IMPLEMENTING AI ETHICS EDUCATION: ENGINEERING COMPETENCIES FOR SUSTAINABLE SOCIETAL IMPACT

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ABSTRACT

The societal impact of engineering practices demands a profound sense of responsibility among engineers to tackle global challenges, yet necessary skills related to ethics, sustainability, and teamwork remain generally weak among engineering professionals. An interdisciplinary course can act as a springboard for integrating transferable skills and knowledge recommended by CDIO into engineering education. A master's seminar at RWTH Aachen University is training engineering students on ethics, responsibility, and sustainability in the context of Artificial Intelligence (AI), topics which are requisite for engineers to understand societal needs and their active role in society. Through active and integrated learning, this course provides students with a holistic view of technology embedded within the diverse societal contexts. While evaluating students' anonymized reflection papers using Qualitative Content Analysis (QCA), we found that many students appreciated the unique seminar structure, and the seminar topics. We speculate that interest in the course and creative freedom, among other factors, may have fostered deeper engagement and plans for lifelong learning. Many students considered this course an "eye opener" since it introduces them to interdisciplinary and holistic thinking. This paper presents the course structure, methodology, and findings from a QCA of students' reflections to approach the following research question: *What competencies from CDIO Syllabus 3.0 can be acquired in an interdisciplinary course for engineers such as this seminar on AI ethics, and how?* We also discuss planned improvements based on student feedback, which adds to the discourse on how to best implement an interdisciplinary course that accomplishes several CDIO Syllabus objectives and Standards.

KEYWORDS

AI, Ethics, Engineering, Sustainability, Competencies, Standards: 1, 2, 6, 7, 8, 11, 12, Optional Standard 1

INTRODUCTION

Industry 4.0, accelerated by and largely composed of AI, demands a shift in engineering education (Bühler et al., 2022), as does Industry 5.0's focus on a human-centered approach including socially sustainable technology (Renda et al., 2021). However, competencies related to ethics, sustainability, responsibility, and teamwork remain generally weak among engineering professionals (Kovacs et al., 2023), even though they are requisite for engineers to understand societal needs (Kenyon, 2023) and their active role in society (Kjelsberg & Kahrs, 2023).

A master's seminar at RWTH Aachen University called *Innovation & Diversity* (I&D) is now training engineering students on ethics, responsibility, and sustainability in the context of AI (see also Decker et al., forthcoming). In self-organized groups, students complete a project-based portfolio examination, which has been recommended for integrating ethical themes (Angelva et al., 2023), professional and sustainability competencies, and being highly motivating for students (Hansen & Sindre, 2023; Pettersen & Lundqvist, 2023). Through active and integrated learning, this course provides students with a holistic view of technology embedded within the diverse societal contexts which are often largely overlooked in engineering education (Cañavate et al., 2015). This interdisciplinary course on AI ethics shall therefore serve as a springboard for integrating these and numerous other transferable skills and knowledge recommended by CDIO (Crawley, et al., 2011; Malmqvist et al., 2022), such as reasoning, problem solving, holistic thinking, communication, digital literacy, balancing competing objectives, and the impact of engineering on society.

Thus, this paper presents the course structure, methodology, and findings from a Qualitative Content Analysis (QCA) of students' reflections to approach the following research question (RQ): *What competencies from CDIO Syllabus 3.0 can be acquired in an interdisciplinary course for engineers such as this seminar on AI ethics, and how?*

Related Work

Engineers have long been recognized as shapers of societal progress, designing the world we inhabit (Winner, 1980) and tackling global challenges (Yortsos, 2021). However, this influence brings with it a profound responsibility to instill the right values, necessitating a focus on ethical considerations (Sunderland, 2019; de Vries, 2022). The growing awareness of the societal impact of engineering practices has led to the widespread acknowledgment of the need for engineering ethics to serve as a compass for engineers, guiding them towards decisions that consider the broader implications of their work on individuals and communities (Bosen et al., 2023; Decker et al., 2021; Decker et al., 2022).

In recent years, artificial intelligence (AI) has become an integral part of our daily lives, exerting a substantial influence, both visible and invisible, on thousands of people. The use of AI technologies, however, has raised ethical concerns, with instances of problematic consequences (Barocas et al., 2022; Barocas & Selbst, 2016). This underscores the critical need for ethical considerations during the development and deployment of AI technologies in all stages of development and deployment. This influence extends to the engineering profession, where AI is increasingly employed to enhance efficiency and capabilities. As AI becomes intertwined with engineering practices, the intersection of AI, ethics, and engineering emerges as a critical focal point (Decker et al., forthcoming).

Higher education institutions play a crucial role in shaping the ethical foundations of future professionals, and this is particularly relevant in engineering education (Mitchell, 2023). Criticism has been directed towards the predominantly technical focus of engineering study programs, suggesting that students may lack the necessary skills to navigate morally opaque situations (Devon, 1999; Pierrakos et al., 2019). However, many engineering education accreditation criteria remain vague about how to implement ethical engineering courses (Saltz et al., 2019). While engineering ethics often focuses on codes of conduct and practical case studies, a deficiency exists in incorporating ethical theories into the curriculum (Bouville, 2008). Pierrakos et al. (2019) propose a broad perspective, stating that ethics should inform not only rare, extreme decisions but also guide engineers in their daily problem-solving, interactions with colleagues and clients, and relationships with various stakeholders in the community. Studies have consistently demonstrated the positive impact of introducing ethics early in the education of engineering students. The earlier students engage with ethical considerations, the better equipped they are to incorporate ethical considerations into their professional practice. Moreover, research suggests that ethics is most effectively taught when considerations are interwoven into every course throughout the curriculum, fostering a holistic approach to ethical decision-making (Mitchell et al., 2021; Pierrakos et al., 2019).

The Innovation & Diversity Seminar

As part of the research group Gender and Diversity in Engineering (GDI) at RWTH Aachen University, we developed an elective master's seminar called *Innovation & Diversity* (I&D) with a focus on ethical AI in (civil and environmental) engineering (see also Decker et al., forthcoming). The GDI is led by a bridging professorship between the humanities and engineering and, thus, anchored at two different faculties. This focus on interdisciplinarity brings together students from different disciplines. Therefore, the seminar is attended by students from civil engineering, environmental engineering, business administration and engineering, sustainable management of water and energy, construction and robotics, sociology, communication studies, and the bachelor program for linguistics and communication studies. The interdisciplinarity of the I&D seminar is offered by this mix of students from different disciplines as well as the interdisciplinary nature of the topic of AI ethics in engineering; it necessarily involves topics from sociology, ethics, data science, and engineering, bringing with it novel educational experiences. In the inaugural semester in Winter 2022-2023, 20 students attended the seminar.

The course introduces students to basic technical aspects of AI as well as societal impacts in the context of AI as an innovative technology. The seminar does not instruct students on developing the algorithms themselves but should allow them to understand how they operate, be able to work with them, and critically reflect on them in the future. The seminar begins with a brief introduction on the basics of AI so that students have a high-level understanding of the design, development, and implementation of AI. Societal impacts of AI are then introduced, comprising discussions on justice, responsibility, diversity, and sustainability. Ethical guidelines for AI were compiled and adapted into a checklist meant as a starting point to aid students in their ethical evaluations of real-world AI applications. Ethical checklists are likely popular in policy and industry due to the ease of legal compliance that they enable. Although checklists may also overgeneralize ethical applications and may lead to complacency, we nevertheless chose to work with a checklist, as many others do, since they provide an easy way to remember broad principles and make ethics more approachable, while still encouraging creative thinking. Our list consists of the FAST (Fairness, Accountability, Sustainability, Transparency; Leslie, 2019) and FACT (Fairness, Accuracy, Confidentiality, Transparency) ethical principles for AI. Additional guided reading tasks extend students' knowledge and delve deeper into technical and ethical aspects of AI and real applications of AI in engineering. As per students' request, we also offer a supplementary session on scientific writing and citation.

Finally, a portfolio examination mainly composed of groupwork tasks put the students in charge of the direction of their learning as they critically reflect on the use of AI in engineering using the examples that they discover in their own independent literature research. The portfolio examination consists of four different examination tasks (ETs). Groups of 4-5 students work together on the first three tasks, each task building upon the previous one. The first task (ET1) has groups select an example of AI in engineering in which the AI has degenerative effects on human lives and answer a set of questions about this example. The second task (ET2) instructs each group to jointly write a 10-15-page paper introducing and evaluating their chosen example. One week before the submission deadline of ET2, a mediated, online peer feedback session allows students to meet with representatives from other groups to discuss their work so far and exchange feedback. For the third task (ET3) groups design scientific posters that present the findings from their paper and 90-second videos that present possible solutions or recommendations for action in response to the ethical risks or issues discovered. On the penultimate session of the seminar, groups take turns presenting their work in a mock conference. Finally, after the presentations of ET3, the last task (ET4) asks students to individually write reflection papers of 1-2 pages answering the following three open-ended questions: What was most interesting in the course? What was most surprising? What are your takeaways?

METHODS

Due to the open-ended nature of ET4, students provided insights that went beyond the three questions that were presented to them when prompted to complete the ET. Furthermore, students self-reported their acquired competencies, among other things, which inspired new and more precise themes to be analyzed. We thus realized the wealth of valuable information that the reflections provided and became interested in further exploring students' self-reported positions on the topics of the course and on the course itself (see also Decker et al., forthcoming) as well as the competencies successfully acquired during the seminar. Hence, this paper conducts an exploratory thematic analysis of students' ET4 reflection papers with respect to the RQ.

All twenty ungraded reflection papers of ET4 form the basis of our post-hoc qualitative data analysis, although it should be noted that one reflection paper was of low-quality as it was very short, superficial, and did not provide much valuable insight. Since students were allowed to answer in an unstructured format, we found a complex overlapping of categories, which lends itself to Kuckartz's QCA (2019) to discover and compare these themes while supporting an exploratory style of analysis. Before beginning our analysis, we cyclically defined categories for and coded our students' anonymized reflection papers in accordance with Kuckartz's (2014, 2019; Kuckartz & Rädiker, 2019) methodology and using MAXQDA qualitative data analysis software. This was done in three cycles: (1) a concept-driven (deductive) cycle to develop a first draft of our main categories, (2) a second data-driven (inductive) cycle to refine our list of main categories via open-coding and finish coding all segments for main categories, and (3) a final inductive cycle to derive and code for subcategories.

Based on our research questions and the ET4 writing prompt, the first cycle consisted of deductively compiling an initial list of 13 main categories while individually coding 5 of the 20 papers. The segment length was not limited; we agreed that a coded segment should include what was necessary to view it out of context and still understand the student's argument as well as why it fit in the assigned category. During this first cycle, we also inductively discovered other categories, merged, and renamed categories with significant overlap. We reviewed and edited the coding of the initial 5 papers before continuing with the next 5 papers. Subsequently, we compared our coded segments for all main categories to finalize our coding rules before coding the rest of the 20 papers and resolving any coding disagreements, thus concluding the second cycle. This "consensual coding" strategy (Kuckartz, 2014, p. 46) was preferred over intercoder reliability coefficients for its simplicity in qualitative text analysis and full agreement at the end of coding. The final eleven main categories were thus identified: *Course Structure and Methods*, *Expectations Before the Seminar*, *Interest in the Seminar Topics*, *Value-Neutrality of Technology*, *Relevance of AI Ethics (to a Future Engineer)*, *Applications of AI in Engineering*, *Previous Experience with AI*, *Previous Experience with Ethics*, *Surprising*, *Misunderstandings*, and *Challenges*. In the third cycle, we inductively derived possible subcategories for each main category by reviewing all the coded segments of a single main category and combined subcategories where possible before assigning each main category segment to one or more of its subcategories. Four of the final eleven main categories are relevant to this paper and are listed in Table 1 along with the relevant subcategories. Categories remained non-exclusive in the sense that some excerpts may belong to multiple overlapping categories. This non-exclusive categorization allowed us to analyze segments from various angles.

Table 1. Relevant Categories and Subcategories for Thematic Analysis in This Paper
(* indicates subcategories used in the QCA that do not have their own dedicated sections.)

Main Categories (# Coded Segments, # Students Out Of 20)	Subcategories (# Coded Segments, # Students Out Of 20)
Surprising (37, 19)	Need for Interdisciplinarity in Technical Fields (8, 7)
Course Structure and Methods (109, 19)	Course Organization and Examination Structure (28, 11) *
	Topics and Tools (31, 14)
	Class Activities and Examples (6, 4) *
	Assignments (22, 12)
	Groupwork (21, 12)
	Improved Skills (10, 6)
	Creative Freedom (4, 3)
	Overall Evaluation / Compliments (21, 9) *
	Constructive Criticism / Suggestions (14, 5) *
Challenges (22, 13)	Applying Ethical Principles (5, 5)
	Finding Relevant Literature and Choosing an Appropriate Topic (9, 9) *
	Challenging Groupwork (8, 6) *
Misunderstandings (13, 10)	N/A

Keywords and phrases for the *Surprising* category included “surprising,” “could not believe,” or “did not expect.” Statements in this category refer to unexpected discoveries. From the “surprising” main category, we derived six subcategories. Segments in the subcategory, *Need for Interdisciplinarity in Technical Fields*, discuss the desire or need for combining technical fields with non-technical fields such as ethics, sociology, and human–technology interaction in education and in the workforce. This could be described, for example, as a need for engineers to understand diversity or how AI affects humans.

The *Course Structure and Methods* category includes comments regarding course assignments, the portfolio examination style, group work, in-class tasks or interactions, and a partial evaluation of any of these elements or overall evaluation of the seminar. This large main category was subdivided into nine non-exclusive subcategories. *Course Organization and Examination Structure* includes but is not limited to mentions of peer feedback sessions, other structured opportunities to provide feedback, lecturer content delivery, group formation, the supplemental lecture on citations and writing, sharing group presentations on the last day, and the portfolio examination structure. In this case, discussion of the portfolio examination should be specifically related to the division of the examination into several ETs, not related to the task contents, timing, or workload (which will be captured in other subcategories). The *Topics and Tools* excerpts discuss seminar topics covered—especially the relevance or importance of topics to AI, engineering, or students—and tools we provided to students such as the FAST (Fairness, Accountability, Sustainability, Transparency; Leslie, 2019) and FACT (Fairness, Accuracy, Confidentiality, Transparency) ethical principles and checklist. *Class Activities and Examples* refer to any specific examples or interactive activities that were presented during the seminar. Of particular interest are examples and class activities that made an impression on a student and helped them understand key seminar concepts. The *Assignments* subcategory covers optional reading task and compulsory ET content, including independent research, reading and writing academic papers, creating a scientific poster, and students' own presentations. When students discuss working in a group, such as the group dynamics, challenges, and successes, this belongs in the *Groupwork* subcategory. Again, ET content and portfolio examination structure belong to other subcategories. Mentions of both ET content or structure and groupwork in the same segment would result in non-exclusive assignment to both subcategories ("assignments" and "groupwork"). Many students reflected on their *Improved Skills*, such as critical thinking, analytical and interpersonal skills, digital tool literacy, and academic literature research skills. Moreover, some of the interpersonal and professional skills include compromise, communication, groupwork, and time management. The keywords for the subcategory *Creative Freedom* are "creative," "creativity," and "freedom." Although not originally defined, these keywords referring to the creative freedom allowed by the ETs reoccurred in several students' reflection papers such that we decided it was important enough to have its own sub-category. It seemed a significant and unique experience for many students. Broader excerpts related to *Overall Evaluation / Compliments* have a positive or neutral evaluative valence. Optional keywords include "overall," "liked," "special." More importantly, the text must refer to a positive or neutral evaluation of the seminar overall or a positive evaluation (compliment) of a specific aspect of the seminar. Lastly, *Constructive Criticism / Suggestions* refer to aspects of the seminar that some students did not like and/or suggestions they had for improvement of the seminar in future semesters. This is an exciting sub-category that will help us make the appropriate adjustments before the next semester.

The *Challenges* category comprises of any difficulties students had during the course, including but not limited to challenges regarding group work, researching AI applications in engineering, and applying ethical principles. Keywords for this category were, for example, "challenging" or "difficult." This main category was further subdivided into four subcategories with only one instance of overlapping assignment; they are otherwise mutually exclusive. The subcategory, *Applying Ethical Principles*, includes segments discussing the difficulty students encountered while attempting to evaluate real applications of AI in engineering for the ethical principles learned in class. *Finding Relevant Literature and Choosing an Appropriate Topic* covers statements describing the difficulty in attempting academic literature research for the first time, finding academic literature relevant to the seminar in that it sufficiently describes an application of AI in engineering, and selecting an appropriate application area or example to work through in group assignments for the rest of the seminar. Segments that belong to the *Challenging Groupwork* subcategory always also belong to the "groupwork" subcategory of "course methods and structures," but not necessarily the other way around. These segments refer to challenges encountered during groupwork, such as challenges regarding selecting group members, scheduling meetings that all group members can attend, equally dividing groupwork, communicating with group members, making compromises in groupwork, and understanding the requirements of group assignments when group members had different interpretations of the instructions.

Misunderstandings became a category when we encountered instances of students making claims that were incorrect or showed a fundamental misunderstanding of the seminar content. These are highlighted as a main category to investigate any common misunderstandings among students so that these can be more carefully explained in future semesters.

In this paper, we mainly analyse the main categories Course Structure and Methods, Challenges, and Misunderstandings as we are interested in *how* a course such as I&D can teach sustainability and other competencies from the CDIO Syllabus. We refer to future work (Decker et al., forthcoming) for analysis of the other categories.

RESULTS AND DISCUSSION

In this section we present the results of our analysis of students' anonymized reflection papers with respect to the competencies that can be learned from a course such as the seminar presented in this paper, as well as how they can be achieved. We are particularly interested in the competencies that can transfer from this interdisciplinary course to other courses or professional activities with a focus on different topics. We first discuss how several competencies from the (proposed) CDIO Syllabus 3.0 (Malmqvist et al., 2022) can be achieved. Then, we combine our findings from the Challenges and Misunderstandings main categories to discuss some difficulties in realizing the intended competencies. Finally, compliance with CDIO Standards 3.0 (Malmqvist et al., 2020a, 2020b) is examined.

To differentiate between students' reflections regardless of anonymization, we will refer to individual papers by a number randomly assigned between 1 and 20 for the 20 papers received. Thus, every quote will be followed by a number between 1 and 20 and a page number indicating on which page of the reflection paper the segment was found. This permits the assignment of different segments to the same student's opinion.

RQ: What competencies from CDIO Syllabus 3.0 can be acquired in an interdisciplinary course for engineers such as this seminar on AI ethics, and how?

Our research question specifically focuses on the competencies that can be learned from a course such as the I&D seminar. Hence, we present the prescriptions of the (proposed) CDIO Syllabus 3.0 (Table 2; Malmqvist et al., 2022) below. This framework forms a basis of our understanding of valuable competencies for engineering students as we perform our analysis with respect to it. We mainly discuss the RQ with respect to the competencies (up to the second level of detail: X.X) prescribed in sections 2 and 3 of the proposed CDIO Syllabus 3.0, but we also examine 1.4, 4.1, 5.1, and 5.3. For brevity in the analysis below, we will refer to competency sections from the proposed CDIO Syllabus 3.0 as SX.X (e.g., S1.4). See Table 2 for a concise overview of I&D's compliance with the entire proposed CDIO Syllabus 3.0.

Surprising: Need for Interdisciplinarity in Technical Fields

Oftentimes students are only aware of "ethics playing an important part of machines and AI in [movies] and TV shows with extreme cases, for example, 'I, Robot' and 'Black Mirror' but it never occurred to [one student] that Ethics could be applied to other sectors, least of all to construction [in civil engineering]," (2, p. 1; S2.3, S2.5, S4.1). While attending the course, students realized that "discrimination in AI is more common than previously thought and its connection to diversity is equally surprising," (4, p. 1). One student reflected after the course, "Initially, I had a narrow understanding of ethics and mostly thought of data privacy and safety when thinking about ethics. However, throughout the course and through group discussions, I learned that there are many more aspects to consider, such as accountability, transparency, and social impact," (S1.4, S2.1, S2.3) and was also "surprised by the relevance of the ethics for the innovation process," (5, p. 1-2). Another student reflected, "As an engineer, I was always considering the technical aspect of it. Nevertheless, I got to know that the social aspect is significantly important, and it could be a key element in deciding whether AI should be implemented or not," (6, p. 1; S2.4, S2.5, S4.1). Without interdisciplinary content covering knowledge from social sciences and humanities (S1.4), students in technical fields would be unlikely to understand the connection between social and technical aspects. In fact, as our students have explained, they would be unlikely to have ever been exposed to ideas such as societal impact and accountability in their purely technical courses. These quotations show that during this interdisciplinary seminar, our students were able to grasp the importance and interconnectedness of ethics, societal impact, and (engineering) technology, enabling sustainable development within societal and environmental contexts.

Table 2. (Proposed) CDIO Syllabus 3.0 At the Second Level of Detail (Malmqvist et al., 2022). (+ = largely covered; ~ = partially covered; – = out of scope)

(Proposed) CDIO Syllabus 3.0	Fulfilled by I&D
1. Fundamental Knowledge and Reasoning	
1.1 Knowledge of Underlying Mathematics and Science	–
1.2 Core Engineering Fundamental Knowledge	~
1.3 Advanced Engineering Fundamental Knowledge, Methods, and Tools	~
1.4 Knowledge of Social Sciences and Humanities	+
2. Personal and Professional Skills and Attributes	
2.1 Analytic Reasoning and Problem Solving	+
2.2 Experimentation, Investigation, and Knowledge Discovery	~
2.3 System Thinking	+
2.4 Attitudes, Thought, and Learning	+
2.5 Ethics, Equity, and Other Responsibilities	+
3. Interpersonal Skills: Collaboration, Teamwork, and Communication	
3.1 Teamwork and Collaboration	+
3.2 Communications	+
3.3 Communications in Foreign Languages	+
4. Conceiving, Designing, Implementing, and Operating Systems in the Enterprise, Societal, and Environmental Context – The Innovation Process	
4.1 Societal and Environmental Context	+
4.2 Enterprise and Business Context	–
4.3 Conceiving, System Engineering, and Management	~
4.4 Designing	~
4.5 Implementing	~
4.6 Operating	~
5. The Expanded CDIO Syllabus: Leadership, Entrepreneurship, and Research	
5.1 Leading Engineering Endeavors	~
5.2 Engineering Entrepreneurship	–
5.3 Research	+

Course Structure and Methods: Topics and Tools

Most students appreciated the introductory lectures. Students learned that "diversity is not a simple word, it is indeed complex and it has different concepts," (6, p. 1). As another student articulated, "topics discussed in the lecture broadened my horizon and understanding on fairness, discrimination, and diversity… Understanding and especially defining diversity is an important foundation in order to actually consider and respect the diversity of societies while making use of AI," (10, p. 1) or other engineering innovations (S1.4, S2.3, S2.5, S4.1). During one class, students were asked to fill out a paper asking them to which diversity dimensions they felt that they belong. One student stated that "the dimension paper that [they] filled out… showed new facets to the topic of diversity [that they] previously didn't pay attention to and helped understanding the term diversity and its importance in the context of AI-models… while showing simultaneously the challenges that arise when trying to measure diversity objectively," (4, p. 1; S1.4, 2.4, 2.5, 4.1). Another explained that the course "[emphasized] the importance of staying updated and informed about the advancements in [engineering innovations such as] AI technology, as well as being aware of the ethical and social implications of its use," (18, p. 1). This shows that at least some students learned the value of keeping oneself up to date with ethical discourse and engineering advancements (S2.4, S2.5, S4.1). Overall, students lauded the introductory lectures, which provided necessary background knowledge on AI as well as relevant sociological and ethical topics, enabling a holistic understanding of engineering systems embedded within societal and environmental contexts.

Course Structure and Methods: Assignments

The assignments given in the various ETs provided students with opportunities to complete new types of tasks, such as writing an academic paper for the first time and "helped the students develop knowledge about different ways of presenting results," (10, p.1; S3.2). One student commented, "it was interesting to choose an example [use case] by ourselves," (14, p. 2) while another elaborated, "I liked that we had a concrete practical example, in which we had to consider the possible negative ethical aspects of AI devices, but also possible solutions on how to ensure that AI systems are implemented in a way that maximizes the benefits for the society, while minimizing their negative impacts," (19, p. 2; S2.1, S2.3, S2.4, S5.1). It seems that it is unusual for students to be offered a chance to select the subject of their studies within the context of a course. Through the ETs, students also gained awareness about current AI applications, the complexity of ethically evaluating AI, and the possible negative effects of using AI (S2.5). Especially during ET3 presentations, students gained "an insight into relevant fields where the application of AI is becoming an integral part of it," (7, p. 2). By being present for other groups' presentations, students were able to learn about other AI applications in engineering they had not researched as well as observe different styles of presentation. Many students commented that they particularly appreciated seeing other groups' presentations near the end of the course. Thus, students gained exposure to different AI applications in engineering, awareness of AI's complex and at times negative effects (S2.5), researched a practical use case (S2.2, S5.3), and practiced presenting their results or reflections in various ways: via academic paper, scientific poster, video crafted using digital tools, oral presentation, and reflection paper (S3.2).

Course Structure and Methods: Groupwork

Many found groupwork to be challenging, but as will be discussed, it was worthwhile for the relevant professional and future skills learned that will be directly applicable to future teamwork. Several students expressed that it was their first time engaging in groupwork in university and that they felt inexperienced when it came to working as a team though having a course with groupwork was “refreshing,” (11, p.1). Many also enjoyed that they were able to organize themselves into diverse groups of students from different social backgrounds since this led to more diverse ideas and discussions (S3.1). One student explained, “the diversity of our team allowed for a wide range of ideas and perspectives to be considered, which ultimately led to a final product that we all were happy with. Despite some disagreements, we were able to work with each other. This most likely also helped us prepare for the workplace, where things won't always go as planned,” (14, p. 3). Although some found groupwork to be challenging due to difficulties coordinating meeting times and dividing tasks (S2.4, S3.2), some likewise explicitly stated that they thought that the groupwork required in this seminar might help them in the future. For example, one student wrote, “I also appreciated the opportunity to work in such a diverse group during the course. Our group consisted of people with different backgrounds and perspectives, which led to stimulating discussions and a more comprehensive understanding of the material [S3.1] … As a contrast from the other courses when I had to write exams or other essays on my own, I found the group work to be quite helpful. I was able to pick up soft skills that will benefit me in both my future academic and professional activities,” (8, pp. 2-3). Another student further reflected that “the group work was as challenging as it was enriching,” (10, p.1). Incorporating groupwork into the ETs therefore enabled students to develop their interpersonal collaboration skills (S3) as well as personal skills such as time management, organization, and task prioritization (S2.4). This will undoubtedly be helpful in future work.

Course Structure and Methods: Improved Skills

Five students specifically referenced groupwork as the source of their improved personal and interpersonal skills including communication, presentation, conflict resolution, time and task management, as well as digital literacy (S3.2). Other than the skills improved during groupwork, one student explicitly stated, “the course helped me develop my critical thinking skills,” (8, p. 2) necessary for ethical evaluation and subsequent solution generation in ET2 and ET3 (S2.3, S2.4, S5.1). Additionally, since the seminar was conducted in a university in Germany, English was a foreign language for most students, and this course allowed them to practice speaking, reading, and presenting in an academically appropriate level of English. Even communication within some groups was conducted in English due to diverse backgrounds (S3.3). At least two students clearly expressed that they saw a great improvement in their ability to research, read, and comprehend scientific literature (S2.2, S5.3). One student commented, “from the perspective of analysing skills, like reading scientific papers and writing an essay, I would say that this course has helped me a lot to improve for the future. It displayed my weakness regarding reading scientific papers (this was really exhausting) and lacking ability to find appropriate wording in the essay,” (11, p. 1) while another shared, “the individual research for appropriate articles was one of the most interesting but also most challenging aspects of the course [S2.2, S5.3]. I could develop my research abilities here. I gained knowledge on how to read articles more quickly and effortlessly, as well as how to find relevant papers. Along with finding relevant papers, I learned how to work with scientific literature. By the end, I was able to comprehend texts that were difficult to understand,” (8, p. 2). In addition to the fact that the students requested a supplemental session on scientific writing and citation, it has become clear to us that during this seminar, many of the students may have learned to conduct scientific research, write academically or professionally, and cite sources for the first time (S2.2, S3.2, S5.3). Regardless of whether they will go on to an academic career, it is nevertheless important to know how to conduct research, write professionally, and to demonstrate scientific integrity by citing sources.

Course Structure and Methods: Creative Freedom

There were only four segments coded for creative freedom. Nevertheless, it stood out to us as a unique category worthy of investigation since it was an unexpected, recurrent theme among students' reflections. Furthermore, the three students who wrote about the creative freedom afforded by the ETs explained that this was unique to this seminar, and that they had not had a similar opportunity in their other courses. One student wrote, "I highly appreciate the creative freedom that we had for every examination task, from choosing our group work topic to structuring the essay… this creative freedom made this course special to me in terms of a learning experience," (3, p. 2). While these students agreed that they appreciated the creative freedom, two of them felt uncertain about what was being asked of them in the ETs and how they would be graded. Nonetheless, we maintain that creative freedom, wherever possible, allows students to explore more possibilities and adapt the assignments more to their own interests (S2.4). It provides a unique learning experience and opportunity. Furthermore, creative thinking is a skill rarely offered the chance to flourish in engineering programs. We speculate that interest in the course and creative freedom, among other factors, may have fostered deeper engagement and plans for lifelong learning.

Challenges and Misunderstandings

Through the QCA of students' reflections, we discovered a few persistent challenges and misunderstandings that made it difficult for some students to develop the intended competencies. For example, one student expressed uncertainty as to "whether [they] should mostly concentrate on engineering itself or on ethics," (9, p. 2) when asked to ethically evaluate an example of AI in engineering, which unfortunately shows that some engineering students may be confused when faced with an interdisciplinary problem. With more exposure to interdisciplinary problems and courses, this apparent incongruence between technical and non-technical subjects should fade, replaced by interdisciplinary understanding (Wächter, 2011). Moreover, several students found applying the ethical principles to a real use case to be more difficult than initially expected. A student explained that "at first glance, the explanations [of the FAST and FACT ethical principles] seemed logical and simple. However, if you look more closely at the principles - which [they] did in Examination Task 2 - the consideration and especially the application to a particular case was more complex and difficult than expected," (12, p. 1). Meanwhile, two students misunderstood what the motivation for ethical AI should be. One of them explained that "the reality is that for technologies to be applied, the first predisposition is that they are profitable and that those responsible for their introduction are convinced of their benefits," (5, p. 2). While financial goals are often prioritized in industry, this is not the competency we tried to instill. It is important to be able to differentiate between business objectives and ethical ones in order to adequately balance the often-competing objectives. Some other concepts were at times also misunderstood by some students (e.g., the responsibility gap). Therefore, some students continued to struggle to understand the ethical concepts themselves and their interconnectedness with engineering topics, as well as how to apply this knowledge once it had been attained. We will take care to explain these difficult concepts more clearly in the future; however, some concepts are simply difficult to grasp when only introduced in one lecture. Many others agree (see Abate, 2011; Hess & Fore, 2018; Newberry, 2004) that students would benefit greatly from more interdisciplinary or multidisciplinary programs as opposed to a single elective, interdisciplinary course.

CDIO Standards 3.0

While the CDIO Standards (Malmqvist et al., 2020a, 2020b) are meant to guide the implementation of an entire engineering program, we use them to evaluate the accordance of a single seminar (I&D) to the CDIO mission and its potential to act as an initial course introduced into an engineering program. Our hope is that our seminar would be followed by other courses that similarly meet these Standards as well as the Standards not covered by this seminar. Below, we demonstrate how the I&D seminar incorporates Standards 1, 2, 6, 7, 8, 11, 12, and Optional Standard 1.

According to the CDIO, engineers must be able to participate in each stage of the sustainable lifecycle of a product or service. They must be able to *conceive* of the customer and societal needs, *design* a solution to address this need, *implement* the design, and maintain the product or service during *operation*. Throughout the lifecycle, engineers must "understand the implications of technology on social, economic and environmental sustainability factors," (Malmqvist et al., 2020a, p. 63). This (Standard 1: The Context) is precisely the mentality and awareness that the I&D seminar aims to cultivate in its engineering students.

In accordance with Standard 2: Learning Outcomes, the I&D seminar provides students with ample opportunity to (1) experiment with knowledge discovery via independent academic literature research, (2) develop critical and creative thinking when asked to come up with solutions to the ethical dilemmas they discovered in real examples of AI in engineering, (3) practice teamwork and communication (including in English as a foreign language), and (4) consider these applications in business, but particularly in societal contexts. Additionally, learning outcomes are announced at the beginning of each session along with expected levels of proficiency.

Standard 6: Engineering Learning Workspaces demands the combination of physical and digital learning environments. I&D was mostly conducted in a physical classroom, where lectures were given, students were provided with time and space to collaborate on group activities and discussions, and present ET3 at the end of the semester. There were also occasional online sessions for lecture and collaboration, in addition to the wealth of online resources provided via Moodle (an online education platform) including a platform for communication between group members. Nevertheless, some students wished for more dedicated time during the seminar for groupwork.

The I&D seminar is able to provide Integrated Learning Experiences (Standard 7) by teaching about applications of AI in engineering, clearly disciplinary issues, while simultaneously offering abundant opportunity to develop professional, personal, and interpersonal as well as sustainable product, process, and system building skills (see Standard 2) through the less traditional ETs. Students also found the course focus on real-world issues to be engaging. Thus, the ETs present professional engineering issues within contexts of disciplinary issues.

The seminar incorporates Active Learning (Standard 8) during the introductory lectures using class discussions, small-group activities, and individual reflection handouts (e.g., diversity dimensions handout). Several students articulated their enthusiasm for the course's "interaction and liveliness," (7, p. 2) as "the lectures were always structured in an interactive way, with regular questions asked to involve the students and help follow the lectures contents," (10, p. 1). According to the students, this interactive style of teaching and learning is rare among engineering courses. Even so, other students expressed that they would have liked to have even *more* discussion during class since "[they] did not have that much time to debate and discuss during the lecture time," (9, p. 2). Students later practice experiential learning when they simulate the role of an AI ethics consultant for the AI in engineering case study their group chooses. The course thus "encouraged students to take a hands-on approach to apply ethical considerations of AI in their chosen domain," (3, p. 2) when asked to ethically evaluate their chosen examples in the ETs. Several students lauded this practical training (of ethical evaluation) with real use cases.

Like most courses, the I&D seminar also includes Learning Assessments (Standard 11) of the students. However, in this case it is via four different portfolio ETs, each measuring a different set or level of the intended learning outcomes. Learning assessments are hence aligned with the stated learning goals.

The seminar includes Program Evaluation (Standard 12) via the students' reflections (ET4) and instructor reflections and continuous revision of plans for improvement. For example, as part of this data analysis, we discovered instances in which the course could be improved based on the students' feedback, and we have already implemented some of these changes in the seminar this year.

Finally, the seminar incorporates environmental and social sustainability (Optional Standard 1: Sustainable Development) within all CDIO Standards it covers (1, 2, 6, 7, 8, 11, and 12), especially since we define sustainability as a main theme of ethical AI applications in engineering. Furthermore, I&D fulfills UNESCO's (2017) eight Key Competencies for Sustainability, which have been shown to map well to many CDIO Syllabus sections and was proposed as a basis to update the CDIO Syllabus to 3.0 (see Rosén et al., 2019). The normative competency is developed during introductory lectures on AI's impact on society and AI ethics, as well as during the ETs, especially while ethically evaluating AI engineering applications for ET2. The collaboration competency is practiced via the groupwork required for ETs 1-3. Critical thinking, systems thinking, anticipatory, strategic, and integrated problem-solving competencies are all trained while completing ET2 and ET3 which entail a critical ethical evaluation of complex systems, applying the precautionary principle when anticipating possilbe outcomes, and considering integrated solutions that further ethical, and therefore sustainable, applications of AI in engineering. Lastly, self-awareness is practiced while writing a reflection paper for ET4.

CONCLUSION

As a result of the seminar, one student summarized, "I now have a deeper appreciation for the importance of considering the ethical implications of AI and I am committed to using my skills and knowledge to contribute to the responsible and ethical development and use of these systems. So, I believe that this seminar has been a valuable learning experience that will be useful in my future career as an engineer working with artificial intelligence," (16, p. 1). Through the seminar and ETs, students learn to think critically and creatively, discover the interconnections between engineering and other disciplines, and comprehend the positive and negative social and environmental impacts of an innovation such as AI. They use this newly acquired interdisciplinary understanding to address societal challenges and brainstorm possible solutions. The design of I&D's portfolio ETs engage and enable students to acquire and develop personal, professional, and interpersonal skills and other competencies enumerated in the proposed CDIO Syllabus 3.0. Furthermore, at least some students subsequently accept their responsibility as engineers to society and to a sustainable, ethical future.

However, as with any research project, there are some limitations to our case study. First, we did not have the research idea in mind when we designed the course, so it was not designed in such a way as to maximize the usefulness of anonymized reflections and feedback from the students with respect to any specific research questions. To assess the learning outcomes of the students quantitatively, we must (and will) implement more explicit ethical AI competency assessment scales at the end of the course, especially since reflection papers likely suffer from social desirability bias. In addition, I&D is a single course rather than an entire engineering curriculum, which limits how much we can teach as well as the timespan of our investigations. This means we cannot be sure of students' competency retention and continued commitment to upholding ethical and sustainable standards in engineering applications. Nevertheless, our analysis should provide valuable insight into how an interdisciplinary course in engineering can be taught and how similar courses can contribute to educating future responsible engineers.

One student mirrored our "[belief that] RWTH University should offer more courses, like 'Innovation and Diversity', that go beyond technical and engineering subjects independent from the main study course implementing more multidisciplinary and ethical discussions," (9, p. 2). Our hope is that our work will guide future attempts to restructure or introduce new courses to engineering curricula that engage engineering students in interdisciplinary topics while at the same time teaching the sustainability, interpersonal, and professional competencies that are now required of engineers.

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