IS MY MASTER THESIS RESEARCH PROJECT SUSTAINABLE? INCLUDING SUSTAINABILITY IN "RESEARCH METHODOLOGIES"

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ABSTRACT

Training socially conscious engineers and researchers is a core objective of the Delft University of Technology. One of the long-term goals is to give sustainability a central role in all educational programs, acting as a connecting thread. The Faculty of Aerospace Engineering at Delft University of Technology is working towards this common goal through several curriculum changes. This study focuses on the integration of a sustainability learning module into the online course Research Methodologies. Research Methodologies is a self-paced master's course where students start their research project for their master's thesis. The intervention's aim was to encourage students to incorporate sustainability into their master's thesis projects. Students were introduced to the Engineering for One Planet framework and motivated to view their research project through a sustainability lens. The responses of the students to the online discussion questions and their final research plans were examined to determine the effectiveness of the intervention.

KEYWORDS

MSc thesis, research, sustainability, Optional Standard 1

INTRODUCTION

The Delft University of Technology places a primary focus on training researchers and engineers with a strong sense of social responsibility. According to the TU Delft code of conduct's core values of Diversity, Integrity, Respect, Engagement, Courage, and Trust (DIRECT), educators must not only teach students to focus on problem resolution but also to critically examine its societal implications.

As a result, one of the university's long-term goals is to incorporate the concept of sustainable development throughout all educational and research programs [1]. This is based on the understanding that engineering and engineering education play critical roles in the societal transformations required to ensure a healthy planet and sustainable living conditions for current and future generations.

This understanding is also critical to the CDIO (Conceive-Design-Implement-Operate) frame-

[1] https://www.tudelft.nl/en/sustainability

work (Enelund, Knutson Wedel, Lundqvist, & Malmqvist, 2013). The CDIO framework was introduced to guide the development of engineers and researchers so that they are not only technically proficient but also understand the context in which their work is carried out. For this reason, sustainability and sustainable development are part of all of the core CDIO standards (Malmqvist, Edström, & Rosén, 2020). The importance of engineering education and opportunities for sustainable development is further emphasized by Optional Standard 1 for sustainable development (Malmqvist, Edström, Rosén, Hugo, & Campbell, 2020). CDIO Optional Standard 1 says that the goals and learning outcomes of an engineering program must include key sustainability competencies.

The TU Delft faculty of Aerospace Engineering has already implemented a number of initiatives that reflect the key sustainability competencies. For example, in the bachelor's graduation projects, sustainability is included as an explicit requirement and grading criterion (Brügemann et al., 2005). The aerospace engineering faculty fully supports Green Team Aerospace, a student-led sustainability committee, and hosts frequent seminars and lunch lectures on sustainable development. Additionally, a master's level course on sustainability in engineering was introduced in 2022. The course provides students with a theoretical basis and practical tools to apply in the context of aerospace engineering.

Major research initiatives within the faculty also prioritize sustainability. Our university's researchers believe complex technological solutions can reduce aerospace's climate impact. The European Partnership for Clean Aviation, the world's most ambitious aviation research and innovation partnership, welcomed TU Delft in 2021. AeroDelft [2], a student team, is developing the first manned liquid hydrogen-powered aircraft to demonstrate emission-free aviation.

However, even with all of these activities, the societal and environmental implications of the students own research were not explicitly considered in master's thesis projects outside of the sustainability-focused research initiatives. Given the time and resources devoted to the master's thesis work within the master of aerospace engineering program, this is pertinent. As described by Audunsson, Rouvrais, Rudd, Kristjánsson, and Moschetta (2022) the main goal of the master's thesis project is to bring together the student's knowledge of the field and their personal skills and to prepare the student for professional engineering work.

Because sustainable development was not intentionally considered in master's thesis projects, students were left with an educational gap. This gap was recently discovered, prompting the intervention described in this paper. The intervention's goal is to bridge the gap by incorporating a new sustainability module into the introductory research methodologies course. Since this course is taken at the beginning of the master's thesis research, the changes in the course materials are intended to introduce some valuable changes in practice in terms of sustainable research at this early stage.

[2] https://aerodelft.nl/

INTERVENTION

Course Description

This study discusses the implementation of a sustainability learning module within the online course Research Methodologies. The course has a workload of 2EC (54 hours) and is taken at the beginning of the thesis research process. The course is given online and is continuously available so that students can adapt it to their own thesis timeline. The course aims to equip students with the skills and tools to become better researchers and to develop their own research projects. The learning outcomes, as stated in CDIO Standard 2 (Malmqvist, Edström, & Rosén, 2020), detail what students should know and be able to do at the end of their engineering programs. For successful course completion, the following learning objectives are defined:

1. Formulate a research question(s)
2. Correctly cite the literature relevant to the research field.
3. Select the appropriate research tools and methods
4. Set up a clear research plan

A more detailed overview of the content of the course can be seen in Figure 1. The new Sustainable Research section discussed in the current study acts as bridge between the content on sampling, data management and project planning. The conexion with data management is especially relevant since as discussed by Pommerening (2021), sustainable data management and storage are an important part of research and not much attention has been paid to this in the past.

In order to evaluate these learning goals, the assessment is done via a report where the student needs to introduce their research project, describe the state of the art, and point out the research gaps. Then relevant research questions are formulated, and the methods, set-up, and expected results are described. The report concludes with a motivated plan for their research. This report is graded on a 10-criteria rubric. Each criteria establishes five levels: missing, needs work, acceptable, good, and excellent.

Theoretical content

The framework "Engineering for One Planet" (EOP) was used as a starting point to develop the module content. The literature relevant to the EOP is sumarized by Reynante (2022). EOP is an approach to sustainable engineering that emphasizes the importance of considering the impacts of technology on the environment and society and developing solutions that are both environmentally and socially responsible. This approach views the planet as a finite resource and recognizes that human activities have the potential to deplete the planet's resources and cause harm to the natural environment.

The EOP framework emphasizes the importance of taking a holistic, systems-based approach to sustainable engineering and encourages engineers to think beyond the boundaries of their

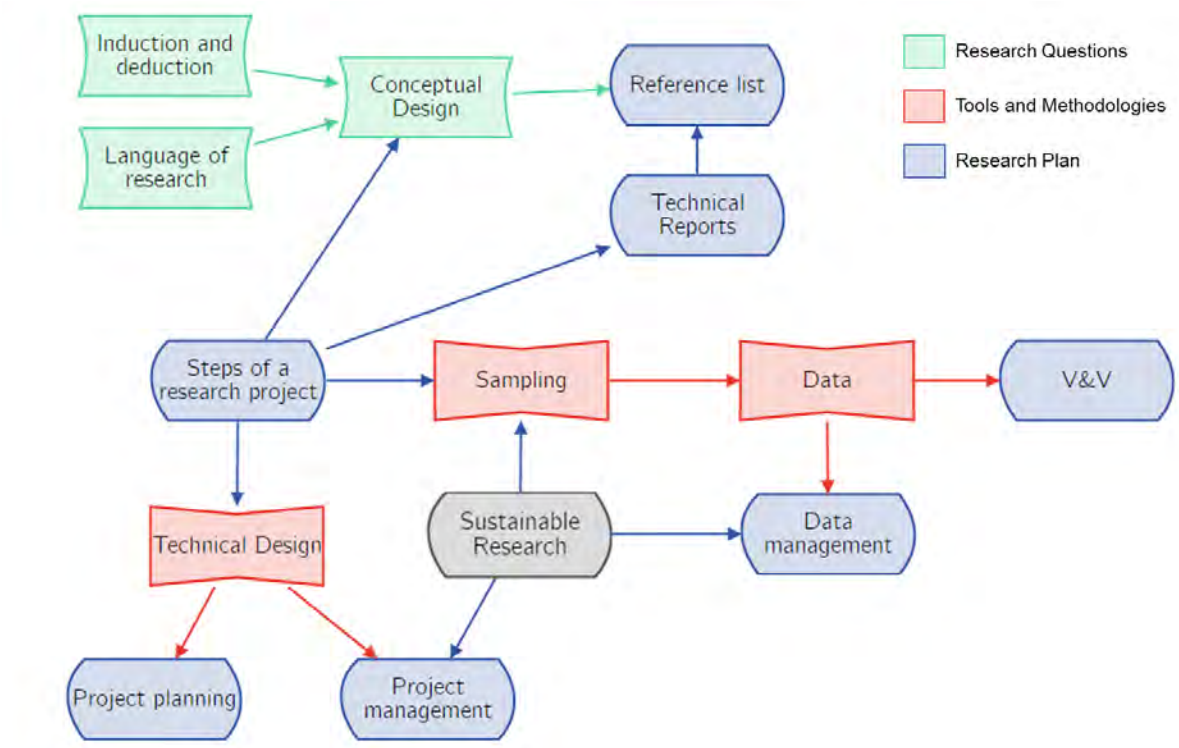

Figure 1. Overview of the Research Methodologies Course Content

own disciplines and consider the interconnections between technology, environment, and society. This corresponds directly to CDIO Standard 1 (Malmqvist, Edström, & Rosén, 2020), which stipulates that engineers must comprehend the implications of technology on social, economic, and environmental sustainability concerns in order to design acceptable technical solutions in conjunction with other actors.

The course's new sustainability module's materials encouraged students to think about the implications of their specific research's activities, bringing the often well-known but abstract and high level principles into concrete focus. Three things about research sustainability were included in the materials: the value of research, research resources management and the importance of reproducible research.

The first aspect, the **value of research**, emphasized that the first step to making research sustainable is choosing a relevant topic that has the potential to add value to the scientific community, the industry, and society. It is critical to ensure that the students can identify the potential for added value. Failing to do this can result in wasting time and resources on irrelevant findings. In order to accomplish this, they must investigate their chosen issue and be critical about the environmental, social, cultural, and/or economic implications of researching this gap.

The second aspect is the development of awareness of the **resources used** during the research project to help students make more environmentally conscious decisions. Resource management is related to research methods, but it focuses specifically on digital resources. Such resources include electricity, data storage, cloud computing, and other digital resources, which are increasingly utilized in modern research. Developing an understanding of the most

efficient ways to use digital resources is beneficial not only for creating a sustainable environment but also for students' future work. Given the broad nature of the research methods used in the faculty of aerospace engineering, the materials regarding the use of resources are still of a high level. A much higher focus and specificity needed to induce a concrete change in practice are left for future iterations of the module content.

The final aspect is conducting **reproducible research**. This is an important aspect of ensuring that any research work has future value because not only does reproducible research indicate transparency and rigor in the research, but it also allows for additional research exploring similar topics to be conducted using fewer resources (Alston & Rick, 2021). By conducting reproducible research, more efficient collaboration with supervisors, reviewers, and potential researchers who would like to conduct supplementary analyses is possible. The material focuses on sustainable data management practices as well as specific open science best practices. Formerly, such resources were not available in the aerospace engineering master's curriculum and supervisors provided ad-hoc feeback related to this issues.

Learning Materials

Since the course is completely self-paced and online, much attention was placed on the development of efficient learning materials for this module. This was done by ensuring a clear outline of the topics covered, providing detailed descriptions of each subject, and making use of interactive tools to engage students.

The course already used a mix between short videos, in-depth texts and interactive activities. As discussed by Wiger, Gillström, and Sallnäs (2022), video lectures have many advantages in modern education but they are accompanied by their own challenges and pitfalls. The advantages of using video is that students have the opportunity to repeat specific parts that were more difficult to understand. Wiger et al. (2022) discussed that being able to pause and rewind the videos reduced the stress for the students.

However, in an online course where there is no face-to-face interaction between instructor and student, a diversity of materials is necessary. For example, there is the concern that teaching only through videos won't work for all kinds of learners. Videos should include support activities for processing the content, avoiding one-way communication in which students process the videos without receiving feedback on their learning. To create a successful online learning environment, a thoughtful mix of available learning experiences must be designed.

Short videos were the first material to be developed. The content was split so that none of the videos were longer than 10 minutes. This ensured that each video discussed only one or two key concepts. For the lecturer, the advantage of using short videos is that it allows for faster rerecording. This also allows for an easier update of the course content. The videos always start and conclude with the key concept discussed and include an example from the faculty of aerospace engineering. Accessing the videos was mandatory to progress in the course content.

Then, **in-depth texts with questions** were developed. The text provided was composed of lecture notes produced by the instructor and fragments of textbooks relevant to the topic (e.g.:Pommerening (2021)). Moreover, to add an interactive element to the reading experience,

in this intervention, the in-depth texts were coupled with questions. The questions range from multiple-choice questions to open-ended answers. The questions were mainly used to facilitate the processing of key concepts. They were also thought to be valuable in sparking reflection and creating an online community among the students. FeedbackFruits was the tool used for this purpose. Although access to the text was required, answering the questions and responding to the discussion points were optional and anonymous.

The module was closed with a **self-assessment exercise**. Self-assessment exercises can help students assess their own progress and understanding of the course material. There were two main differences between the self-assessment and the questions asked in the texts. The first difference is that completing all questions of the self-assessment was mandatory to proceed with the rest of the course. The second difference was that the results of the self-assessment questions were not collected, and thus they can't be described in this paper. The self-assessments were short, relating each question to the key concept outlined in each video of the unit.

Finally, all the course material was complemented with an **open online forum**. Students used this tool more for course logistics than for content questions.

RESULTS

The intervention was implemented in the student cohort of the 22/23 year. Only the results of students who had already been assigned a grade were studied, as advised by the TU Delft's Human Research Ethics Committee [3]. This restricts the current evaluation to the students who submitted by the first deadline of the year, which is 64 out of the 463 enrolled students. There are two types of results discussed here: the engagement with the interactive material and the impact on the assessment.

Engagement with the interactive material

The engagement with the interactive materials was related to the in-depth texts described in the learning materials. Accessing this material was mandatory, but answering the questions was anonymous and voluntary. There were two ways the questions were asked: multiple-choice questions and open-ended answers.

Participation on open-ended questions was expected to be lower than that on multiple-choice questions. Therefore, the balance between both types of questions was set up to be 1 open-ended question per 5 multiple-choice questions, with a minimum of 1 open-ended question per text provided. In the current intervention, no question went unanswered. The lowest participation in a question was 6 students out of 64 (9.4%), while the largest participation was 33 students out of 64 (51.5%). Students either did not engage at all or engaged with at least three or more questions.

The multiple-choice format questions could be divided into two groups: questions to consolidate key concepts and questions to spark reflection. There was no significant difference in the

[3] https://www.tudelft.nl/en/about-tu-delft/strategy/integrity-policy/human-research-ethics

answer rate for the different types of questions. Some examples of this type of question are:

Content Consolidation Question: Is it always best to choose the least amount of resources? (Correct answer: No). Percentage correct answer: 87.5%.

Feedback given after answering: "You must strike a balance between the amount of resources used and the need to conduct valuable research. An optimal amount must be carefully considered. If you use fewer resources but your research is not valuable, then your research process is not as sustainable as it could be. If you use a larger number of resources than required for high-quality results, then your research is also not as sustainable as it could be."

Reflection Question: Had you ever considered your digital habits from a sustainability perspective? (No correct answer) Percentage Yes: 33.3%.

Feedback given after answering: "You might not have considered it, but there is a high chance your laptop is your most used resource during your research. Digital habits have a big impact on your research and should be considered as carefully as any other tool when drafting your research plan."

The purpose of the open-ended questions was different, since there were fewer of them and the participation was expected to decrease. In this case, there were also questions to spark reflection, but the primary objective was community building. Although all the responses were anonymous, they were assigned an alias so students could see their peers' answers and react to them either by liking the response or by directly answering it. Some examples of these questions are:

Reflection Question: Would you feel responsible if your research is used for (harmful) unintended purposes? (No correct answer) 10 answers out of 64 students (15.6% response rate)

Example student answers:
"Depends, if the technology is not by itself harmful, but it requires a choice made by someone else to be harmful, than that person would be responsible. If the technology can do harm on its own and then is used for bad stuff, then it's also my responsibility"
"Yes, to an extent. Ultimately, a lot of technology could be used for harmful purposes, and it is up to the scientific community to safeguard technology and limit the potential harmful implication"

Community Building Question: Do you have a particular system for this [organizing your own data] that you would like to share? (No correct answer) 6 answers out of 64 students (9.4% response rate)

Example student answers:
"I usually use a lot of nested folders, organized by topic and then (if needed) by date. All of this is contained in the names of the folders, and sometimes I add ReadMe.txt files. Then, I save the files themselves using no spaces or special characters to ensure compatibility with different programs in post processing"
"For my literature study, I have composed a list of sources which includes autor names, article/book titles, a short description, weblink if applicable and publication year. Each of these sources has been given a descriptive code e.g., PROP-01 or COST-04, and several have been

saved to to my drive under their respective codes."

Impact in the assessment

Another important metric for the intervention was whether students included sustainability concerns in their research project plans. This was not explicitly included in the rubric used for assessment. However, the project plan template suggested that there were three places where concerns about sustainability could be addressed: in the introduction section, in the section on methodology and set-up, and in the section on expected results.

In the introduction section, students are expected to discuss the relevance and value of their research. This is related to the first aspect described to them in the theoretical content of the sustainability module: the value of research. It was analyzed if students included environmental or societal concerns as drivers in the values of their research and if they explored the intended and unintended consequences of their research. From the student cohort studied, only 27% explicitly included sustainability notions related to the value of research in the project plan. However, a large number of research plans did include the expected impact of their research. There was a lack of interdisciplinary approach to their description; most of them failed to see the interconnections between different stakeholders, and they mostly presented the relevance from their field's perspective.

In the methodology and setup section, students are expected to discuss the methods and tools specifically used to perform their research. This is related to the second aspect described to them in the theoretical content of the sustainability module: resources. It was analyzed if students included environmental or societal concerns as drivers in their choice of methods and set-up. Surprisingly, the percentage of students who included sustainable methods and setup in their reports is remarkably low: only 6% explicitly addressed it. A possible explanation for this is that students prioritized describing accurately the methods and set-up and did not think it relevant to discuss the sustainability considerations. Furthermore, the majority of research plans were focused on the technical aspects and lacked discussion of how their methods and practices would impact society.

In the results section, students are expected to anticipate the potential results of their research and their desired outcomes. The verification and validation of their results, as well as the data management practices, must be defined. This is related to the second aspect described to them in the theoretical content of the sustainability module: reproducible research. It was analyzed if students included sustainable data management practices in their results discussions. Sustainable data management practices were included in 34% of the students' project plans. This was also surprising because students had not yet encountered this aspect of sustainability in their studies. The higher percentage can be attributed to the content's inclusion of practical examples and test cases.

Finally, 28% of students mentioned at least one criteria, 8% mentioned two, and 3% mentioned all three. The majority of the course 55% did not mention explicitly any of the key sustainability criteria.

DISCUSSION AND FUTURE WORK

In the final feedback form, students showed a positive response to the new sustainability module. A majority found the new videos and in-depth texts with questions to be useful. The results of the interactive section showed a moderate level of engagement, especially considering the interactive activities were voluntary. This indicates that the module was successful in capturing the students' attention towards the material. In the next iteration of the course, participation in at least one question of the module will be mandatory in order to proceed with the course. It is expected that this will raise the engagement of the students with the course content.

Unfortunately, the assessment analysis revealed that only a minority of students discussed their research projects through a sustainable lens. Only projects that take part in one of the sustainability initiatives thoroughly discuss sustainable development in their research plans. This shows that, even though the interactive module told students how important sustainability is in research, it wasn't enough to make a lasting impression on most of them because they didn't fully engage with the idea.

These findings are thought to be the result of the grading rubric's lack of explicit sustainability criteria. Because the grading rubric did not specify how sustainability should be evaluated, students had no incentive to incorporate sustainable thinking into their projects, even if they were aware of its importance. As a result, when it came time to evaluate the research plans, instructors couldn't accurately measure how much thought had gone into sustainable development and couldn't provide feedback that encouraged further sustainability considerations. Therefore, the work in the next iteration of the sustainability module would be to include it directly in the rubrics of the assessment.

CONCLUSIONS

The integration of a sustainability learning module into the online course Research Methodologies at Delft University of Technology has shown promising results in promoting socially conscious research in engineering among their master's students. The use of the Engineering for One Planet framework helped students view their research projects through a sustainability lens in three specific aspects: the value of their research, their research resources and the reproducibility of their results.

The responses of the students to the online discussion questions and their final research plans showed an improved understanding of the importance of conducting sustainable research. This study highlights the limitations on the effectiveness of the integration of the sustainability learning module and serves as a valuable example for other universities looking to promote technological innovation with a concern for society and research. This intervention helps the Faculty of Aerospace Engineering at Delft University of Technology reach its goal of making sustainability a central part of all educational programs, even if more improvements to the module still need to be performed.

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