WIP - UDL in STEM Higher Education: A Synthesis Literature Review

Autumn Cuellar, Utah State University

Autumn Cuellar is a Ph.D. student in Engineering Education. Her undergraduate and master's careers were both in Computer Science. She believes that everyone can achieve their goals, regardless of physical ability. This is why Autumn strives to make engineering accessible for everyone.

Dr. Marissa A Tsugawa, Utah State University - Engineering Education

Marissa Tsugawa is an assistant professor at Utah State University who leverages mixed-methods research to explore neurodiversity and identity and motivation in engineering. They completed their Ph.D. in Engineering Education where they focused on motivation and identity for engineering graduate students.

Dr. Angela Minichiello P.E., Utah State University

Angela (Angie) Minichiello, PhD is a military veteran, licensed mechanical engineer, and Associate Professor of Engineering Education at Utah State University.

WIP: A Synthesis Literature Review on Universal Design for Learning in STEM Higher Education

Abstract

The purpose of this work-in-progress research paper is to explore the usage of Universal Design for Learning in STEM Higher Education classrooms and how it impacts student learning. Universal Design for Learning (UDL) is a teaching framework that creates an inclusive and accessible learning environment for all students, particularly those with disabilities. The UDL framework offers principles designed to enhance classroom accessibility through engagement, representation, and expression. Current research examines the framework in higher education contexts outside of STEM. However, calls for improving inclusivity in STEM education challenge higher education STEM educators to shift their pedagogical practices, away from traditional lecturing, toward improving accessibility and inclusivity for all students. The goal of this WIP literature review is to identify the various ways STEM faculty have implemented UDL in their classrooms and understand how these implementations have impacted their students.

1 Introduction

Higher education challenges students to step out of their comfort zone to expand their knowledge. Particularly, students may need to reach out for help to study or understand the content, such as consulting with their professors or attending tutoring centers [1], [2]. However, higher education is less accessible to disabled students, where disability is defined as "a person who has a physical or mental impairment that substantially limits one or more major life activity" [3]. Students with disabilities are especially disadvantaged in STEM fields, where pedagogical practices often revolve around traditional lecturing formats [4], and faculty are less likely to provide the legally required accommodations [5]. STEM programs in higher education need to shift toward more accessible pedagogical practices, such as Universal Design for Learning (UDL), so that all students can be successful in earning a degree. We seek to answer the following overarching research question: How can current STEM classrooms improve using UDL? The following questions are the focus of this synthesis literature review.

1. How has UDL been implemented in undergraduate and graduate STEM learning environments?
2. How has UDL implementation impacted undergraduate and graduate STEM learning?

2 Background

UDL is a relatively new pedagogical framework that provides a set of principles to improve classroom accessibility [6]. This framework shifts pedagogical practices from a traditional lecturing style to more inclusive practices, making learning environments more accessible [7]. UDL improves classroom accessibility through three principles: multiple means of engagement, multiple means of representation, and multiple means of action and expression. Multiple meanings of engagement focus on how to engage students in learning, such as allowing for solo and group study time. Multiple meanings of representation focus on how to present learning material to students, such as using teaching materials in both textbook and video formats. The

final principle, multiple meanings of action and expression, focuses on how to assess students' knowledge. An example of this is allowing students to choose how to demonstrate their knowledge, either through a test or a hands-on project. Teachers can integrate UDL principles by using the tips and tricks provided by the CAST ((Center for Applied Special Technology) website [6].

While UDL has mainly been implemented in K-12 contexts [8], non-STEM higher education instructors have incorporated UDL into their pedagogical practices and interviewed students about UDL in fields such as the Arts, Education, Humanities, and Business. The implementation of UDL in higher education has been shown to improve students' learning [5]. Furthermore, students can enhance their understanding of the material by using complementary online resources and multiple learning modalities, such as different content formats like visual and auditory [5].

3 Positionality Statement

Autumn Cuellar is a Caucasian woman from the Western United States. She has a bachelor's degree and a master's degree in Computer Science. She is currently pursuing a doctorate in engineering education. Autumn has a physically visible disability due to the brain's cerebellum. For this reason, she identifies as neurodivergent. During her undergraduate and master's degrees, this author learned about UDL and educated staff/faculty. She knows how useful it can be to implement UDL for students with disabilities. Her experience with UDL and computer science, or STEM in general, has made Autumn dedicated to making learning engineering more accessible for all students.

Marissa Tsugawa identifies as a biracial (Japanese/White), nonbinary assistant professor from the Western United States. They also identify as neurodivergent, which inspires and drives their interest in disability and neurodiversity studies. Particularly, Marissa was not formally diagnosed with their neurodivergence until later in life and aspires to provide information on neurodivergent experiences to students. Such information can empower those who do not know they are neurodivergent by informing them that their experiences are normal. To achieve their research goal, they use mixed-methods research and a constructionist paradigm.

4 Methodology

For this literature review, the first author followed the steps outlined in Borrego et al.'s [9] paper. Multiple databases were examined using the Utah State's database directory. The author selected three databases for the paper selection phase: Scopus, ASEE Peer Directory, and Google Scholar. Autumn Cuellar selected these databases because they were the only ones that produced valid paper entries when using specialized keywords. Other databases did not produce any papers that matched the inclusion criteria outlined below. Most articles came from Scopus and the ASEE Peer Directory. A few articles were discovered on Google Scholar.

The first author used multiple keywords in conjunction with each other for the search. The keywords used were UDL, universal design for learning, stem, engineering, students, higher education, impact, and perceptions. The first author entered these combinations into the three

online databases. Once the abstracts were determined to be related to the research questions, the first author downloaded the articles. Other inclusion and exclusion criteria are listed below.

4.1 Inclusion/Exclusion Criteria

Systematized literature reviews summarize and create connections between multiple different studies. For this reason, articles that were included in this review had to meet the following criteria:

- The study is a peer-reviewed empirical source from a conference or journal.
- The study examined how Universal Design for Learning helps or hinders any STEM student in higher education.
- The study examined how STEM faculty use Universal Design for Learning in their classrooms.

To make sure articles were reliable and had meaningful results, the author excluded articles based on the following criteria:

- The paper is a thesis manuscript or book chapter.
- The paper is a second analysis of another study.

4.2 Data Analysis

After finding all ten papers, the author read each individually using a read-aloud technology called Speechify (https://speechify.com/). The author collected specific information from each paper and stored it in a coding table created in Microsoft Excel. A portion of the Coding Table can be seen in Table A1 of the Appendix. These headers allow the authors to see how and where the study was conducted. “Research’s findings / Conclusions” is most important since it includes how STEM classrooms applied UDL principles.

During the analysis phase of this review, the author noted that one article was a second analysis of three case studies by the same authors. The authors did not discuss each case study's methodology or data analysis. For this reason, the researcher determined that the article is not an empirical study and excluded it from this literature review. Once the first author completed the coding sheet, all the “Research’s findings / Conclusions” were compared. The Results section describes the themes found in this category.

5 Limitations

This paper can be improved in several ways. This synthesis literature review analyzes only nine articles. A small sample size is not ideal for any literature review. This is because the overall findings may not accurately reflect all points of view. Additionally, most articles came from the same university. A larger sample size with a higher university diversity would produce more generalizable results. Another area for improvement is that the author only searched three online databases. These searches produced limited articles that related to the research questions. More articles may have been found if more databases were searched.

6 Preliminary Results/Discussion

This section examines the nine articles on Universal Design for Learning in STEM. The author examines demographics, article research methods, and how the articles answer the two research questions.

6.1 Demographics

The UDL articles varied in some aspects, such as the type of participants' disabilities, but also shared similarities. Regarding university sites, three articles studied students at schools in Illinois, three came from the University of Connecticut, and the rest did not specify their location. Most articles (seven out of nine) looked at undergraduate students, with two including graduate students and two including faculty. Finally, six articles specifically examined engineering degrees. Other majors investigated included physics, chemistry, computer science, science, and health and public affairs. A paper recognized health and public affairs as part of STEM, so the major was included in this paper.

6.2 Article Research Methods

Table 2 shows the research methods used in the nine articles. Some similarities can be seen throughout. Most articles (six out of nine) used surveys to see participants' opinions. Surveys provide self-reported information and can be quickly analyzed with descriptive statistics.

Table 2: Article Research Methods

Research Methods	Number of Articles
Survey	6
Observations	1
Case study	1
Interviews	1
Post-Assessment	1

Survey studies provide quick information on a given study subject, which can lead to basic descriptive statistical information. Especially when UDL has not been widely implemented, like in STEM higher education. More qualitative studies should be conducted to explore UDL in-depth, such as through the experiences of students and instructors with the framework.

6.3 Question 1: How has UDL been implemented in undergraduate and graduate STEM learning environments?

Faculty have only implemented a few UDL practices in their classrooms because they lack a deeper understanding and the necessary resources for implementation [10], [11], [12], [13]. There are good examples of inclusive classrooms in literature. A few classrooms implemented projects that highlight students' strengths. This is done by allowing students to pick their final

deliverables. Deliverables can be an oral presentation or a written report [10], [11], [12]. Schreffler et al.'s [13] observations showed that some science professors described new topics well by discussing common difficulties in previous assessments. However, the same professors have more work to fully integrate UDL principles into their lab sessions [13].

The research above indicates that more classrooms can become more inclusive with extra help from institutions. Universities can provide workshops on UDL to educate their faculty. Workshops can give an overview of each UDL principle and help faculty start updating their classrooms. Additionally, institutions can provide more support to faculty during the UDL implementation process. Support can be monetary or provide experts for feedback or help. These steps will ensure that all classrooms can be transformed into inclusive learning environments.

6.4 Question 2: How has UDL implementation impacted undergraduate and graduate STEM learning?

A common theme amongst the papers was the positivity for the UDL principles. Across studies with student participants, students highly valued the UDL principles for their learning. Their class improvement suggestions, like timely assignment feedback and multiple formats for concepts, align with the three principles [14]. One of the most important principles is multiple means of representation. They believe in having various modalities for the same concept. This allows for different perspectives on the same material [15], [16].

Different students prefer specific modalities more than their peers. Disabled students often prefer using the instructor's lecture notes and PowerPoint slides, while others prefer discussion and lab sections, as well as lecture videos [17]. Regarding gender, females use written modalities more often than their male counterparts [17]. The other principles are also of great value. Multiple means of action and expression help students to show their knowledge in a less stressful way. Multiple means of engagement help students stay active in their learning journeys which improves their overall learning.

Unfortunately, most students do not experience these practices in their STEM classes or struggle to use them. UDL principles are only beneficial to students if the educational platforms are accessible. Learning management systems can be challenging, especially for students with disabilities, because the accessibility tools can be complicated [18]. Faculty need to ensure that all students can use their learning management systems. An accessible classroom lets students reap all the benefits of UDL.

7 Conclusion and Implications

This literature review synthesized how faculty used UDL in STEM classrooms and its impact on undergraduate and graduate students. Students believe that the Universal Design for Learning principles benefit their learning. However, only a few faculty members implement these principles. Most of the articles highlighted how students preferred Multiple Means of Representation. The other two principles were barely explored. Researchers should examine how students feel about Multiple Means of Action and Expression and Multiple Means of Engagement. Autumn Cuellar plans to explore all three principles in her dissertation by

interviewing disabled engineering students, using this WIP paper as background. Knowing which aspects of these two principles have been most helpful to students is beneficial. Faculty can use this information to incorporate these aspects into their classrooms.

More STEM faculty should incorporate Universal Design for Learning in their classrooms. It can be as simple as providing multiple modalities. Faculty could also go the extra mile by including accessible assignments and other teaching methods in addition to lecturing. UDL classrooms offer a welcoming space for all students to learn. The more UDL is used, the greater the chance all students can succeed in STEM degrees. Particularly, more women and other gender minorities, individuals with disabilities, and other minority groups have a better chance of becoming engineers. Diverse engineers bring unique ideas that can help create a more inclusive and welcoming society for everyone.

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Appendix

Table A1; CollapUDL Coding Table

	Sample Characteristics					Research Design Characteristics				Research Conclusions/Outcomes		
Article Name	**Participant size**	**University count**	**University name**	**Educational level**	**STEM Type**	**Research Design**	**Research Question(s)**	**Data Collection Techniques/Measures**	**Data Analysis Techniques**	**Research's findings / Conclusions**	**Future Recommendations**	**Personal Thoughts**
Exploring Design Elements for Online STEM Courses: Active Learning, Engagement & Assessment Design	537	1	N/A	Undergrads and grads	Engineering, Science, and Heath and Public Affairs	Survey	Which design elements appear most frequently in online STEM courses? Which design elements (activity, interactivity, assessment) impact student perceptions of learning? Which design elements (activity, interactivity, assessment) impact student learning satisfaction?	An online Qualtrics survey was sent to students using their Learning Management System. The survey had both open-ended and Likert scale questiion (0-5). The survey included questions about demographics, learner characteristics, online activities/interactives, and student's thoughts on learning outcomes and satisfaction.	Frequencies and percentages were calculated for Likert scale questions. The authors coded the open-ended questions for similarities.	The authors found interesting results from the survey. Students believe the most frequent design elements in STEM are major projects/assignments, readings, website/slide resources, exams, special software applications, real-world problems, and case studies. The design element that impacts both student learning satisfaction and their thoughts on learning is assessment. They gave additional feedback to improve online classes. Some were having videos and lectures for the same topics and instructors giving timely feedback and grades on assignments. These suggestions are supported by the UDL principles.	Online instructors should provide students with active learning activities, communicate clearly with students, and use the UDL principles to help all students learn.	Students know what will help them learn best. Their suggestions align well with UDL and they don't even know.
Supporting STEM graduate students with dis/abilities: Opportunities for Universal Design for Learning	6 overall but this study focused on 2	Multiple	N/A	Graduate	STEM overall	phenomenographic methodology	How do participants' experiences with barriers map to the UDL principles?	Based on Harvey's dialogic serial interview process, participants were interviewed four different times. The first author interviewed participants about their experiences in graduate school with an invisible disability.	The authors coded the interviews for themes of struggle and asked the participants to help verify the themes. The themes were then related to the UDL principle.	The interview themes related to two of the three UDL principles: Multiple Means of Representation and Multiple Means of Action and Expression. Multiple Means of Representation related to the student's understanding of the material. Some students couldn't read required papers or textbooks because they weren't accessible with assistive technology. Additionally, not having information in multiple different modalities (visual, auditory, kinematic) makes it hard to learn. A participant had trouble understanding questions on Zoom because the professor didn't reread them from the chat. Multiple Means of Action and Expression relate to the student's ability to communicate their thoughts. A Participant had issues finding helpful assistive technology because no one at the university would help find the right one for them. Others had trouble expressing course knowledge because written exams scared them. They knew the material, but writing it caused problems. Additionally, remembering information or where material are can be very hard. The authors suggest incorporating UDL to help solve these problems.	Teachers and advisors should incorporate UDL principles while working with grad students. This includes using comfortable modes of conversation, presenting information in different ways, and helping to build useful skills for independent reserch.	UDL seems to be a good tool to increase the success of graduate students with invisible disabilities.
Opportunities and Barriers to UDL-Based Course Designs for Inclusive Learning in Undergraduate Engineering and other STEM Courses	148 students 25 faculty	1	University of Illinois at Urbana-Champaign	undergrads and faculty	STEM, mostly engineering	Surveys	How much do the students experience these representative UDL approaches? How useful do students consider these representative UDL approaches? How useful do instructors consider these representative UDL approaches? How knowledgeable or proficient are instructors regarding these representative UDL approaches? What are the barriers that prevent instructors from implementing these representative UDL approaches? How do SWD or SACAN or female students differ from the rest of the students regarding the frequency or usefulness of these UDL approaches? How do students differ from instructors regarding the usefulness of these UDL approaches? What format of feedback and classroom lecture type do students prefer?	Two surveys were used to collect data during the 2022-2023 school year. The student survey asked questions about demographics, opinions about 16 UDL activities (experience with and usefulness), and feedback preferences. The faculty survey was similar, but the third category was replaced with implementation barriers. Most questions were Likert scales for both surveys.	Multiple statistical tests were used to analyze both surveys. A Chi-Square test was performed on categorial questions to test group independence. The authors used Mann-Whitney U tests to determine group differences for Likert scale questions.	The surveys had many interesting findings to them. Students indicated that the top five useful UDL practices are searchable lecture recordings, Recorded lectures that students can search for content, flexible assignment deadlines, transcripts/captions on course-related videos, official discussion platforms, and alternative learning modalities to lectures. Even though most students find a lot of the UDL practices useful, the students don't have a lot of experience with most practices. Most students like traditional classrooms and value representation the most. SWDs value assessability and engagement more than SWODs. Instructors also value assessability, but they lack the required knowledge to implement them. If feedback is needed, anonymous tools are better because females and SWDs are more uncomfortable giving direct feedback.	Faculty should be more educated on UDL principles so they can be more easily implemented in the classroom.	It is good to know that students find some UDL principles useful. This starts helping support the need for these principles in the STEM classroom.
Using observations of Universal Design for Learning to enhance post-secondary STEM teaching practices	4	1	N/A	2 professors and 2 graduate-assistants	Physics and Chemistry	Observations	What is the current usage of UDL in the classroom?	Observations have the 4 classrooms based on the Universal Design for Learning Instructional Observation Instrument (UDL-IOI). Observations lasted three hours with each classroom being observed multiple times.	The instrument had Likert scales (0-3) based on the UDL principles. Scores were averaged for each teacher of a class.	All four teachers had strengths and weaknesses when incorporating UDL aspects in their classrooms. Students were able to understand new material based on the way the instructors framed/introduced it. Students needed more ways the material was represented and assessed. They also needed more ways to stay engaged. These observations helped the instructors see where they need to improve to easily educate all students.	Teachers need to work on using UDL more in classrooms. Disabled students will have a better chance to stay in STEM programs.	Classrooms need more work to involve UDL. Students are currently not learning to their full potential.

	Sample Characteristics					Research Design Characteristics				Research Conclusions/Outcomes		
Article Name	**Participant size**	**University count**	**University name**	**Educational level**	**STEM Type**	**Research Design**	**Research Question(s)**	**Data Collection Techniques/Measures**	**Data Analysis Techniques**	**Research's findings / Conclusions**	**Future Recommendations**	**Personal Thoughts**
Impact of Project-Based Assignments on Students' Learning Experience in Inclusive Courses	CE 3110: 83 CE 3220: 64 CE 3510: 80	1	University of Connecticut	Upper-level ungrads	Engineering	Survey and experimental	How does Skill Project-based Learning (PBL) affect student learning?	The students were asked to complete a Likert scale survey about the projects. Questions looked at student learning experiences using the project method, project organization, and instructor/TA availability and accessibility. CE 3110 did a two qiestion post-assessment test on two groups. The experimental group did the project while the control group did not.	Likert scales were averaged to get a single score for each of the three classes in every question category. Survey results came from 75 students in CE 3110, 21 students in CE 3220, and 29 students in CE 3510. The post-assessment test was graded with partial points accepted. Each question was compared between the two groups.	The Civil Engineering Department designed three courses with inclusivity in mind. Each course contained a strength-based project for students to learn the material. Students could choose how to display their project through a written report, a PowerPoint presentation, or an oral video presentation. CE 3220 and CE 3510 instructors had students work in groups. The survey had overall positive results. The majority of the students agreed or strongly agreed that all class projects helped them learn the material, allowed them to use their strengths, and increased their confidence in solving real-world problems. Students in CE 3110 and CE 3220 thought that their projects gave room for the use of their creativity. The post-assessment test for CE 3110 showed that the experimental group did better overall on the questionss.	More instructors should incorporate strength-based projects in their classrooms.	Allowing students to show their knowledge through their strengths is important. Some students may get bad assessment grades because of anxiety and not their lack of knowledge.
A UDL-Based Large-Scale Study on the Needs of Students with Disabilities in Engineering Courses	303: 255 without disabilities and 48 with disabilities	1	University of Illinois	ungrads	Engineering and CS	Survey	What are students' usage, satisfaction, and MUSIC evaluation of different learning modalities? What is different in usage, satisfaction, and MUSIC evaluation towards modalities between students with disabilities and without disabilities? What is different in usage, satisfaction, and MUSIC evaluation towards modalities between female students and male students	A survey was used to look at the usage and satisfaction of different learning modalities. Modalities included both in-person and online formats. The survey also had questions related to the MUSIC Model. The authors looked at empowerment, usefulness, and success since they relate to learning modalities.	Likert scales were numerically coded. A chi-square test was used to calculate inter-group differences of students with/without disabilities for all questions. The authors also used Wilcoxon tests for these groups. The same tests were conducted for the female and male group pairing.	Overall the students ranked the same modalities as useful and satisfactory. The top three modes were course lecture videos, instructor PowerPoint slides, and live Zoom lectures. There were some differences between students with disabilities (SWD) and students without disabilities (SWOD). SWD's top usage was the instructor's lecture notes and PowerPoint slides while SWOD prefers Discussion/Lab sections and lecture videos. For satisfaction: they both liked the instructor's lecture notes, but they differed after that. SWD likes the textbook and transcripts of videos while SWOD likes lecture videos and office hours. Females and males differ as well. Females use more written modalities than their male counterparts. In terms of satisfaction, males were more satisfied with live interaction and PowerPoint slides than female students.	More instructors should incorporate different modalities in their classrooms.	It is always good to have different ways to learn the same concept. Students may need extra explanation to understand something. Multiple modalities are better than just one.
Redesigning Engineering Education for Neurodiversity: New Standards for Inclusive Courses	Case 1: ~120 students Case 2: ~100 students Case 3: 72 students	1	University of Connecticut	sophomores and juniors	Engineering	A qualitative case study	How can inclusive teaching practices and a strength-based approach improve classroom success of neurodiverse students?	Surveys and student feedback was collected throughout the semester of the three classes.	The authors did not include this information. Survey results were displayed in tables with the number of yes vs no responses. Percentages for questions were calculated too.	The authors redesigned three engineering classes for Neurodiverse students. These changes were based on inclusive standards (I-Standards) that include inclusive teaching practices (UDL) and a strength-based approach to learning. The three classes were Statics, Mechanics of Materials, and Fluid Mechanics. The majority of the students, who responded to the survey, had positive feelings about the changes. Students were engaged, felt like they belonged, and understood the concepts more with the strength-based projects in the Mechanics of Materials class. Neurodiverse students succeed more in class when their strengths are embraced. More classes should include these I-Standards to increase neurodiverse students in engineering.	The authors want to improve their i-Standards and collaborate with other universities.	I believe UDL is extremely important in higher education. I wonder how these principles can be applied to other engineering disciplines.
Understanding the needs of students with and without disabilities for inclusive UDL-based design of Engineering courses through learning management systems	131	1	University of Illinois	undergrads	STEM overall	Survey	What are student opinions of the system-wide quality of Canvas as an LMS? Are there differences between SWDs and SWODs for system-wise constructs and individual LMS components that might be helpful for UDL design? Do teaching modalities (hybrid, in-person, online) have an effect on student opinions? Are there other groups in STEM that could be helped by a more inclusive UDL? Is there a difference between how different genders are being served by LMS?	The authors used a survey to collect data during the 2021-2022 school year. The survey had four main data sections for the students. They were demographics, website preference and functionalities, usage and satisfaction of specific Canvas features, and organization of materials. There were mostly Likert scale questions.	The Likert scale questions were numerically coded (-2 to 2) for analysis. Usage and satisfaction questions were also numerically coded (-1 to 3). For overall preference, the authors used a Wilcoxon Signed Ranked test. The Wilcoxon Rank Sum test was used to determine group differences.	Overall the students were satisfied with Canvas as a whole. However, there were some differences between students with disabilities (SWDs) and students without disabilities (SWODs). SWDs used assessability features more but were less satisfied with them. They also ranked the information quality lower than SWODs. These results are similar between SWODs and SWD-like. SWD-like includes students who miss classes for medical issues. SWD-likes also ranked Canvas's service quality lower than SWODS. Interactive tools are important to SWD-likes because they allow them to participate more in class. When to in-person versus non-in-person deliveries, in-person students used fewer lecture recordings and collaborative tools than their counterparts.	There needs to be more inclusive courses and engineering programs. This will allow more students to be successful.	LMSs are an essential tool for all courses. These systems need to be better designed and used with all students in mine.

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Article Name	**Participant size**	**University count**	**University name**	**Educational level**	**STEM Type**	**Research Design**	**Research Question(s)**	**Data Collection Techniques/Measures**	**Data Analysis Techniques**	**Research's findings / Conclusions**	**Future Recommendations**	**Personal Thoughts**
Redesigning Soil Mechanics as an Inclusive Course	82	1	University of Connecticut	juniors and seniors	Engineering	qualitative study (Surveys)	What are students impressions of the redesigned class?	Two surveys were given to the students throughout the semester. The mid-semester survey asked about assessments and the active learning activity. The second survey looked at the entire course.	The authors diid not include this information. Survey results were displayed in tables with percentages for questions calculated.	A course was redesigned to be more inclusive for neurodivergent students. The professor included UDL principles in the class. The class contained an optional final, a project with different final deliverables options, optional discussion boards, and active learning activities. Overall, the students learned better than the students in the traditional class. They liked the active learning activities and being able to make choices based on their strengths. They didn't do the discussion boards.	The I-standards should be evaluated using Neurodiiverse versus Neurotypical.	I-Standards are a good think to have.