provides a collection of OER online lessons that instructors and educational developers can use to inform the practice of engaging biology students.

KEYWORDS

online learning, OERs, UDL, active learning, biology education

INTRODUCTION

During the COVID-19 pandemic, colleges and universities moved to emergency remote teaching, and instructors had to immediately adjust their curricula. Out of necessity, many instructors adapted and/or developed new online courses and lessons. In the biological sciences, instructors were tasked with moving both lecture and laboratory components of their courses online, with interactive laboratory activities being particularly challenging to implement remotely (Procko et al. 2020). While much research has been devoted to understanding how entire courses were delivered during this time period (Anghel 2023; Ozfidan, Ismail, and Fayez 2021; Tomej 2022), less is known about how college instructors used evidence-based instructional practices such as universal design for learning (UDL) guidelines (CAST 2018) and active learning strategies (Doolittle, Wojdak, and Walters 2023; Driessen et al. 2020) in individual lessons. One way to study these classroom materials is to examine Open Educational Resources (OERs) which are "learning, teaching and research materials in any format and medium that reside in the public domain or are under copyright that have been

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released under an open license, that permit no-cost access, re-use, re-purpose, adaptation and redistribution by others" (UNESCO). OERs are course materials that are often designed in smaller chunks, such as lessons or units, with the goal of being portable and adaptable. In this transition to online teaching, instructors were presented with an opportunity to implement interactive and accessible practices in an online setting by using, adapting, and creating OERs (Huang et al. 2020). The goal of this study is to address the research question: How do instructors implement UDL guidelines and active learning strategies in online biology lessons? To explore this question, we analyzed online classroom lessons that undergraduate biology instructors published as OERs in the journal *CourseSource*.

Open educational resources

OERs are an important part of the online teaching and learning ecosystem as they provide freely available lessons that can be adopted by anyone. While there are several rubrics available to evaluate the quality of OERs on a variety of criteria, ranging from technological compatibility to quality of interactivity (Albeanu and Posdarascu 2017), we examined the accessibility of designed lessons with the UDL guidelines. These were also used to assess how lessons engaged students with active learning strategies. Aligning instruction with the UDL framework and active learning strategies has been shown to decrease failure rates, increase student learning, and provide equitable opportunities for undergraduate students (Ballen et al. 2017; Beichner et al. 2007; Dewsbury et al. 2022; Eddy and Hogan 2014; Freeman et al. 2014; Haak et al. 2011; Super et al. 2021; Theobald et al. 2020). Here we introduce both the UDL framework and active learning strategies, and how they apply to online instructional environments. Then, we discuss how we found examples of lessons that have been implemented in online college-level biology classrooms using articles in the open-access journal *CourseSource.*

Universal design for learning

The UDL framework (CAST 2018) provides descriptions of inclusive strategies that can be integrated into courses regardless of modality. UDL is closely linked with the architectural principles of universal design, which encourages instructors to create environments to minimize barriers that then reduce the need for individual accommodations (Tobin and Behling 2018). UDL guidelines are applicable across disciplines, are supportive of the development of flexible learning opportunities for learners of all ages, and are grounded in learning and neuroscience research (Meyer, Rose, and Gordon 2014). The UDL framework (CAST 2018) provides instructors with guidance on integrating intentional and inclusive strategies to align the "why," "what," and "how" with the affective, recognition, and strategic brain networks in order to scaffold the development of "expert learners" (Meyer, Rose, and Gordon 2014; Rao 2021).

The UDL framework includes 31 individual instructional strategies organized into nine guidelines. As such, it can be challenging to define, measure, and operationalize UDL implementation (Basham, Gardner, and Smith 2020; Rao et al. 2020). While there is general agreement that the UDL framework shows promise and is generally supported theoretically (Cumming and Rose 2022), the number of empirical studies remains small (Schreffler et al. 2019; Seok, DaCosta, and Hodges 2018), indicating a need to continue to identify avenues for implementation and evaluation. There also are calls to increase the rigor of studies exploring how UDL impacts student learning, for example controlling for demographics and pre/post knowledge changes, before implementing more broadly (Boysen 2021; Murphy 2021).

UDL can be used to guide the design of multiple types of instructional environments including online modalities, which must be intentionally designed to ensure that all learners can access and engage with all aspects of the learning experience (Darby and Lang 2019; Meyer, Rose, and Gordon 2014). As noted by Rogers and Gronseth (2021), online courses have been shifting from expository to active and interactive approaches, addressing the need to support learners with variability in learning abilities, experiences, and other dimensions. When designing courses that are inclusive of diverse learners' needs and are equitable, the affordances of the online modality need to be considered (Artze-Vega et al. 2022). Specifically, engaging students in online courses presents considerations around creating accessible media (Gin et al. 2021; Lee 2017), and including strategies that facilitate a sense of presence (Garrison and Anderson 2003). Another key consideration is nurturing the general learner experience in order to develop relationships and dynamics that emulate in-person experiences (Conceição and Howles [2021] 2023).

Active learning

There are several definitions of active learning, but a consensus definition based on the literature and surveying undergraduate biology instructors is: "an interactive and engaging process for students that may be implemented through the employment of strategies that involve metacognition, discussion, group work, formative assessment, practicing core competencies, live-action visuals, conceptual class design, worksheets, and/or games" (Driessen et al. 2020, 7).

Multiple studies have investigated the impact active learning has on students during in-person undergraduate STEM courses. For example, a meta-analysis compared student achievement and failure rates between students in undergraduate STEM courses that used active learning approaches versus lecture (Freeman et al. 2014). Students in the active learning courses had lower failure rates and higher performance on standardized assessments. Subsequent studies explored whether active learning strategies influenced student outcomes when the data were disaggregated by several demographic variables. Collectively, these studies disproportionately showed beneficial learning gains among several student groups including those who are first in their families to attend college and students who identify with persons historically excluded because of their ethnicity and race (Ballen et al. 2017; Bauer et al. 2020; Beichner et al. 2007; Eddy and Hogan 2014; Haak et al. 2011; Theobald et al. 2020; Wilton et al. 2019).

Prior to the pandemic, the majority of studies about active learning in undergraduate STEM courses focused on in-person classrooms (e.g., Smith et al. 2014; Stains et al. 2018). The switch to online teaching provided the opportunity for many instructors to try active learning in their online courses and to share their instructional resources (Lashley et al. 2020). To date, discipline-based education research on undergraduate online courses, including biology, focuses on recommendations and general examples of how to facilitate active learning strategies (e.g., Arcila Hernández et al. 2021; Gahl et al. 2021), transitioning laboratory and field courses to online environments (e.g., Gerhart et al. 2021; Gya and Bjune 2021; Race et al. 2021), surveying students about their preferences for instructional techniques in online active learning environments (e.g., Anghel 2023; Castelli and Sarvary 2021; Nguyen et al. 2021), and developing new observation protocols to document instructional practices in an online setting (Pusey et al. 2023).

For instructors, there can be a "theory to practice" gap for both UDL frameworks and active learning strategies, meaning that they know these instructional strategies are valuable, but they are not sure how to implement them in the classroom (Dewsbury et al. 2022; Hills, Overend, and Hildebrandt 2022; LaRocco and Wilken 2013; Lombardi et al. 2021). While active learning strategies have been widely studied, the concept itself is broad and, as such, can lack definitional clarity that provides instructors and instructional designers with specific implementation guidance (Doolittle, Wojdak, and Walters 2023). Therefore, identifying, describing, and analyzing these instructional strategies using lessons that have been implemented in online settings informs the continued development of high-quality, student-centered learning. Having a collection of these lessons also provides tangible examples that can be used in educational and professional development initiatives focused on online lesson development. 2023). Therefore, identifying, describing, and analyzing these instructional strategies using lessons that have been implemented in online settings informs the continued development of high-quality, student-centered learning. Having a collection of these lessons also provides tangible examples that can be used in educational and professional development initiatives focused on online lesson development.

***CourseSource*: An OER journal for undergraduate biology education**

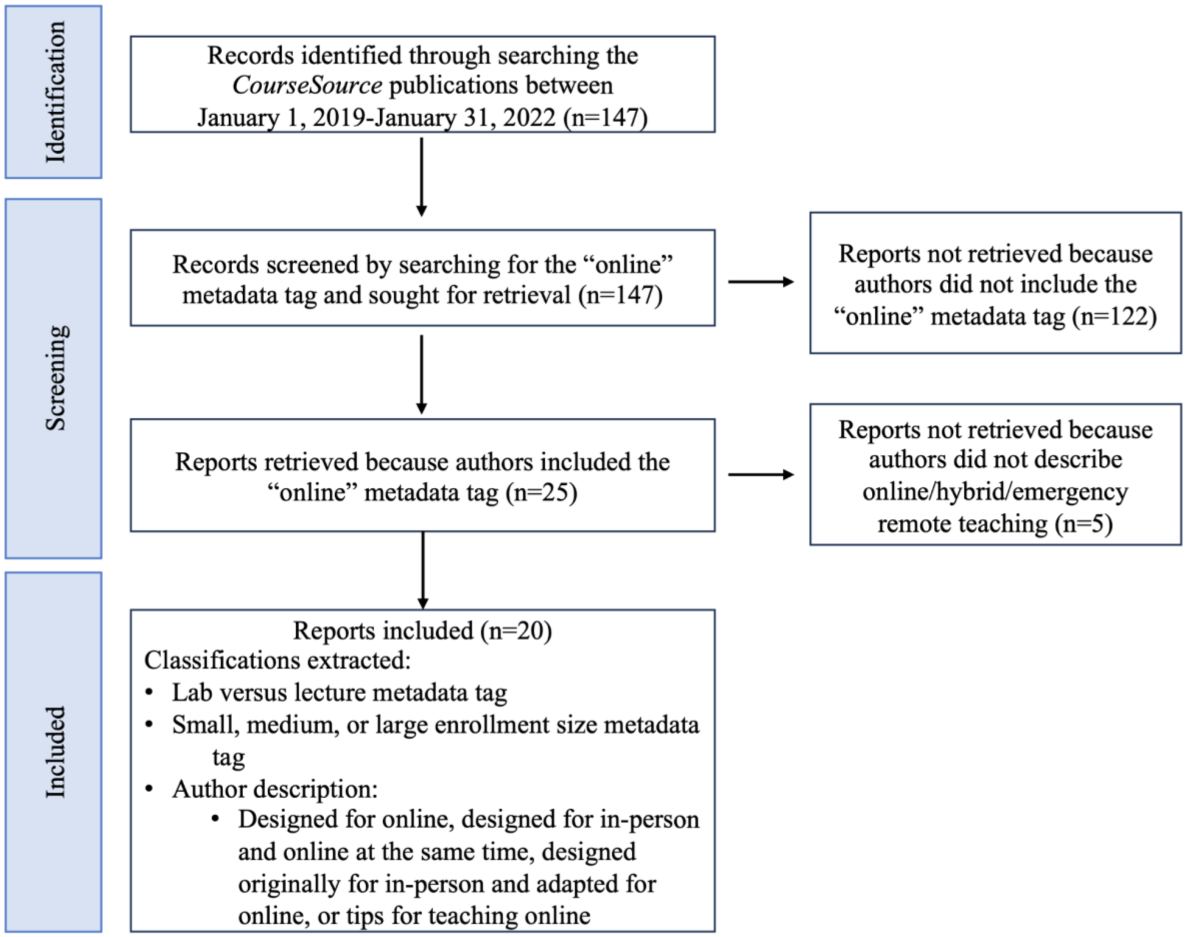
To find examples of how undergraduate instructors teach online lessons, we used OERs published in the journal *CourseSource,* which provides undergraduate teaching materials for biology courses that implement research-based pedagogical techniques. All articles are tagged to the core concepts and competencies included in "Vision and Change in Undergraduate Biology Education: A Call to Action," which is a document describing what undergraduate students should learn and be able to do and advocates for student-centered instructional strategies (AAAS 2011). *CourseSource* has over 10,000 users who hold a range of positions at different types of institutions with varied research activity levels (Senn et al. 2022). Nearly all (>95%) of the *CourseSource* articles that describe lessons published prior to spring 2020 focused on in-person, active-learning instruction. To help instructors share their online lessons, several *CourseSource* writing workshops were offered where participants learned about each section of the manuscript, were given writing time, and participated in sharing and receiving feedback with the other workshop participants. Because *CourseSource* articles include descriptions of instructor learning goals and how the lesson was taught, the OER published lessons can be used to explore how instructors engaged students with UDL guidelines and active learning strategies in online teaching environments.

As faculty seek to convert "lessons learned" from the pivot to online learning (Jaggars 2021; Moore et al. 2021), this paper adds to the emerging literature base by specifically delineating how undergraduate biology instructors operationalized UDL and active learning in their online lessons published in *CourseSource*. Notably, these practices were used by instructors who are not typically trained in developing lessons focused on online teaching and learning strategies. It is the aim of this study, therefore, to identify how active learning strategies were authentically implemented in OERs in order to add to the literature of evidence-based and inclusive strategies in online instances.

METHODOLOGY

We searched *CourseSource* articles published between January 1, 2019–January 31, 2022, using "online" metadata tags for each article. Figure 1 is a PRISMA diagram that describes how we started with 147 articles and screened down to 20.

Figure 1: Identification, screening, and inclusion of *CourseSource* articles



Of the 147 articles, 25 included an online metadata tag (Figure 1). We then checked that the article narrative described lessons involving online modalities. These descriptions were often included in the intended audience section of the article. For example, "This experiment was developed as part of the ecology content block in the second semester of the lab course after the abrupt transition to online instruction due to the SARS-CoV2 pandemic" (Rahn 2020). Five of the articles did not provide details about teaching the lesson in an online/hybrid/emergency remote teaching classroom. For example, one article provided a collection of 25 different activity files that could be used in a face-to-face classroom or online, but the focus of the article was on the collection rather than describing the instructional practices of each activity (Tsotakos et al. 2021).

To describe the course environment in the 20 remaining articles, we used the *CourseSource* metadata tag included in all articles (Table 1). In the tag, authors indicate if the lesson was designed for a laboratory or a lecture environment. We also used the authors' descriptions of the courses to check if it aligned with the metadata tag. For example, a lesson with a laboratory metadata tag might include details such as, "The COVID-19 pandemic created a need to convert in-person laboratory courses into an online format in a short amount of time. For this reason, we converted our face-to-face molecular biology lab course to an online version in Spring 2020" (McDonnell et al. 2021).

Table 1: *CourseSource* articles analyzed

Citation Ω	**Description***	**Article development history**
Barker, Jandcui, and Young 2019	Lecture, large	Originally in-person, adapted for online
Cafferty 2021	Lecture, small	Originally in-person, adapted for online
Daypuk et al. 2021	Lab, small	Originally in-person, adapted for online
Dizney et al. 2021	Lecture/lab, small/medium	Originally in-person, adapted for online
Garretson and Crerar 2021	Lab, small	Originally in-person, adapted for online
Giamanco 2020	Lab, small	Originally in-person, adapted for online
Goller, Johnson, and Casimo 2022	Lecture/lab, small	Originally in-person, adapted for online
Lilly and Forbes-Lorman 2020	Lab, small	Originally in-person, adapted for online
McDonnell et al. 2021	Lab, large	Originally in-person, adapted for online
Palmer et al. 2020	Lab, large	Originally in-person, adapted for online
Popolizio and Killpack 2021	Lab, small	Tips for teaching online
Prüß 2021	Lecture, small	Originally in-person, adapted for online
Rahn 2020	Lab, large	Designed for online
Samsa et al. 2021	Lab, small	Designed for in-person and online
Santiago-Narvaez and Habgood 2021	Lab, small	Designed for in-person and online
Shelden, Offerdahl, and Johnson 2019	Lab, small	Designed for in-person and online
Stockwell and Davids 2021	Lecture, large	Originally in-person, adapted for online
Tinsley 2020	Lecture, small	Originally in-person, adapted for online
Vita, Royse, and Pullen 2021	Lecture, small	Designed for online
Walsh 2021	Lab, small	Originally in-person, adapted for online

Ω Titles are articles that are available in the references. *CourseSource* URL: https://qubeshub.org/community/groups/coursesource/
*Class sizes are classified into three enrollment categories: small (< 50 students), medium (50–110 students), and large (> 110 students) based on designations outlined in Freeman et al. (2014).

To determine the course size, we matched metadata tags listing the course size for each CourseSource article to the enrollment size designations outlined in Freeman et al. (2014; Table 1).

CourseSource authors indicate if the lesson was taught to course sizes of 1–50 students (small), 51–100 students (medium), or 101+ students (large). Occasionally, authors would select multiple course size metadata tags, indicating that the lesson has the potential to work for multiple environments. When this occurred, we examined the article descriptions for more information. For example, (Shelden, Offerdahl, and Johnson 2019) selected all three sizes in the metadata but in the intended audience section of the manuscript wrote, "The course is offered three times a year (fall, spring, and summer) with course enrollments ranging between 25 and 50," so we classified it as a small enrollment course.

Finally, we explored the history of how these lessons were developed using descriptions from the authors. The majority of lessons were designated as designed originally for in-person and adapted for online (Table 1). For example, "In spring 2020, the sudden mid-semester closure of my campus in response to the global COVID-19 pandemic necessitated a rapid transition to emergency online learning. Consequently, I adapted the small group activities and facilitation methods of my face-to-face introductory biology class to a fully online format" (Cafferty 2021).

Research overview

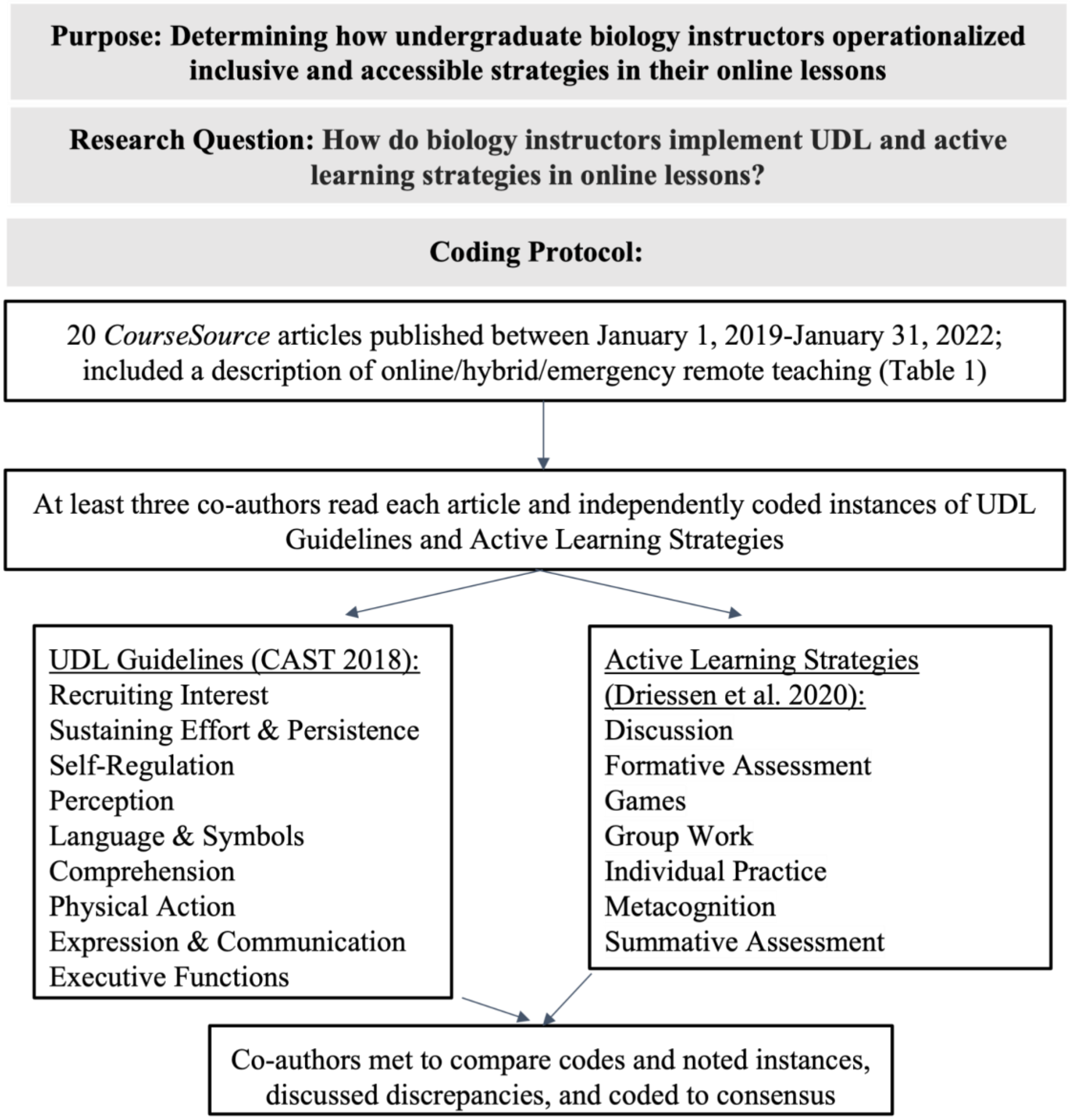
A summary of the purpose, research question, and coding protocol for both UDL and active learning is described in Figure 2. The purpose of the research is to determine how undergraduate biology instructors operationalized inclusive and accessible strategies in their online lessons. To explore this purpose, we asked: How do biology instructors implement UDL guidelines and active learning strategies in online lessons?

To answer this question, we coded UDL guidelines (CAST 2018) and active learning strategies (Driessen et al. 2020) in the 20 *CourseSource* articles described in Figure 1.

Coding process: Universal design for learning

We evaluated the lessons at the level of the nine UDL guidelines using the checkpoints associated with each guideline as indicators (CAST 2018). At least three co-authors independently evaluated each lesson for the presence or absence of each UDL guideline (Figure 2). If a coder selected a UDL guideline, they would make notes about the instance and extract relevant information from the article. To preserve coding independence, the codes were entered into a Google Forms survey. Once at least three coders had evaluated an article, the co-authors met, compared the coding responses and individual coder notes, discussed any discrepancies, and coded to consensus. A UDL guideline was coded as present if at least one checkpoint within the guideline was implemented to offer multiple means of engagement, representation, or action and expression to learners. For example, offering all learners the option to write, draw, or verbally explain a concept in order to demonstrate their understanding of a concept would indicate presence of the UDL guideline *Expression and Communication*.

Figure 2: Summary of the purpose, research question, and *CourseSource* article coding process for UDL guidelines and active learning strategies



Coding process: Active learning

We used the Active-Learning Strategy Guide (Driessen et al. 2020) to identify active learning strategies utilized in the lessons. This guide provides a definition of active learning and grouped over 300 active learning strategies into nine categories: metacognition, discussion, group work, assessment, practicing core competencies, visuals, conceptual class design, paperwork, and games (Driessen et al. 2020). We reduced and modified these categories into seven (Table 2). The protocol for coding active learning strategies was the same as the UDL coding (Figure 2).

Table 2: Active learning strategy definitions based on Driessen et al. 2020

Active learning strategy	Definition
Discussion	Activities characterized by the task of answering a discussion prompt or probing question, either in small or large group formation.
Formative assessment	Assessments designed to gather data on students' progress toward achievement of learning outcomes. They are generally "low stakes" activities, such as quizzes.
Games	Any games that are considered a form of play or sport, especially a competitive one played according to rules and decided by skill or luck.
Group work	Activities that are collaborative, cooperative, and inquiry-based and involve groups composed of two to six students tasked with completion of a project.
Individual practice	Course activities completed by the individual student.
Metacognition	Activities that encourage students to develop awareness of their own skills, strategies, and knowledge connections, therefore operating at a "meta" level, above just merely engaging with content.
Summative assessment	Assessments designed to measure student achievement of learning outcomes and are generally "high stakes" exams, projects, etc.

FINDINGS

Frequency of inclusive universal design for learning guidelines

The frequency analysis of UDL guidelines indicates that online instructors most frequently focus on engagement practices (Figure 3).

The most commonly implemented UDL guidelines were "recruiting interest" and "sustaining effort and persistence" with 100% of coded articles incorporating these two UDL guidelines. To recruit interest, instructors heightened the authenticity of article activities. For example, instructors drew explicit connections between the skills used in activities to those of STEM professionals and/or used real data. To sustain effort and persistence, instructors offered opportunities for learners to work independently, in small groups (synchronously and asynchronously), and as a class rather than utilizing only one mode of collaboration. When students worked in groups, they were often given clear roles and responsibilities to ensure participation of all group members.

Figure 3: Frequency of UDL strategies used in online *CourseSource* articles

"Comprehension" was also a frequently implemented UDL guideline, found in 90% of the articles. For example, several articles included activities to draw connections between learners' prior knowledge and the topic of the activity through independent research, small group activities, or full class discussions. These activities planned for differences in learners' background knowledge, and used multiple representations or interpretations of one concept, another strategy for supporting comprehension.

Conversely, the least implemented UDL guidelines were "executive functions" (58%) and "self-regulation" (26%). Both of these UDL guidelines focus on supporting learners as they internalize metacognitive skills. In "executive functions," a few articles supported learners in managing information and resources. One self-regulation strategy included asking learners to reflect on their mastery of learning objectives after completing the activity, prompting reflection on both their own learning as well as the utility of instructional strategies used in the article.

To help instructors and instructional designers find tangible examples of UDL in classroom lessons, we listed the UDL principles and guidelines, more details about examples of instances, and example citations in Table 3.

Table 3: Examples of CourseSource articles that align with UDL guidelines

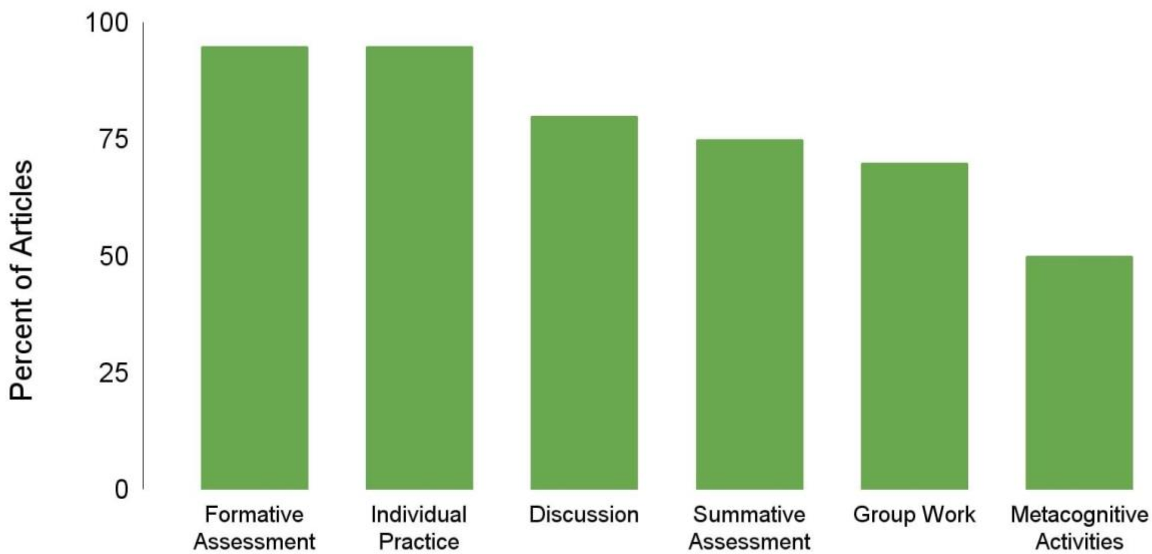
UDL principle	UDL guideline	Examples of instances	Example citations
Engagement	Recruiting interest	Highlighting how the content and activities relate to the work of real professionals. Enabling students to use real data generated from research to conduct their own inquiry.	Dizney et al. 2021; Goller, Johnson, and Casimo 2022; Palmer et al. 2020; Samsa et al. 2021
	Sustaining effort and persistence	Explicitly introducing activity objectives and explaining how they relate to course goals and the work of different professions. Incorporating structured group work with clear roles and expectations on how to contribute to the group.	Goller, Johnson, and Casimo 2022; McDonnell et al. 2021; Palmer et al. 2020; Samsa et al. 2021; Vita, Royse, and Pullen 2021
	Self-regulation	Asking learners to reflect on whether activity objectives were met and how different instructional strategies supported them in meeting the objectives.	Lilly and Forbes-Lorman 2020; Samsa et al. 2021
Representation	Perception	Providing options for accessing data. Offering raw data learners can use in addition to visual representations.	Daypuk et al. 2021; Dizney et al. 2021; Rahn 2020
	Language and symbols	Communicating key ideas through different types of media such as readings, videos, images, and audio, and labeling complex images and diagrams with vocabulary.	Goller, Johnson, and Casimo 2022; Tinsley 2020
	Comprehension	Dedicating time to activating background knowledge through independent research/activities or in-class discussions. Providing multiple examples of the same concept to highlight critical features and non-models to demonstrate what a concept is not.	Daypuk et al. 2021; Goller, Johnson, and Casimo 2022; Lilly and Forbes-Lorman 2020; Tinsley 2020; Walsh 2021
Action and expression	Physical action	Planning for variability in how learners will engage with and collect data by offering already collected data for analysis. Establishing roles in data collection and processing.	Daypuk et al. 2021; Dizney et al. 2021; Rahn 2020
	Expression and communication	Beginning long projects with focused, specific instructions that gradually move learners towards heightened decision making and more complex problem solving.	McDonnell et al. 2021; Palmer et al. 2020; Popolizio and Killpack 2021; Samsa et al. 2021

	Executive functions	Providing templates and checklists that support learners in project planning and chunking big goals into manageable objectives. Being explicit in asking learners to demonstrate their thinking about a problem.	Goller, Johnson, and Casimo 2022; Palmer et al. 2020; Samsa et al. 2021

Frequency of active learning strategies

We also coded for the frequency analysis of active learning strategies in these articles (Figure 4). The most utilized active learning strategies were "formative assessments" and "individual practice." This result suggests that online instructors prioritize low-stakes assessments that help them learn about student progress and implement activities encouraging sustained effort from students. The least utilized strategy is "games" which was not used by any of the authors, and "metacognitive activities," which was used by about half of all authors.

Figure 4: Frequency of active learning strategies used in online *CourseSource* articles



Types and patterns of active learning strategies

For "formative assessment," students often met in small groups in video conferencing rooms (e.g., Zoom breakout rooms). Instructors would typically rotate throughout these rooms and ask open-response questions, provide feedback, and offer words of encouragement. Another common formative assessment strategy was to set course management systems (e.g., Canvas) to automatically grade closed-response questions and ask students to check their answers against a key.

For "individual practice," students were often asked to do work in preparation for synchronous online sessions. Examples include researching topics related to the course, reading manuscripts, watching video simulations, and writing reflections. Notably, laboratory and field courses, which tend to be experiences where students are making observations and conducting experiments, emphasized individual work. Students designed experiments in their homes, recording data individually, and then they contributed the data to a larger course-wide dataset. “Individual practice” was also often coded during summative assessments, as described below.

“Discussion” between students was typically facilitated through conference software (e.g., Zoom). Instructors often used a combination of small group breakout rooms and whole class discussions. The discussion topics included wrapping up class content, brainstorming, and sharing results and class reflections. Less frequently, instructors facilitated discussions through written discussion forums often embedded in course management systems.

The majority of “summative assessments” were open responses which were graded online using written comments and/or scored on a rubric. Students typically submitted their assignments through an online course management system, and instructors often used plagiarism detection programs (e.g., Turnitin) to verify originality. Students often submitted written reports at the end of the semester, with some courses offering students the opportunity to record and submit video presentations.

For “group work” activities, students typically met in small groups in online breakout rooms. Often groups discussed questions or data facilitated through shareable documents, such as Google Documents and Google Slides.

A more rarely used active learning strategy was “metacognitive activities.” Students were asked to practice metacognition through written reflection activities, such as self-reflection and reports on individual and group performance. Some courses allowed students to submit answers to prompted reflections as audio files.

We list the active learning strategies, more details about examples of instances, and example lessons in Table 4. This information can be used to help instructors and educational developers find tangible examples of active learning in classroom lessons.

Table 4: Types and patterns of active learning strategies in *CourseSource* articles

Active learning strategy	Examples of instances	Example lessons
Discussion	Providing structure to facilitate active discussion involving the instructor and students.	McDonnell et al. 2021; Palmer et al. 2020; Walsh 2021
Formative assessment	Providing feedback through online reading quizzes and video wrap-up to review student understanding.	Tinsley 2020
Group work	Facilitating collaboration through video conferencing software (e.g., Zoom breakout rooms).	Cafferty 2021; McDonnell et al. 2021; Vita, Royse, and Pullen 2021
Individual work	Offering the opportunity to conduct entire experiments on their own, from designing the study, collecting data, and analyzing results.	Daypuk et al. 2021
Metacognitive activities	Explicitly asking students to reflect on their learning.	Goller, Johnson, and Casimo 2022; Palmer et al. 2020; Samsa et al. 2021; Shelden, Offerdahl, and Johnson 2019

Summative assessment	Assigning take-home tests that include open response questions to engage higher cognitive levels, and allowing for additional time to complete assessments.	McDonnell et al. 2021

Connecting universal design for learning and active learning strategies: An exemplar

Although looking at UDL guidelines and active learning strategies across articles provides a picture of the techniques used in online undergraduate biology courses, there are also important opportunities to examine how UDL and active learning are integrated within the same lesson. One example lesson entitled “Exploring Species Interactions with ‘Snapshot Serengeti’” (Palmer et al. 2020) is described in Table 5. Based on the learning objectives in this lesson, the instructors intentionally designed the activity to recruit interest, sustain effort and persistence, and provide options for learners to express and communicate their knowledge and skills. For example, one learning objective is “develop and conduct an authentic scientific inquiry.” The authors recruited interest by using authentic data from an online citizen science camera trap study where students classify organisms in images. Using authentic data and drawing connections to the work of actual scientists heightened relevance, value, and authenticity. In short, students engaged in the work of ecologists.

The authors also intentionally optimized learner choice and autonomy; students developed their own research questions and investigated them. Importantly, the level of choice was optimized; students reviewed portfolios to generate research questions or create new questions based on their interest. These portfolios, however, did not provide unlimited choice so they would not overwhelm and intimidate some learners.

Once students identified research questions, they used several active learning strategies. They used group work to practice collecting data, generating hypotheses, and creating data visualizations. This group work facilitated collaboration and community, and it provided practice with the tasks. Then, students engaged in individual work, using guides to refine their hypotheses, and developed a plan for testing their ideas. These guides varied in demands and resources so that they optimized student challenge while also providing graduated levels of support for practice and performance. Throughout this process, students engaged in formative assessment, including structured peer review and feedback which fostered collaboration and community, and applied mastery-oriented feedback that heightened task relevance. For the summative assessment, students communicated the results of their inquiry through a written report or video presentation, offering the use of multiple media for communication.

Table 5: Exemplar of UDL and active learning strategies in Exploring Species Interactions with "Snapshot Serengeti" (Palmer et al. 2020)

<table>
<tr><th>Learning objective</th><th>Instructional strategy from article*</th><th>Active learning</th><th>Universal design for learning</th></tr>
<tr><td rowspan="5">Generate and interpret graphs to answer questions.</td><td rowspan="5">Students work in groups to create graphs that address the guided inquiry questions and the hypotheses that they generated the previous week. Each student creates their own graphs and shares them with their group. The group then discusses the pros and cons of each other's graphing approach. As a team, they submit one final set of graphs to the course website.</td><td rowspan="5">Group work, Formative assessment</td><td>Foster collaboration and community (engagement)</td></tr>
<tr><td>Increase mastery-oriented feedback (engagement)</td></tr>
<tr><td>Highlight patterns, critical features, big ideas, and relationships (representation)</td></tr>
<tr><td>Use multiple media for communication (action and expression)</td></tr>
<tr><td>Support planning and strategy development (action and expression)</td></tr>
<tr><td rowspan="5">Develop and conduct an authentic scientific inquiry.</td><td rowspan="5">Students fill out a draft guide for designing their own research project using the "Snapshot Serengeti" data. In this document, students answer questions which help them refine their hypotheses and develop an approach to test their hypotheses.</td><td rowspan="5">Individual work, formative assessment</td><td>Optimize individual choice and autonomy (engagement)</td></tr>
<tr><td>Vary demands and resources to optimize challenge (engagement)</td></tr>
<tr><td>Guide information processing and visualization (representation)</td></tr>
<tr><td>Build fluencies with graduated levels of support for practice and performance (action and expression)</td></tr>
<tr><td>Facilitate managing information and resources (action and expression)</td></tr>
</table>

*Details related to specific files and biology concepts removed for clarity.

CONCLUSIONS

The pivot to remote online teaching and learning, and the lessons delivered thereafter provide continual opportunities for reconsidering pedagogical approaches in many areas, including how to foster diversity, equity, and inclusion in online courses (Super et al. 2021). While the use of UDL strategies is gaining acceptance as a way to decrease barriers to learning and increase engagement for all learners, further operationalization guidance and empirical research are still needed (Boysen 2021; Murphy 2021). Providing instances of such strategies adds to the evolving understanding of which strategies contribute to the development of engaging, accessible online courses. Additionally, while active learning has become solidly situated as an effective evidence-based practice (Freeman et al. 2014), there still exists a wide variance of practices, a lack of definitional clarity, and a need to identify which active learning practices work in which settings (Bernstein 2018; Dewsbury et al. 2022; Doolittle, Wojdak, and Walters 2023; Kranzfelder et al. 2020; Lombardi et al. 2021). This study helps

identify which active learning strategies were implemented in online undergraduate biology courses.
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In a relatively short period of time, a collection of *CourseSource* lessons that use inclusive teaching practices and describe active learning strategies for online laboratories and lectures for a variety of class sizes was created and shared with the community (Table 1). This collection provides examples that instructors and professional development leaders can use to illustrate how to integrate UDL guidelines and active learning practices in online courses. These examples capture, articulate, and disseminate approaches that can be effective in a wide variety of online courses. In addition, the lessons are aligned with previous studies about the benefits of UDL and active learning practices (Ballen et al. 2017; Beichner et al. 2007; Dewsbury et al. 2022; Eddy and Hogan 2014; Freeman et al. 2014; Haak et al. 2011; Super et al. 2021; Theobald et al. 2020), and student feedback on preferred practices in online courses collected through surveys (Chen, Bastedo, and Howard 2018; Nguyen et al. 2021), thereby adding to the SoTL literature.

Our findings demonstrate that instructors designed and developed lessons that incorporated a breadth of active learning and inclusive/accessible strategies. Notably, all lessons included "recruiting interest" and "sustaining effort and persistence" UDL strategies, which often connected with active learning approaches such as "formative assessment" and "group work" (Figures 3 and 4). These findings provide examples that biology instructors, who often have little formal training in teaching and learning, can use to encourage engagement, support, and the formation of community in their online classrooms. Lessons also showed a "depth" of UDL and active learning strategies as evidenced by the "*Snapshot Serengeti*" (Palmer et al. 2020) lesson that intentionally aligned evidence-based strategies with all lesson learning objectives (Table 5).

Despite the range of strategies included in these lessons, there are still areas in need of growth. For example, few lessons addressed the UDL category of "executive functions" which is often associated with active learning and is seen as a step towards becoming strategic and goal-directed learners, an ultimate goal of the UDL framework (CAST 2018) (Figure 3). Additionally, "metacognitive activities" were not as prominent as many of the other strategies (Figure 4). Although, arguably, considering that some of these instances are typically more prominently applied to course-level strategies, as opposed to lesson-level activities, this finding does elucidate an instructional need. As instructors are designing future OER lessons, it will be helpful to consider these practices in their design and dissemination.

As instructors engage with this design work, it is important to remember that UDL and active learning are broad strategies with critiques of their use. These critiques argue that UDL should not be rejected, but caution against fully embracing it without additional evidence (Boysen 2021; Murphy 2021). As a step towards this goal, the UDL-Implementation and Research Network (UDL-IRN) developed UDL Reporting Criteria to support researchers in reporting UDL application and outcomes (Rao et al. 2020). There is also interest in having more precise definitions of what is meant by active learning techniques, given that many studies are focused on contrasting active learning with lecture and not describing which techniques are used (Driessen et al. 2020; Doolittle, Wojdak, and Walters 2023). An analysis of categories of specific active learning techniques, such as in Figure 4 and Table 4, provides a more nuanced description and is an important step in determining which active learning techniques in which online settings have the largest impact on student learning.

Taken together these findings collectively provide recommendations for educational developers, instructional designers, and instructors alike as the development of student-centered, evidence-based online biology courses progresses. Providing a data set that shows how these strategies have been applied in biology lessons, as well as elucidating gaps, helps to enhance knowledge and awareness for those who design and develop online courses or augment face-to-face classes with online lessons. Additionally, helping instructors who teach online courses with the general principles of UDL guidelines and active learning strategies enables more intentional development of student-centered courses. Additionally, this approach could prevent siloed "checking off" items in the UDL framework or including commonly used active learning approaches without intentional awareness of the benefits of using such strategies (e.g., Lewin et al. 2016; Turpen and Finkelstein 2009, Kranzfelder et al. 2020). As described above (Table 5), the Palmer et al. (2020) lesson showed an intentional alignment of UDL guidelines and active learning strategies to operationalize the course learning objectives and could serve as a starting example.

As we continue to consider the lessons learned from the pivot to emergency remote teaching, these findings support efforts to help faculty through targeted professional development initiatives focused on understanding the purpose, outcomes, and goals of UDL and active learning strategies. Professional development that encourages purposeful design can be a mechanism for reducing barriers to the implementation of the UDL framework and active learning strategies. Because these lessons are in the OER ecosystem, they become sharable examples to disseminate specific strategies in a variety of contexts. The lessons also provide the necessary material for future studies to test out the efficacy of specific UDL and active learning approaches while measuring student learning and affective variables.

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