ŌTAUTAHI CHRISTCHURCH AOTEAROA NEW ZEALAND
35TH AUSTRALASIAN ASSOCIATION FOR ENGINEERING EDUCATION ANNUAL CONFERENCE
8-11 DEC 2024
THE ENGINEER AND THE WORLD

Exploring Empathy Development in Mechanical Engineering Students During Conceptual Design Task

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ABSTRACT

CONTEXT

Students studying mechanical engineering are exposed to a range of engineering design methodologies to aid them through a variety of engineering design tasks. In a 4th year mechanical systems design class, mechanical engineering students were given a broad design task for a situation where they need to ideate, evaluate, and develop concepts to aid someone with reduced limb function due to a cervical spinal cord injury (SCI). This type of design problem is topical, as engineers are increasingly required to incorporate universal design principles such that the products they develop can be used by a diverse group of users. This study provide insight into how well undergraduate students compete a design task which requires them to empathise with a use that has different function to themselves.

PURPOSE

Few researchers have investigated the development of empathy in undergraduate mechanical engineering students as they complete a conceptual design task. The purpose of this study was to investigate how students' empathy, in terms of their understanding of the specific requirements, limitations and life perspective of an end user with a cervical SCI develop during a concept design task. This data will provide useful insights that will enable the current teaching method to be evaluated and improved.

METHODOLOGY

Three anonymous online surveys were completed with the class to gather information regarding how students' self-reported understanding of the end users' requirements, limitations and life perspective change over the course of the design task. To compare student responses to how well their designs could be used by an individual with a cervical SCI, the designs submitted by students were evaluated against three objective measures.

ACTUAL OUTCOMES

The results of the surveys showed that students' self-reported understanding of requirements, limitations and life perspective increased throughout the duration of the conceptual design task. Students commented on the value of discussing the details of the project with both a registered physiotherapist and an individual with a C6 cervical SCI. When the concept designs were compared to the results from the objective measures, many students had submitted designs that were ultimately unusable by the target population of the design problem. This result indicated that many students overestimated their self-reported understanding of the end user.

CONCLUSIONS

This work highlighted that the current teaching methods enabled students to increase their self-reported empathy and understanding for the end user through the completion of a conceptual design task. However, many students were not able to accurately evaluate their own understanding, as solutions were submitted that were unable to be used independently by the

target population. Future work could investigate changes to the current teaching methods. This could include the development of an alternative or virtual reality experience to help student develop a better understanding of the unique challenges of people who have reduced function.

KEYWORDS

Engineering design process, empathy, inclusive design.

Introduction

Throughout the Bachelor of Engineering with Honours at the University of Canterbury (UC), students in the Mechanical Engineering Department develop experience in engineering design through completing a variety of design projects. Students are exposed to a range of engineering design methodologies including those outlined by Pugh (1991), Beitz et al. (1996) and Ulrich et al. (2008). These methodologies provide students a framework that they can follow when they are developing designs. Using these methods, students can develop ideas and turn them into a functional prototype or technical product. The general systematic approach to engineering design outlined by Hales and Gooch (2004) include the task clarification, conceptual design, embodiment design and detailed design phases. Due to the large amount of time required to complete all phases of the engineering design method, student assignments focus on partial design tasks that focus on particular phases of the process independently, such task clarification and conceptual design or detailed design. Shayne Gooch, the academic coordinating the course in this study has been teaching 4th year mechanical system design since 2001. He has over 30 years of experience in engineering. Each engineering design assessments is developed to give students applicable experience with what they could expect to do when working in industry.

Each year, mechanical engineering students are required to complete a conceptual design task as part of their 4th year mechanical systems design class. The design task often relates to an open-ended, real-world problem, such as devising a way to enable someone with a disability or impairment to complete an activity or task that is not possible in their current situation. The design task is always given to the students in a broad context, such that they need to define a neutral problem statement for the situation. They are also required to develop a criteria for success using a design requirement specification (DRS) for the given situation following the method set out by Hales and Gooch (2004). As observed by Wallace and Hales (2011), it is important that sufficient time is spent on the task clarification phase to ensure a comprehensive criteria is developed to evaluate designs to avoid unforeseen problems during subsequent phases. Students were encouraged to develop neutral problem statements for their design task to allow a broader range of ideas to be investigated before selecting and developing a specific solution based on the specifications noted in their DRS document. The assessment is designed to give student a real application of the engineering design skills that they have developed over the previous three years of their degree.

Students in this study were given a conceptual design project in which they were to develop a concept for a device to aid people with a cervical spinal cord injury (SCI) to transfer independently from their wheelchair to another horizontal surface such as a bed or chair. In New Zealand, traumatic SCIs tend to result in tetraplegia, with 67% of new traumatic SCI in 2022 resulting in tetraplegia (New Zealand Spinal Cord Injury Registry, 2023). The nature of traumatic injuries mean that the lives of these individuals are changed in an instant, with those sustaining cervical SCIs losing a range of physical function and sensation below the injury level. For the upper limbs, this includes a reduction in strength (or complete loss) of the muscles which control the elbow, wrist, forearm and hand, consequently making activities of daily living, such as stabbing food with a fork, difficult to complete (Dunn et al., 2016). Good seating and trunk stability are other important factors to allow people with cervical SCI to use their upper extremities (Bryden et al., 2012). As a result, this population of people would benefit from innovative engineering designs to aid in completing activities of daily living independently, including independent transfers from their wheelchairs.

Increasingly, engineers incorporate universal design principles so that the product they develop can be used by a diverse group of users (Bigelow, 2012; Torkildsby, 2018). For a design to be successful such that it can be used by all, it is critical that the designer is able to empathise with the end users of their design. To do this well, designers must have a clear understanding of the objectives of the design situation as well as a thorough understanding of the life perspective, needs, wants, and limitations of end users that differ from the general population. The importance of empathy in allowing designers to better understand both the design problem and the needs of the end users has been highlighted in a range of studies (Gray et al., 2015; Schmitt & Morkos, 2016; Walther et al., 2017). As the design task given to the students in this study revolves around ideating a solution for a person with a cervical SCI, it is crucial that students take care during the early phases of the engineering process to make sure that they empathise with the end user and understand the nature of their limitations. Subtle design considerations will enable concepts with increased useability to be ideated. If mechanical engineering students have a better understanding of physical limitations associated with an SCI, it is proposed that these students will develop a concept the takes these limitations into consideration and not develop something that cannot be used by the desired end user. Currently, few researchers have investigated how undergraduate mechanical engineering students' empathy towards the end user develops as they complete unique conceptual design tasks.

This study aims to investigate how students' empathy in terms of self-reported understanding of the end users' requirements, limitations and life perspectives change during the task clarification and conceptual design phases of the given design task. The study also aims to investigate how well students are able to evaluate their own understanding of the end user. This data will enable the impact of different teaching methods used to help students develop empathy during concept development to be evaluated. The insights from this project will help enhance current methods that are used by lecturers at university to aid students in developing empathy and ultimately engineering solutions that can be used by all.

Methodology

In the first semester of 2024, a survey was prepared to investigate how students' understanding of the user requirement and life perspective changes as they progress in developing a concept for a unique design problem. Students completing ENME401 were eligible and invited to participate in the study as they were required to complete a concept development task that required them to empathise with and understand the end users of their design. Before the surveys were distributed to collect responses, the study was reviewed and accepted by the UC Human Research Ethics Committee (Ref: HEC Ref: 2023/138/LR-PS). The survey questions were also approved by the Evaluation & Student Insights (ESI) team at UC. The research questions that were used in the study are included below. It should be noted that Question 2 and 5 were not included in the initial survey.

Question 1: On a scale of 1 to 5, how well do you think you currently understand the requirements and limitations of the end user for your design task?

Question 2: Has your understanding of the user requirements and limitations of the end user changed since your last response?

Question 3: What is your reasoning/justification for you answer to the Questions 1 and 2?

Question 4: On a scale of 1 to 5, how well do you think you currently understand the life perspective of the end user for your design task?

Question 5: Has your understanding of the life perspective of the end user changed since your last response?

Question 6: What is your reasoning/justification for you answer to the Questions 4 and 5?

Question 7: Do you have any general comments about your understanding of the context of this design task?

Students were invited to participate in the study though a post made to the ENME401 course page which included the information sheet for the study and a link to complete the survey. Physical copies of the information sheet were given out during the first tutorial of the class. The information from the post to the course page was also shown in class on the day that each survey was available. All survey data was recorded online anonymously using Qualtrics. Participation in the study was voluntary and students had the option to opt out of study if they did not want to be included. The responses to the surveys were processed using Microsoft Excel.

The first survey was given to the students in the first week of the term, two days after the assignment brief was released. Following this, further detail was presented to the students highlighting research that has been completed in the area of understanding the strength of people with cervical a spinal cord injury (SCI). The second survey was given to the students approximately two weeks after the first survey. At this time, the students had submitted a problem statement and list of design specifications (DRS) and were actively ideating and evaluating possible concepts that may solve the design problem they were given. After the second survey, students had an opportunity to learn more about the context of the project through asking questions in class with a registered physiotherapist as well as with an individual with a C6 SCI. The physiotherapist is also a Senior Research Fellow at the University of Otago, and has worked in the field of SCI rehabilitation for over 25 years. The role of the registered physiotherapist and the individual with a C6 SCI was to provide students with insight into what it is like to live with an SCI including the challenges this population of people have when completing tasks of daily living. Students were able to improve their understanding of these aspects of the design task through asking questions. The third survey was given to the students approximately two weeks after the second survey. At this point in the project, students had narrowed down their ideas and complete a short video presentation highlighting their top 3 solutions along with outlining the final concept that they would develop to submit for the final part of the assignment. This final submission was made approximately two weeks after the third survey was completed.

After the final submission of the design task, student submissions (a single page concept drawing and two-page report) were reviewed and evaluated against three objective measures which the authors believe would indicate a good understanding of the end users' requirements, limitations and life perspectives if met by the submitted design. The questions for the objective measures are included below.

- Can a person with no core stability safely use this concept independently?
- Is the concept operatable within the reach envelope of a person with a cervical SCI?
- Can the concept be operated by a person with limited hand dexterity?

The results from evaluating the objective measures were recorded and processed in Microsoft Excel. Answers were recorded as either yes, no or unclear. Unclear was recorded for submissions where there was insufficient detail in the design documents to evaluate the question of interest. For completeness, Figure 1 outlines the methodological steps followed in this study

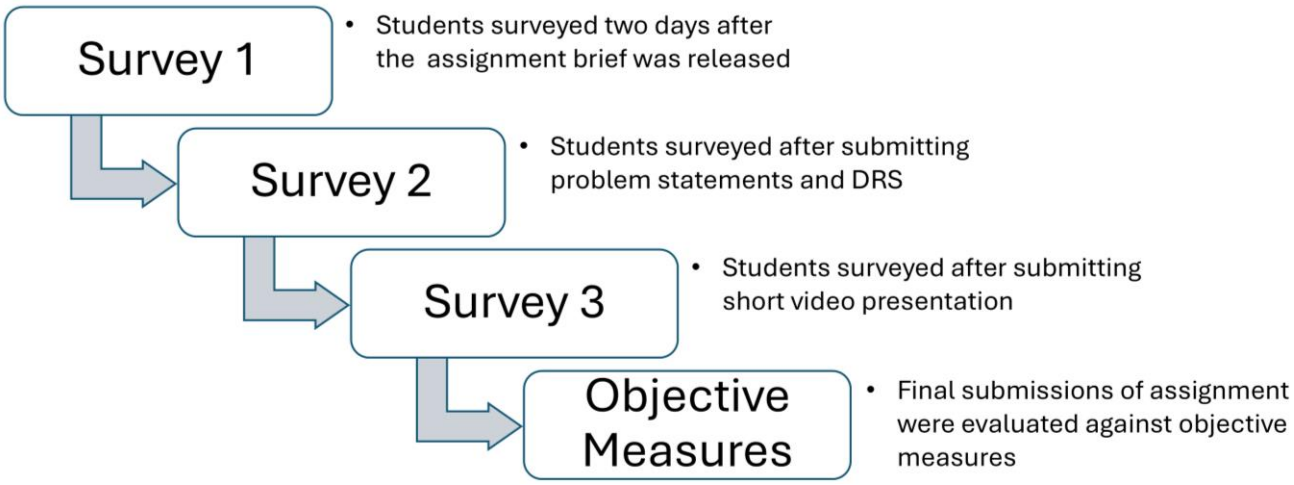

Figure 1: Overview of methodological steps followed in this study

Results

Of the 131 students in the class, approximately 57%, 42%, and 30% of the students enrolled in the course participated in the first, second and third survey respectively. The breakdowns of the responses to Questions 1, 2, 4 and 5 are included Figures 2 to 5.

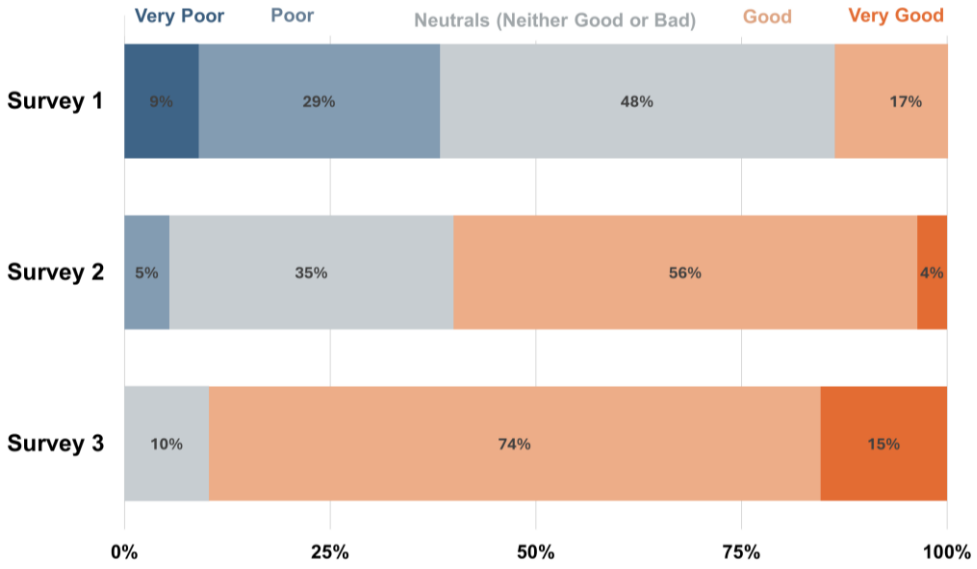

Figure 2: Breakdown of responses to "How well do you think you currently understand the requirements and limitations of the end user for your design task?"

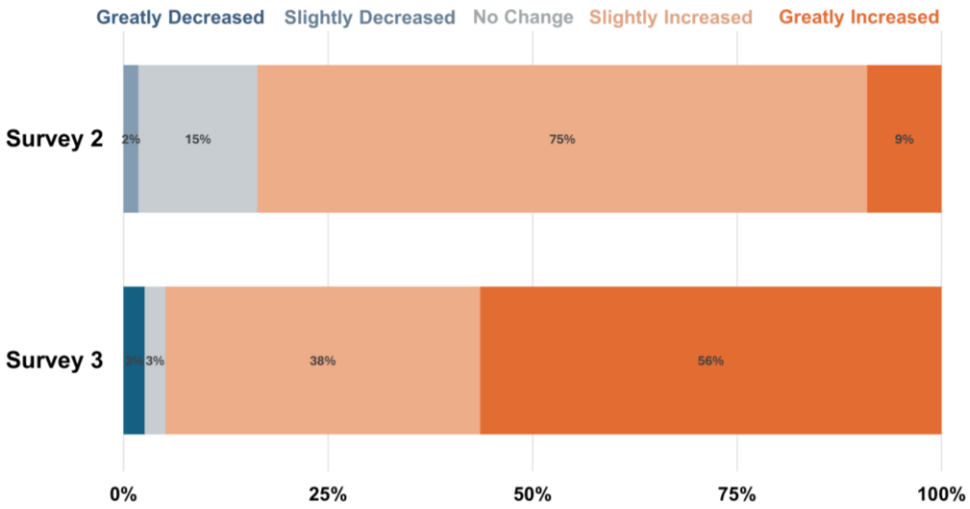

Figure 3: Breakdown of responses to "Has your understanding of the user requirements and limitations of the end user changed since your last response?"

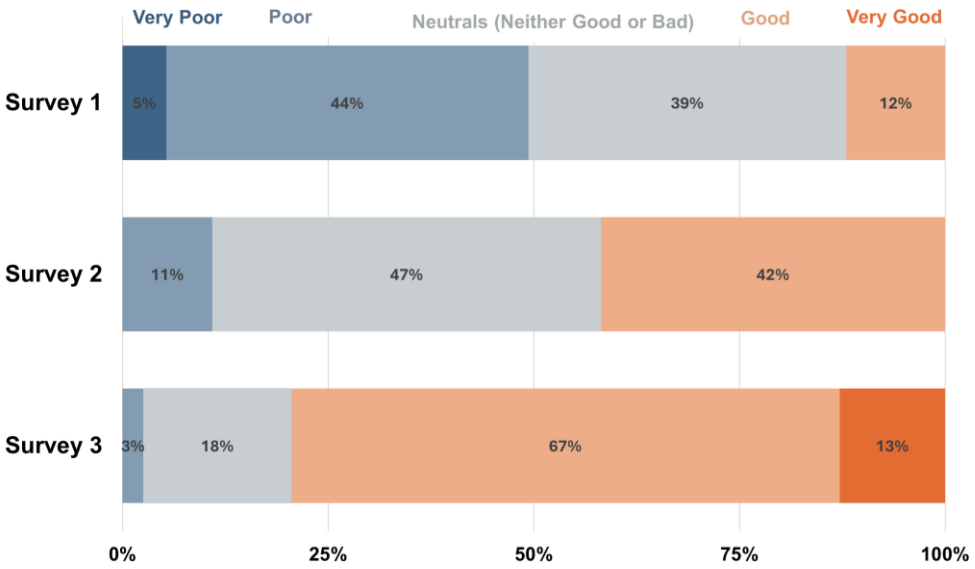

Figure 4: Breakdown of responses to "How well do you think you currently understand the life perspective of the end user for your design task?"

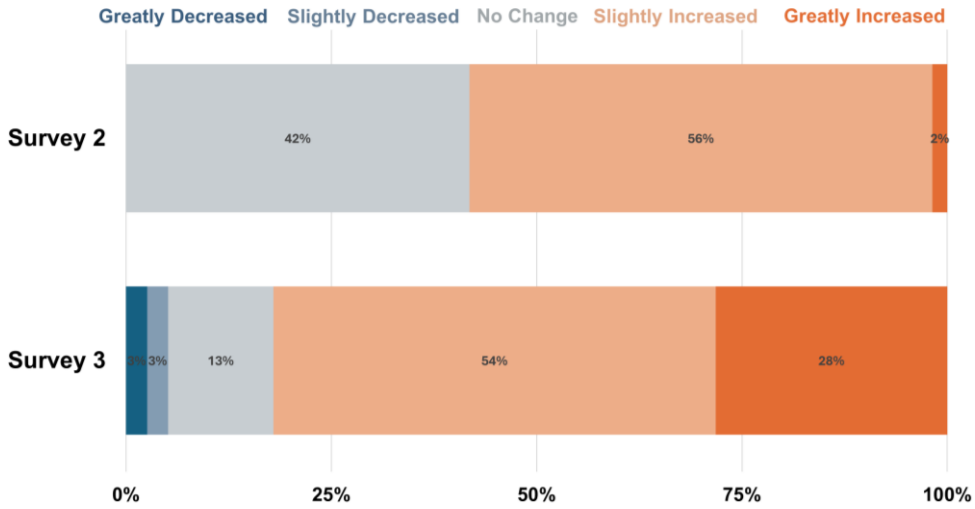

Figure 5: Breakdown of responses to "Has your understanding of the life perspective of the end user changed since your last response?"

The results from reviewing the students' designs against the objective measures are shown in Table 1. It should be noted that nine students submitted a drawing that were unable to be evaluated against any of the objective measures. These submissions were not included when calculating the percentages shown in Table 1.

Table 1: Results from evaluating objective measures against students' concepts

	Yes	Unclear	No
Can a person with no core stability safely use this concept independently?	37%	2%	61%
Is the concept operatable within the reach envelope of a person with a C6 cervical SCI?	50%	20%	30%
Can the concept be operated by a person with limited hand dexterity?	36%	21%	43%

Discussion

Overall, the study was successful in gathering responses from students about their perceived understanding of the end users requirements, limitations and life perspective. The responses to the three surveys show that in general, students regard their understanding to improve as they develop their concepts for the given design task. This is an expected results as students should improve their understanding around a given design task as they complete their own research to clarify the task and develop a set of specifications that they will develop a design to meet. Figure 2 shows that the percentage of students who thought they had a "Good" and "Very Good" understanding of the user requirements and limitations of the end user increases from 17% and 0% in the first survey (when they had only just been introduced to the design task), to 56% and 4% in the second survey, and 74% and 15% in the third survey. A similar trend is seen for the students perceived understanding of the life perspective of the end user, as detailed in Figure 4. The results show that the number of "Good" and "Very Good" responses increases from 12% and 0% in the first survey, to 42% and 0% in the second survey and 67% and 13% in the third survey. This result indicates that the students have gained an improved understanding of the requirements, limitations and life perspectives of individuals living with a cervical SCI through completing the design task. This increase in perceived understanding is expected as students have engaged with a range of relevant resources, that will help them to understand the design problem such that they can develop a solution which may help to solve the problem. After the first two surveys, where students have spent time clarifying and designing the task, the results indicate that classes where students engage with a physiotherapist and an individual with a

cervical SCI are an effective teaching method to enable students to continue to gain empathy around the design task. Many students noted that they learned a lot in the tutorials when they had an opportunity to discuss aspects of the project with a registered physiotherapist and with an individual with a C6 SCI. Examples of comments from students about this are included below.

"The tutorials with [name of physiotherapist] and [name of individual with C6 SCI] was the most helpful thing for this course"

"Speaking to experts and a person with tetraplegia helped to understand the exact needs"

Interestingly, the results from the objective measures detailed in Table 1 show that 61% of the designs were not able to be safely used by a person with no core stability. This result is similar to the other two objective measures, with 30% of the concepts not being operatable within the reach envelope of someone with a C6 cervical SCI and 43% of the concepts not being operatable by a person with limited hand dexterity. The mismatch in design useability and perceived understanding of the students highlights that there is an opportunity to improve teaching methods that promote students to develop useable designs for people with disabilities. The results of the objective measures are interesting when compared with the student ratings from the third survey where no students rated their understanding of the requirements and limitations of the end user as "Poor" or "Very Poor." This a surprising, but not entirely unexpected result when considering the fact that people with limited knowledge in a domain tend to overestimate their performance relative to an objective measure (Kruger & Dunning, 1999). Studies using undergraduate engineering students found that students who did less well tended to overestimate their exam and lab performance compared to the grade they received (Zvacek et al., 2015; Kribs, 2022). These studies help to explain why students overestimated their level of understanding.

Figure 3 and 5 highlight the changes in student understanding from the previous survey. In the second survey, 84% of respondents indicated that their understanding of the requirements and limitations of the end user had increased since the first survey. This response increased in the third survey, with 94% of students indicating that their understanding had increased from the second survey. A similar trend was seen in Figure 5, where 58% and 82% of students reported an increase in their understanding of the end user's life perspective in the second and third survey respectively. This result makes sense, as many students would not have understood the impacts cervical SCIs have on upper limb function and the thus the ability to complete tasks of daily living independently before completing this design task. For this reason, it is expected that there would be an increase in understanding from the first to the second survey. The results of the third survey show that the teaching method, including discussions with a both a registered physiotherapist and an individual with a cervical SCI were effective in enabling students to continue to improve their empathy and understanding of the end user. Interestingly, the results of the third survey suggest that some students did not report their understanding to have increased. The results show that 6% of survey respondents reported their understanding of the requirements and limitations, and life perspectives to have "Slightly" or "Greatly" decreased. This result might be explained by some students realising that their understanding of the end user was not as good as they thought in the second survey after discussing the project with the physiotherapist and someone living with a cervical SCI. Overall, the results from Figure 3 and 5 show that throughout the design task, the majority of students indicated that they were continuing to improve their understanding of both the requirements, limitations and life perspective of the end user.

The online anonymous survey was effective in gathering responses from students during the project. One improvement to this study would be to aim to get a larger number of responses in the final survey as only 30% of the class responded to the final survey. This number of responses was useful in investigating how students assess their level of understanding throughout a design task. One limitation to the objective measures that were used to evaluate the quality of the concepts that students submitted is that it is possible that the measure is not totally objective. As noted in the method, designs were evaluated using the drawing and report that students submitted. Aspects of the concept that were unclear after reviewing these documents, resulted in

the answer to the objective measure to be “unclear”. This result was useful to include as it gives an indication of the number of designs that lack detail in the functionality in the area of the objective measure. Overall, the results in Table 1 provide useful insights into how useable the concepts are that students submitted. Another limitation of the study is that the results relied on self-reported evaluations from the students. As novice designers have been found to both over- and under-estimate their ability (Asher, 1974), it is possibly that there are inconsistencies in the quality of the gathered responses. Future work could look to incorporate a more objective self-evaluation for the students to use. This would enable further comparisons to be completed with the objective measures detailed in Table 1.

Following the findings of this paper, future work could look to investigate how teaching practices can be updated to help students better understand how their designs can be made more inclusive and useable for a wider range of people. The results from this paper highlight that students respond well to in person engagement with practicing experts and people from the demographic they wish to include in their design. Previous studies have linked empathetic design experiences (such as simulating actual or situational disabilities) with the development of designs incorporate an increased number of original features (Genco et al., 2011; Johnson et al., 2014). Following this, one update to the teaching methods that could be investigated is the use of reality technology, such as alternative reality (AR) or virtual reality (VR), to give the students a more immersive experience and help them understand the life perspective of people with disabilities. Use of this technology has been shown to be a useful tool to allow designers to enhance empathy towards the end user through experiencing perspectives that are different to their own (Grech et al., 2023; Zhang et al., 2022). Completion of this work would aid in the development of the best teaching methods to help students develop empathy and understanding of the end user when completing a conceptual design task.

Conclusion

The purpose of this study was to gain insight into how undergraduate mechanical engineering students’ empathy changed while undertaking a conceptual design task. To do this, three surveys were used to gather self-reported measures of student empathy in terms of their understanding of the end users’ requirements, limitations and life perspectives. The results from the surveys show that students reported that their understanding of both the end users’ requirements, limitations and life perspectives increased while completing the design task. In the final survey before submission, the majority of students rated their understanding of the end user in these areas to be either “Good” or “Very Good.” However, a comparison of the self-reported survey data to objective measures indicated that although the majority of students reported that they have a good understanding of the end user, many had developed designs that we not able to be used independently by the target population. This showed that students overestimated their own understanding of the end user. Following this finding, future work could look to improve students’ understanding through investigating if changes to the current teaching methods improve the useability of student submissions. The development and incorporation of an alternative or virtual reality experience may be one way to improve students understanding of the end user such that they develop designs that can be used by all.

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Acknowledgements

The authors kindly thank the students who participated in the study, and the administrative staff in the mechanical engineering department for their assistance in completing this research.

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