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Re-design of a Large Statics Course to Forster Creativity and Inclusion

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1. Introduction

The goal of undergraduate engineering programs is to teach how to solve problems [1] with critical thinking and other necessary skills. Engineering programs typically have had a narrow focus and rigid adherence to traditional instruction and assessment [2]. Blickenstaff [3] reported the lecture format that was adopted in most engineering courses can be detrimental in that it potentially creates a barrier between students and instructors. Felder *et al.* [4] and Suresh [5] found that performance in key introductory undergraduate courses is related to engineering persistence. Even long after Seymour and Hewitt's earlier study about students leaving engineering because of poor teaching [6], students are still leaving engineering because of the barrier courses for various reasons. Thus, an effort to foster a diverse and inclusive learning environment in the barrier courses is desired and necessary.

The Statics course is one of the first large courses that engineering students encounter and teaches various foundation topics and rigorous assessment schemes. It is also an important course in that it gives the student the necessary foundation to further succeed in their education and careers. At the University of Connecticut, the Statics course is a required course for the Civil, Environmental, Mechanical, Material, and Biomedical Engineering departments. Sophomore students predominantly take it. Total enrollment has been steadily increasing and is currently about 500 students per academic year. Being required for multiple engineering majors and as a key introductory undergraduate course, the Statics course needed careful attention to be effectively and inclusively taught.

Providing an equal opportunity to success for all students regardless of their background and characteristics – such as race, gender, or disability – is the goal of the inclusive classroom. There has been increased interest in acknowledging the variations in cognitive and learning abilities, and in making accessible the classroom for a neurodiverse population. Neurodiversity – defined as natural differences of human brains that exist from one to another regarding sociability, learning, attention, mood, and other important mental functions [7] – is an important factor to consider. Recently, some researchers explored methods to include neurodiverse student populations to further increase diversity and enhance creative problem-solving [8]-[10]. Rentenbach et al. [11] reported that the traditional lecture-style engineering course penalized neurodiverse students, e.g. students with autism, attention deficit hyperactivity disorder (ADHD), or dyslexia, because of learning environments consisting of one-directional knowledge input, dry atmosphere, no breaks, strict adherence of homework policy, paper textbook, fast closed book exam, and so on. Neurodiversity affects the performance of engineering students largely due to the field's often narrow focus and rigid adherence to such traditional instruction and assessment. For the inclusive classroom to provide the opportunity for success for all students, re-thinking and re-designing our courses and curricula to allow flexibility in courseware and accommodation for students' needs is of vital importance. Thus, the re-design of the Statics course to accommodate neurodiverse students has the potential to be beneficial.

With the accelerating change of pace in the 21st century, Cropley [12] predicted that creative technological solutions will be required to deal with a large growth in new problems. The creation of future solutions can be nurtured by promoting creativity and innovation in engineering education. Solving old problems with old solutions is replication, which will not be sufficient for the future our students will encounter. Recent studies have suggested that neurodiverse students possess creative problem-solving skills which can contribute to providing new technological solutions to the engineering discipline. Re-designs of the Statics course have been proposed to accommodate neurodiverse students, with the prospect that increasing diversity and promoting creative problem-solving skills have the potential to be beneficial for the Civil Engineering (CE) profession.

The objective of this paper is to report a re-design procedure of the Statics course to accommodate neurodiverse students and improve the effectiveness of course instruction in the online distance learning environment, while maintaining academic effectiveness. The procedure includes implementing seven universal design of instructions (UDI) principles [13] and strength-based final project options. The UDI implementation and final project description and rubrics are provided. A work in progress report was previously presented and this paper will provide a complete work [14]. Since Fall 2020, this course has been offered for 3 consecutive semesters. The first cohort in Fall 2020 has 2 groups: 1 comparison group and 1 experimental group. The second cohort in Spring 2021 has 1 experimental group; the third cohort in Fall 2021 has 1 experimental group. Each semester a formative evaluation regarding the UDI implementation has been conducted for the experimental group. For all sections, the summative students' evaluations of teaching (SET) were conducted at the end of the semester, and the results from all sections were compared. This paper will report the implementation results of the re-design for consecutive 3 semesters, summarize the impacts and challenges, and provide insight to apply the re-design scheme to other institutions.

2. Universal Design of Instructions (UDI) for Inclusion

The focus of re-design is to implement UDI to make the Statics course accessible and flexible for an inclusive classroom. The re-design components of the first cohort were detailed in the first paper [14], and this section will briefly summarize the finalized components for completeness of the paper.

Universal design (UD) is the design of products and environments to be usable by all people, to the greatest extent possible, and without the need for adaptation or specialized design [13]. With UDI, the course products and environments meet the needs of potential users with diverse characteristics that include disabilities. Furthermore, making a course accessible to people with disabilities often benefits others. There are seven UD principles, and this course has been re-designed to satisfy all seven principles as summarized (see Table 1).

The first principle is applied to make the design useful and marketable to people with diverse abilities [13]. This was implemented through the course website, textbook, syllabus, and captions. The second principle is applied to provide flexibility for a wide range of individual preferences and abilities [13] for exams and assignments. Students can choose the final project option instead of the final exam. All students were given extended exam time without requiring a special accommodation letter. The third and fourth principles are applied to make the design easy to understand and to communicate necessary information effectively to the user with a diverse background [13]. These were applied to the embedded captions in pre-recorded videos. The fifth principle is applied to minimize adverse consequences of accidental or unintended actions [13], in other words, embracing mistakes and errors. This was applied by adopting a digital textbook package with online homework using McGraw Hill's Connect [15]. Doorn et al. [16] reported the effectiveness of various online homework platforms for flexibility and individualized feedback. Because online homework is personalized for each student, they must work on their own sets of questions, and get feedback. Students were allowed to make mistakes and check their answers multiple times, thus strengthening their problem-solving skills. The sixth and seventh principles are for the design which can be used efficiently, comfortably, and with a minimum of fatigue [13]. In addition, appropriate size and space are provided for approach, reach and manipulation [13]. For all 3 semesters, the lecture was online, and therefore, students can use any accommodations they needed at home and be allowed to use any posture and actions while muted. The lecture was roughly structured with an active recitation (15-25 minutes) and active problem solving (60-70 minutes). Frequent stretch breaks and screen breaks are used about every 10 - 15 minutes throughout the class – based on the course flow, and a one-time 3-minute transition break was used between concept recitation and problem solving during online meetings. In addition to this, students had opportunities to reflect on their efforts and performance in class using self-reflection surveys (after two midterm exams). Smaller student tutor sessions were provided for under-performing students based on their choices.

Table 1. UD Principles and Implementation in the Statics course [14]

UD Principles	Implementation in the Statics Course
Equitable Use	▪ Course website on Blackboard is pre-designed to be accessible to everyone ▪ Digital textbook is adopted for text-to-speech functionality ▪ Captions are embedded in the pre-recorded video lectures ▪ Syllabus and course files are all accessible forms
Flexibility and Use	▪ Final project has an option of written or oral report choices ▪ Students have choices to read the textbook or listen to the textbook from the digital textbook ▪ All students are given extended exam time
Simple and Intuitive Use	▪ Video recordings are captioned
Perceptible Information	▪ Video recordings are captioned ▪ Presentation during online meetings includes captioning options and audio description
Tolerance for Error	▪ Digital textbook provides guidance and background information when students work on homework ▪ Students are allowed unlimited homework attempts until the due date ▪ Students can check the homework answers multiple times so that they can fix their answers before the homework submission date

Low Physical Effort	▪ Online lecture environment allows low physical effort. They can join the lecture in their room with necessary accommodations with minimum fatigue ▪ During online lectures, frequent stretch breaks, screen breaks, and one-time 3-minute transition break were used
Size and Space for Approach and Use	▪ Online lecture environment eliminated physical lecture space ▪ Students may be able to use a more comfortable space for their learning at home and are allowed to use any posture or actions while muted

3. Strength-based Final Project for Creativity

Among all re-design components, the strength-based final project option was mainly offered to students uniquely in the Statics course. "Strength-based" means that students were able to choose how best to demonstrate their learning based on their individual strengths. The goal of this project is to allow students to reflect on their strengths, use them to motivate their learning of the Statics course topics, and eventually prepare them to come up with creative and innovative solutions to new engineering problems.

The final project option is given to students to choose over the final exam, which is 30% of the total grade. The duration of the final project was 4 weeks between the end of the midterm exam 2 and the final exam to provide sufficient time for completion for flexibility. The project description and detailed rubric were posted immediately after midterm exam 1 so that students could review and have time for decision making. Students could choose the format of the final report, either as a written report or an oral presentation to provide multiple formats of final reports. Students could also opt-out from the final project option any time before the preliminary report due date for a final exam option if they were not able to successfully finish their proposed final deliverables.

During the project time, multiple steps of assessment were provided to give timely feedback regarding students' progress. Students were to submit four different reports: a letter of intent, a project proposal, a preliminary report, and a final report. The instructor provided individual feedback to students after the project proposal and the preliminary reports. Project proposal, preliminary report, and final deliverables consisted of 5%, 5%, and 90% of the entire grade, respectively. The percentages of the project proposal and preliminary report are much less than the final report to provide a chance to learn from mistakes and promote a low-risk environment.

Two different tracks were developed: 1) problem-solving track, and 2) creativity track to allow open-ended project topic choices.

Problem-solving track: The problem-solving track required the creation of 9 new problems from specific sections of the Statics textbook [17]. These sections include the most challenging topics in the Statics course: 3-dimensional equilibrium, 3D moment, the centroid of volume, analysis trusses and machines, bending moment diagrams, friction, and moment of inertia. Each problem was graded separately based on the rubric evaluating learning objective, creativity, correctness, and professionalism. For example, a full score means a new problem was solved correctly and presented professionally. Creativity was assessed based on the novelty of the problem.

Creativity Track: The goal of the creativity track is to develop and work on projects based on individual strengths aligned with course learning objectives. This track is open-ended, and students who wish to choose this track are required to contact the instructor and get their proposed ideas approved before working on the projects. The rubric of the creativity track was also developed based on the inclusion of learning objectives, creativity, difficulty, written report, and the final deliverable. The entire project was graded as a whole. Students were able to choose any form of final deliverable as long as they fulfilled their proposal; however, they must explain how their projects included all learning objectives and difficulty requirements to sell their ideas in the written report. Students received a full score if they created a novel product that included all 9 course learning objectives and solved difficult problems with a complete written report. A portion of scores was automatically given to students if they chose the creativity track in the first year, however, it was removed from the rubric and replaced by self-assessment in the summative evaluation in Fall 2021. The self-assessment for Fall 2021 will be reported in Section 4. In addition, the detailed rubrics for both problem-solving and creativity tracks are provided in the previous paper by the author [14].

The statistics of the strength-based final project are shown in Figure 1. The total enrollments of the experimental sections of Fall 2020, Spring 2021, and Fall 2021 semesters were 122, 84, and 120, respectively. In the first cohort in Fall 2020, 51 students submitted the final reports, consisting of 45 projects. Among them, 24 projects were on the problem-solving track, and 21 were on the creativity track. Creativity track projects included songs, drawings, comics, story-telling, tower crane modeling, wood table construction, and string art. In the second cohort in Spring 2021, 35 students submitted a total of 34 projects, among which a majority of 26 projects were on the problem-solving track. The third cohort in Fall 2021 enthusiastically chose the final project option, and 81 students (67.5 % out of total enrollment) submitted 72 projects. Among them, 30 projects were problem-solving, and 42 projects were on the creativity track. The creativity track projects covered a multitude of strengths including music videos, Augmented Reality/Virtual Reality modeling of structures, bridge design comparison, comic books, drawing, game design, skits, origami, social pipeline construction, and poems.

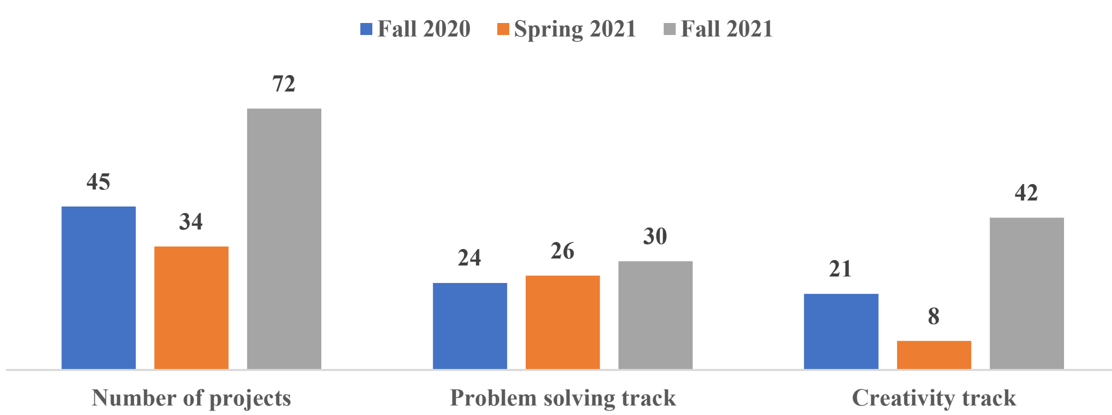

Figure 1. Project Submission Statistics (a) number of total projects, (b) problem-solving track projects, (c) creativity track projects

For cohorts 1 and 2, the numbers of creativity track projects were 21 and 8, therefore, the grading was manageable. However, for cohort 3 there were 42 creativity track projects, and thus grading, communication, and feedback required assistance. For the problem-solving track, A new project grading sheet, examples, and instructions were prepared, and the graduate teaching assistants were employed to assist with grading. The proposals, preliminary reports, and the 42 creativity track final report were still graded by the instructor. Overall, more students chose the final project options over the final exam option.

For cohort 4, an external evaluator was invited to conduct the summative evaluation of the final project option. The survey was conducted after the deadline of the final project and the final exam. In Fall 2021, 2 sections of the Statics course were taught to 238 students. Among them, 160 students chose the final project option; 78 students chose the final exam option. The response rates were 22% for the final project students; 17% for the final exam takers.

The main question that was asked to students was “this assignment allowed me to use my creativity.” 94% of the final project takers agreed, while only 31% of the final exam takers agreed with this statement. These external evaluation results showed that the strength-based final project options allowed students to use their creativity.

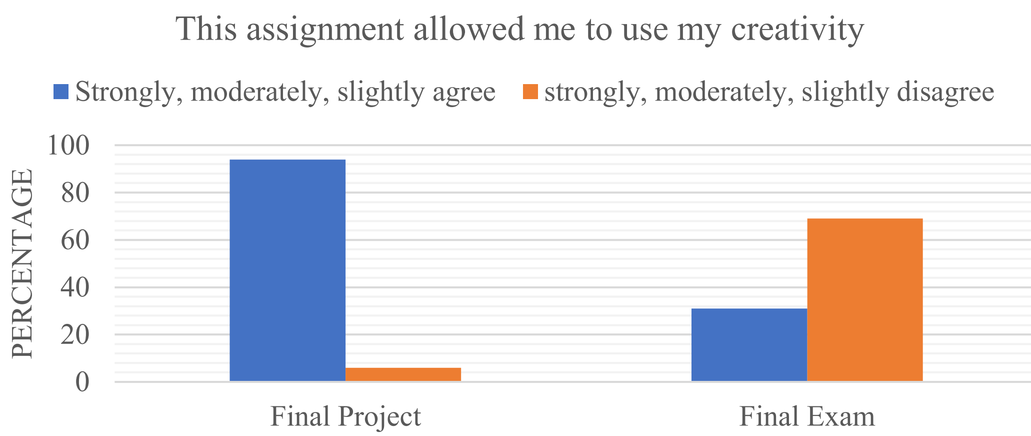

Figure 2. Student Responses Comparison between the Final Project and Final Exam.

4. Summative Evaluation through Student Evaluation Comparison

A summative evaluation was conducted for all sections using student evaluation of teaching (SET) conducted by the University and was used to compare the effectiveness of the re-design components for 3 subsequent semesters. For the first cohort, one experimental group and another comparison group were randomly chosen to avoid self-selection bias. For the second and third cohorts, one experimental group was used per cohort. Therefore, the comparison group of the first cohort was used for reference (Control), and the results of the three experimental groups were compared. Experimental group 1 (E1) is from Fall 2020, Experimental group 2 (E2) is from Spring 2021, and Experimental group 3 (E3) is from Fall 2021. The numbers of the participants are 74, 90, 55, and 81 for Control, E1, E2, and E3, respectively.

The first question is about the instructor’s teaching effectiveness to promote learning (see Figure 5). 61% of control group students either strongly agree or agree, 13% strongly disagree or agree, and 26 % neither agree nor disagree. For the experimental groups, 75%, 88%, and 78% of students either strongly agree or agree, showing the effectiveness of the re-designed teaching methods.

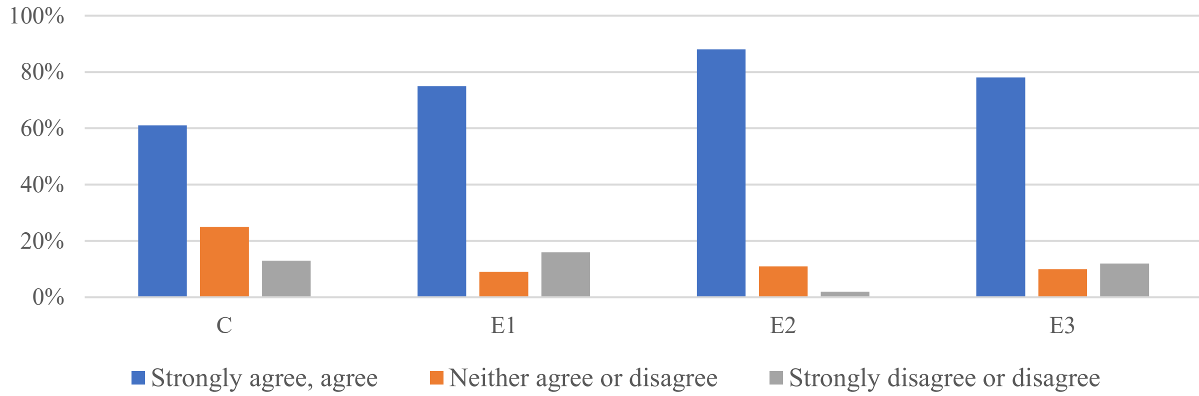

Figure 3. SET Result: The instructor's teaching methods promoted student learning

In addition, three open-ended questions were given to students on top of the default questions in the SET to share their feedback. The first question was 'Do you feel the course activities and course modifications reduced your stress and helped your learning?' This question was only employed for the experimental groups. 83, 50, and 67 students participated from E1, E2, and E3, respectively. Among them, the first cohort has the most enthusiastic responses, showing 92.8% agreeing with the statement. Overall, most respondents positively agreed with the statement showing the course re-design components reduced students' stress and helped their learning.

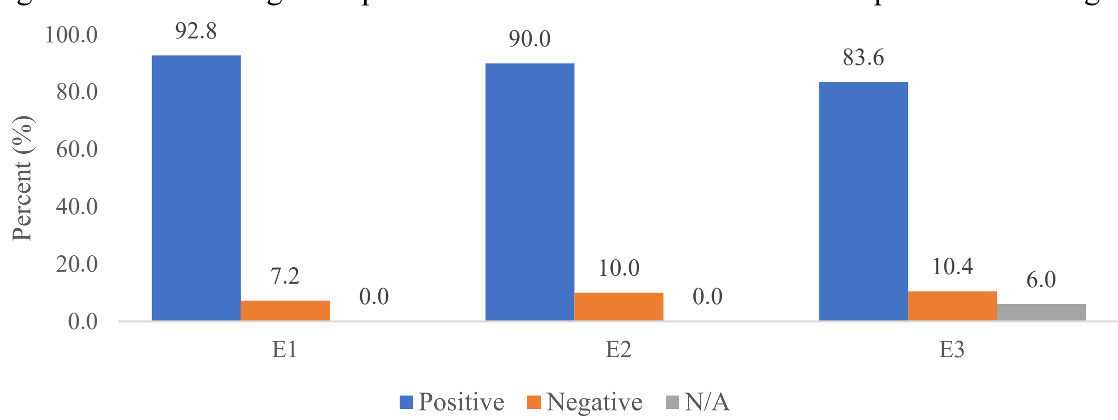

Figure 4. SET Result: Do you feel the course activities and course modifications reduced your stress and helped your learning.

The second open-ended question was about sharing the most helpful re-design components for their learning. The shared comments are shown in Figure 8. For E1, the extended exam time has 20 responses highest among the individual components. For E2, the stretch break was highly voted. For E3, the final project option was highly voted. In general, all re-design components were responded as helpful for all three experimental groups. Among all interventions, stretch breaks, extended exam time, and lecture recording are some of the low-cost interventions other institutions can adopt to help not only the neurodiverse student population but all students.

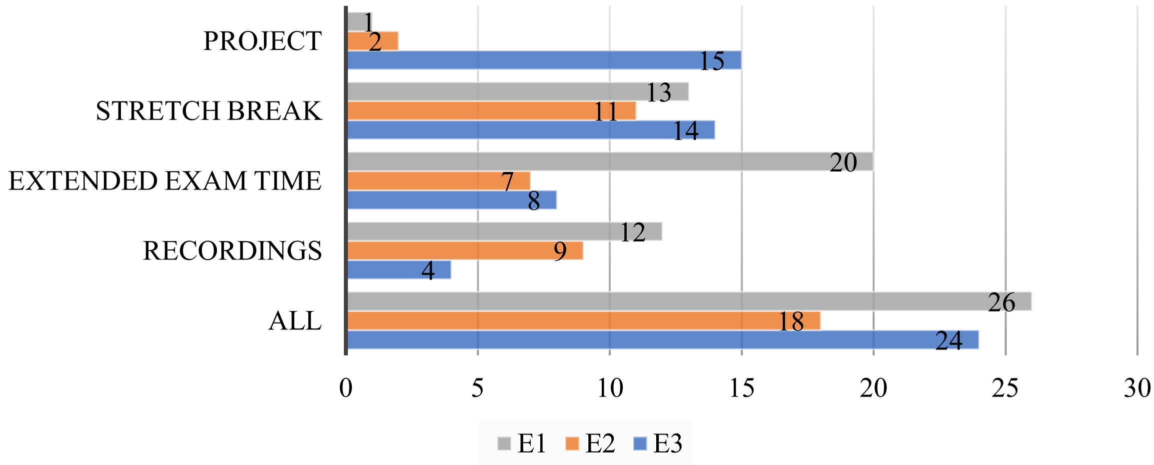

Figure 5. SET Result: Additional feedback question

5. Discussions

In general, the implementation of UDI helps diversity and inclusion by increasing flexibility and improving accessibility. The results of the SET survey suggest that the implementation of UDI was favorably accepted by students. This can be attributed to several factors. In the online exam, having an extended exam time reduced students' stress levels. Having frequent breaks during online meetings was helpful to keep students motivated. Posting lecture recordings helped students who lost their attention during the lecture, or completely missed the lectures. Posting the instructor's digital hand-written class notes eliminated the need for designated note-takers.

The initial development requires a major investment for successful implementation. The creation of accessible material and pre-recorded videos require considerable time and effort from the instructor. An organized online course webpage is desirable to function as a course hub, accessible to instructors, TAs, and students. Because this course was already flipped before Fall 2020, the summer months were used to prepare the course material. Hiring undergraduate teaching assistants was beneficial to manually edit the video captions which were automatically created from Kaltura or YouTube, while the instructor would check and approve the captions.

During the semester after implementation, the instructor also needs to provide individualized feedback to students regarding the proposals and the preliminary reports. Giving feedback per student took about 3 ~ 6 minutes, consuming a significant amount of the instructor's time. For example, for cohort 3, there were 80 final projects and 42 creativity track projects. The instructor had to spend 3 days for proposal grading, 4 days for prelim grading, 4 days for final report grading, on top of the time for email communications. To be equitable and inclusive, the opportunity must be given to all students; however, it must be in a manageable way. In Spring 2022, the instructor eliminated the creativity track and embedded the creativity option in the problem-solving track, so that students can choose to use that option and add open-ended components, but the problem-solving parts can be graded by the TA. The percentages of the proposal and preliminary report were increased to 10 % and 27 %, respectively, to emphasize meaningful effort on both reports. In addition, a more detailed rubric for the creativity portion should be prepared to guide students and answer anticipated questions ahead of time.

In Fall 2020, both the experimental and control groups attended class virtually due to the COVID-19 pandemic. The differences in perceived learning between the two sections could be partially due to pedagogies in the experimental group that were more conducive to remote learning. For example, implementing frequent breaks and eliminating the need for attending classes in person. Most of the pedagogies in the experimental group can also be used for the Face-to-Face modality. Specific interventions for 'low physical effort' and 'size and space for approach and use' categories can be slightly modified for in-person classes, for example, implementing fidget breaks and changing seats in the classroom allowing stretch breaks, and preparing a dedicated space with more room for disabled students. In Spring 2022, the Statics course is offered as in-person classes, and the stretch breaks and a transition break are employed at a similar timeline but in-person with actual physical stretches, and a 3-minute break. The instructor also invited students to use the rear part of the classroom so that they can use any posture while not disrupting other students' learning.

An important consideration of implementing UDI is to facilitate and promote the learning of neurodivergent populations. Student perceptions surveyed from the formative and summative evaluations indicated that the re-design components were positively received by students. The overall goal of the re-design is to accommodate all kinds of neurodiversity through UDI principles assuming everyone has different learning styles, and continuous re-design effort is planned with more data measurement and systematic research.

The initial re-design procedure took one year; planning meeting and workshop in Spring 2020, actual courseware preparation in Summer 2020, and course administration in Fall 2020. Before that, the pre-recorded videos were already prepared; class notes were prepared, and the course was already flipped. This procedure was implemented through a group effort transforming multiple courses in the CEE department, in collaboration with the Center for Excellence for Teaching and Learning, Center of Students with Disabilities, and a colleague in the NEAG School of Education at the University of Connecticut. The results and UDI components are general to other CEE courses such as Fluid Mechanics and Mechanics of Materials, and the results were reported in other publications [18]. This course has been offered every semester since Fall 2020 with slightly modified and improved interventions semester by semester.

6. Conclusions

This paper reported the re-design of a large Statics course to promote creativity and improve inclusion using UDI. Seven UDI principles were successfully implemented for the Statics course with a digital textbook, course website, accessible materials, a final project option, extended exam time, and frequent breaks, among other improvements. Among them, extending exam time, providing breaks in instruction, and making class notes available to students are the interventions with a low cost of implementation for faculty using more traditional pedagogies. In addition, the strength-based final project option was created to reward creativity so that students could use their own individual strengths to learn the course material. For 3 semesters, 167 students participated in the final projects options to replace the final exams and successfully completed them. The students' feedback from the re-designed section and the control group were compared which suggested overall positivity regarding the re-designed section compared to the control group. Some interventions such as stretch breaks, extended exam times, and lecture recording can be easily transferrable to other institutions. If the instructor's time commitment for grading and providing feedback can be addressed, the final project options for the Statics course can also be transferrable to other institutions, and more refinement of effective grading mechanisms and an updated rubric is currently underway. The reported re-design process showed great potential to increase diversity and inclusion using UDI.

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