Integrating Macroethics into Engineering Education: A Case Study of a Challenge-Based Learning Course on Brain on Chip Technology

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***Abstract*—There is a growing body of research suggesting that ethics education should be more aligned with engineering practice. A promising pedagogical approach that has been gaining traction recently is Challenge Based Learning. It combines real-world problem-solving with collaborative and interdisciplinary thinking. This study further elaborates the concept of macroethics and examines the ethical attitudes of engineering students who participated in a 10-week Challenge Based Learning course on Brain-on-Chip technology. The study draws on ethical reflections collected from 18 students to explore their perspectives on responsibility, technological innovation, values, professional identity, and power relations in engineering practice. Findings suggest that students developed a nuanced understanding of responsibility and technological innovation, engaged critically with ethical dilemmas related to their project, and recognized the need to balance corporate, societal, and user-centered concerns in engineering practice. The insights may support educators seeking to integrate ethics into engineering curricula through partnerships with research teams and real-world projects.**

Keywords—Ethics, Challenge Based Learning, Engineering Education, Brain on Chip technology, student reflections

I. Introduction

Technological advancements introduce complex ethical challenges for engineers. Over the past three decades, ethics and professional responsibility have become critical components of engineering education [1]. However, educators often find it challenging to effectively engage students in these areas and are seeking novel methods to instill a deep sense of ethical responsibility in future engineers [2]. Furthermore, hypothetical case-based approaches often struggle to connect theoretical ethics education with real-world applications [3].

Given that engineering students' views on ethics are influenced by how ethics is integrated into their education [4], this study responds to the need to better understand how emerging pedagogical approaches contribute to students' attitudes towards ethics. The study aims to explore students' macroethical orientation after completing a 10-week Challenge Based Learning course. In this course, students worked on an ethics and data analysis challenge presented by a research team developing Brain-on-Chip technology. The research examines students' ethical attitudes, as self-reported at the end of the course via reflections.

By examining engineering students' attitudes towards ethics at the macrolevel, we can gain valuable insights into the role of current educational approaches and identify areas for innovation and improvement. This understanding is crucial for shaping curricula that prepares engineers who are not just technically proficient but also capable of steering technological progress towards societal good.

II. Challenge Based Learning in Engineering Ethics Education

Traditional ethics instruction in engineering education has often relied on case studies and theoretical discussions, emphasizing individual professional responsibilities [5]. However, this approach has been criticized for its limited complexity and engagement due to historical distance [6]. A growing body of research suggests that ethics education should be more aligned with engineering practice [7], considering both individual and collective responsibilities - what scholars identify as macroethics [5], [8]. This shift requires pedagogical approaches that immerse students in ethical decision-making within authentic engineering challenges [8].

Among the newer pedagogies, Challenge Based Learning (CBL) is an experiential pedagogy that brings to the engineering classroom real-life problems proposed by real-life stakeholders [9]. CBL combines real-world problem-solving with collaborative and interdisciplinary thinking [10]. The most comprehensive survey of CBL pedagogy to date has shown that this approach emphasizes content areas with a strong societal focus [11]. These are presented as sociotechnical challenges of global importance embedded in a learning context that students address with localized solutions [9]. CBL thus strives to bridge the gap between disciplinary knowledge and practical application, countering the criticism that engineering ethics cases often lack real-world relevance [12].

Recent studies indicate that CBL enhances awareness of the societal implications of engineering, representative of macroethical approaches [13]. By confronting students with authentic and complex challenges that mirror the ethical dilemmas they may encounter in their professional lives, CBL encourages deep engagement with ethical principles and fosters critical thinking skills essential for responsible engineering practice [14].

III. COURSE DESCRIPTION

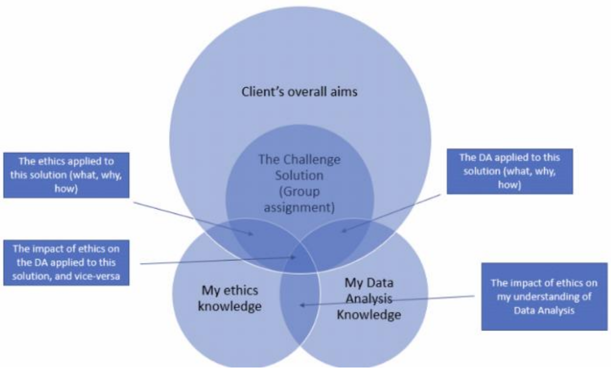
For a 10 week course on Ethics and Data Analytics, the teaching team (Authors 2 and 3) partnered with a research group led by Author 4, based in the same university. The research group does research on Brain on Chip (BoC) technology and is concerned with the ethical aspects related to the privacy of stem cells, informed consent, moral enhancement, brain organoids, and animal testing replacement [15].

Forty students were enrolled in the E3Challenge2 course. The students received a data set from the BoC research team related to their activity. The course asked students to identify a subproblem within the problem domain of the research group who took the role of client. The constraint placed on the problem is that it must involve exploring, analyzing and applying ethical themes and data analysis. As such, to solve the challenge, students need to apply data analysis skills whilst considering the User-Society-Enterprise context and interacting with the research group (Fig 1). The final project for addressing the challenge could take many forms such as adapted models, data processing recommendations, guidelines and frameworks.

The students met with the research group at several points throughout the course, to visit their laboratory and gain an understanding of the tools and techniques involved in their work. The research team also recommended research articles on Brain-on-Chip technology to expose students to state of the art research questions and approaches related to the development of such a technology.

Each week students took a 2h active session on ethical and philosophical aspects relevant to the challenge. These were structured to include lecture moments in conjunction with activities. Students could practice applying ethics to the challenge while doing work directly relevant for the assignment, under the observation of the lecturer. In the first few weeks of the course, this timeslot was also used to introduce students to tools and techniques for project planning and tracking progress.

FIG 1. INTERPLAY OF TECHNICAL AND ETHICAL COMPONENTS IN THE CBL COURSE



Every week, there was also a 1–2 hour session where the student teams could give and receive feedback from other teams regarding the approach to solving challenges. These sessions were facilitated by Data Analysis and Ethics Teaching Assistants. In addition, a coaching TA assisted with teamwork and project development.

The third weekly activity was a 3h working meeting session, where students could work on the challenge. Teachers were available to discuss the approach taken and answer any questions. It was during this timeslot that the external stakeholders was present at some course points.

The course had a mix of ethics and technical outcomes:

E1: Demonstrate a basic ability to reflect on engineering in a temporal and societal context, operationalized in terms of Users, Society and Enterprise (USE).

E2: Demonstrate a basic ability to conduct a descriptive analysis of engineering in a USE context.

E3: Demonstrate a basic ability to conduct a normative analysis of engineering in a USE context.

E4: Demonstrate a basic ability to design solutions to engineering challenges from a USE perspective.

E5: Demonstrate a basic ability to evaluate solutions to engineering challenges from a USE perspective.

E6: Demonstrate a basic ability to reflect on the changing nature and responsibilities of the engineering profession.

T1: Identify a core data analysis problem and its scope.

T2: Identify the functional and non-functional requirements for a data analysis problem with reference to a USE context.

T3: Select and apply established suitable data analysis methods for solving the defined problem using the collected data.

T4: Present statistically relevant results and method overviews suitable for a given audience.

T5: Demonstrate self-reflective awareness of the technical and USE constraints on data analysis problems.

IV. METHODOLOGY

The research question is what macroethical orientation emerges among students following a CBL course on Brain-on-Chip? The study received ethics approval (Ref ID ERB2022IEIS12) and safeguard regarding student anonymity and data protection were followed. For example, each student was assigned a randomly generated pseudonym.

A. Conceptual framing

A central distinction in engineering ethics education is between microethics and macroethics [5]. This distinction, though not fully disambiguated, captures varied attitudes toward technological innovation and values, the role of the engineer, professional responsibility, and assumptions about an engineer's agency and power relations, expressed at different levels. A review of the literature in engineering ethics was conducted to disambiguate and expand the concept of Macroethics, serving as the basis for the conceptual framing proposed in this article (Table 1).

TABLE 1 MACROETHICAL ORIENTATION

Ethics attitude	Macroethical expression
Professional responsibility	Collective, collaborative, communal responsibility
Role of the engineer	Societal, as citizen and community member
Value adoption	Value sensitivity and non-neutrality
Technological innovation	Technoskepticism
Agency and power	Awareness of power dynamics and enabling or constraining contextual factors

Reflecting on the terms we use, we follow [16] to understand attitude as 'an orientation to one's entire life and field of experience.' Building on Husserl, Laferté-Coutu [16] defines ethical attitude as how a person relates to their personal, social, and practical world. Attitudes are closely related to opinions, beliefs and feelings, and are shaped through direct personal experiences or social interactions [17]. According to Ajzen [17], these can be stable yet subject to change based on new information or experiences.

Considering the engineering ethics literature, we posit that a macroethical orientation consists of the expression of several ethical attitudes: towards professional responsibility (expressed as a collective, collaborative and communal responsibility), towards the role of the engineer (expressed as a societal role, emphasizing the engineer's identity as a citizen and community member), towards the adoption of values in engineering design (expressed as acknowledgement of the value-laden nature of engineering practice and artefacts), towards technological innovation (expressed as technoskepticism), and towards agency and power (expressed as awareness of power dynamics and the contextual factors affecting engineering practice).

B. Method

To examine the macroethical orientation of engineering students, we use a narrative case study based on reflections and final essays of 18 students. The 18 students were randomly selected from the 34 students who consented to the use of their course submissions for educational research. The criteria was to ensure a more even gender ratio while keeping the rich data manageable for an in-depth qualitative study.

The course population consisted of 40 first year students, enrolled in programmes of Computer Science (49%), Applied Physics (14%), Mechanical Engineering (8%), Psychology & Technology (8%), Electrical Engineering (5%), Industrial Design (5%), Automotive Engineering (3%), Other degree (1%), with the remaining students opting not to disclose their degree. In terms of gender, 75% students identify as male, 18% as female, 0% as other gender, and the remaining opting not to disclose their gender

Student reflections are frequently used in narrative research, particularly in higher education, where they provide personalized insights into students' experiences, thoughts, and learning processes [18]. Structured reflections prompted students to document their thoughts and feelings of their ethics learning experiences and views on ethics at three points in the course (week 3, week 6 and week 9). Thus, reflections served as a medium for students to process complex aspects pertaining to their macroethical orientation, capturing the nuanced and evolving nature of their ethical attitudes.

For this study, we analyzed the reflections submitted in week 10, at the end of the course. The reflection prompt that students had received was:

"In week 9 the final group submission was made. A week later, in week 10, it is time to look back on everything you have done and been involved in. What did you learn these ten weeks? What has changed (knowledge, skills, …)? Did you achieve your learning goals? If not, why not? How did you learn these things these past nine weeks? How is what you have learned important for your project? How do you think this will be important for your future as individual, citizen, engineer?"

Narrative inquiry allowed us to explore students' own accounts of their ethics learning and development of their professional consciousness as well as their expressed views on the role of ethics in the development of Brain-On-Chip technologies.

The narrative approach gathers rich descriptions of a person's sense-making processes of identity construction and transformational experiences, which are especially suited to be captured via written reflections and course artifacts ([19]; [20]). Although narrative enquiry doesn't establish any strict causality, people often draw connections between various events or viewpoints and explain how these may follow from one another ([21], p.7). In doing so, they explain their perception of how one thing may lead to or influence another. Even if this approach doesn't prove actual causation, it provides insight into people's thought processes and personal beliefs about cause-and-effect relationships [22].

C. Analysis

The rich data is subject to a thematic analysis guided by how the macroethical attitudes identified in Table 1 have been discussed in the engineering ethics literature (see Section 2). To ensure the rigor of the analysis, the narrative case study followed Lincoln and Guba's [23], pp. 301-327) criteria of trustworthiness in qualitative research.

The analysis was subject to two rounds of coding. In the first round, the transcripts were subject to open coding using Saldaña's [24] guidance to identify and categorize ethics mentions. Each mention was coded in-vivo. In the second round, the first author selected several of these quotes as prototypical codes for articulating responsibilities, which served as reference for undertaking an additional round of coding. During the second coding round, the initial in vivo codes were merged at a more abstract level under a limited number of secondary themes, representative of the five ethical attitudes.

V. FINDINGS

Guided by our conceptual frame, the study identifies the expression of the following attitudes at the macro level:

A. Attitude toward responsibility

A prominent focus of students' narratives is the recognition of engineers' broad responsibility to society. This theme was most present in students' responses, capturing considerations of responsibility in connection to future impacts, potential technology misuse, the widespread of technologies, and stakeholder breadth.

Future impact

Emma underscores the significance of this responsibility, stating that ‘an engineer has one of the biggest of all careers because you make the future, quite literally’ and are ‘extremely responsible for every piece.’ Nikos echoes this sentiment, emphasizing that responsibility means ‘planning for the future, seeing the consequences of what you are doing in order to limit possible damage or undesirable consequences.’ Arthur expands this idea, insisting that technological innovations must prioritize ‘the good of humanity’ and that engineers must ‘really make sure that the consumers are not negatively affected.’

The necessity of foresight in ethical engineering is another recurring theme. Corina has observed how ‘in the past 20 years there have been many technological advancements and not enough regulations regarding them,’ emphasizing the need for engineers to proactively address ethical implications. Arthur reinforced this perspective, asserting that engineers must consider ‘implications in the future, rather than implications that are already here.’

Technology misuse

Concerns over dual-use technology and commercial exploitation also emerge in students’ reflections. Luis warns about the potential for Brain-on-Chip research to be misused in military applications, arguing that engineers must ‘mitigate inappropriate usage.’ Bart, reflecting on the commercialization of Brain-on-Chip research for medical applications, pointed to the ethical risks of monopolization, particularly as ‘more people become susceptible to neurodegenerative diseases.’ He asserted that engineers should ‘value quality of life and the health of the world population over financial gain in the healthcare world, particularly given ‘the current model of big pharma has a lack of incentive to collaborate.’ Tudor similarly reflected on the ethical use of technology, noting that his goal was ‘to ensure a product created with integrity, honesty, and fairness’ while preventing stakeholders from ‘misusing the visualization we provided to mislead other parties.’

Large scale impact

Some students highlight ethical concerns beyond physical safety, including mental health impacts. Emma and Bianca noted the dangers of social media algorithms, with Emma arguing that an engineer’s responsibility extends beyond physical structures: that's not a bridge collapsing, but it's someone's mental health collapsing.’ Bianca similarly highlighted the ethical duty to prevent addiction and protect user privacy: if you work at Facebook and you implement a small change in the algorithm, then that change will affect millions of people, so you really have to make sure that everything you do is ethical.’

Data privacy and the ethical risks of big data in engineering applications are also of concern. Bart discusses the dilemma of commercializing technological applications versus ensuring broader accessibility, questioning whether to ‘commercialize my invention and try to make a profit? Or do I share everything with the world, with the risk of losing profit but helping other people with accessibility?’ Bianca, Lev, and Eline also expressed concerns over the ethical risks associated with personal data collection.

Stakeholder breadth

All students included in the study emphasized the necessity of considering stakeholders and societal impact in engineering practice. Arthur exemplified this by noting that ‘if the solution affects more people, then you really have to make sure that everything you do is ethical.’ Monica highlights the importance of user-centered design, stating: ‘I need to consider ethics in everything that I do. I need to also consider the users and what kind of implication that software might have on the users, not only what benefit it can have for the company I'm working for.’

Bianca stressed the importance of stakeholder inclusion in design, while Lev reflected on economic disparities in technology access, noting that ‘research companies are mostly well-funded, whilst most people driven to donate cells by the financial incentive come from low-income backgrounds.’ Eline extended this ethical concern to future generations, highlighting that data collection also affects ‘family members of donors, including those not yet born, who were not asked for consent.’

B. Attitude toward technological innovation

By week 10, students widely recognized technological innovation as a double-edged sword, acknowledging both its potential benefits and ethical challenges. Lucas reflects on this complexity, stating that ‘this project has allowed me to see technology more as a two-sided thing and consider the dangers of innovation.’ He expressed skepticism about artificial intelligence, describing many of its applications as ‘never-ending work with no benefit’ and questioning whether society is prepared to prevent historical ethical failures from recurring. Lukas asks ‘what would stop us from making artificial consciousness the same type of robotic slave […] what is stopping us from repeating the mistakes of the past?’ This perspective underscores a technoskeptical approach, urging caution in technological development.

Bart also highlights the risks of monopolization, drawing from historical examples such as the electric lamp and personal computers. He warns that ‘high-tech has shown cases of monopolization before […] which brings negative effects to the economic and scientific realm.’ His concerns are echoed by Dirk, who points out that ‘if one company gets a monopoly on producing lifesaving medicine, it opens a window for personal gain.’ Both students emphasize the need for transparency in technology development to prevent excessive corporate control.

Sebastian, while recognizing the transformative potential of Brain-on-Chip technology, cautions against the risks of mishandling sensitive data. He asserts, ‘Brain-on-Chip is a very important and potentially game-changing technology [...] However, there must be careful consideration when developing it due to the large number of potential risks associated with the usage of the data that will be output from it.’ His perspective reinforces the importance of ethical data management, particularly concerning stem cell donors’ personal information.

These reflections highlight a growing awareness among students by week 10 of the need to balance innovation with ethical responsibility. Upon spending time critically assessing the implications of Brain-on-Chip technology for their project deliverables, students started recognizing both its potential societal benefits and the necessity for oversight in its development and implementation. By advocating for responsible innovation that prioritizes ethical considerations, students' perspectives are reflective of the emergence of a techno-sceptical stance.

C. Attitude toward values

Students recognize the significance of ethical values in engineering, particularly as technological advancements intersect with societal and environmental concerns. Tudor stresses the necessity of creating products that uphold 'integrity, honesty, and fairness', especially in data privacy and ethical technology use. Ren reinforces this perspective, stating that 'learning about the ethics involved in technical projects is important in this advancing society where the societal and political implications of people's data and one's digital footprint have become so important.'

Transparency is another recurring theme. Tudor emphasizes the importance of clarity in data use, stating that 'our main ethical concern was to ensure proper understanding and misuse prevention of the visualization.' He implemented a strategy to 'maximize the transparency of our work by clearly stating what has been done at each step.' Lucas extends this discussion to inclusivity, noting that 'I did learn to look at ethical problems from a big picture perspective, in a more inclusive way.'

Hendrik applies Aristotelian virtues to biobank management, identifying 'courage, magnanimity, ambition, temperance, and truthfulness' as essential ethical traits. Lucas also highlights the importance of caution in engineering, stating his commitment to 'be cautious with my work as an engineer and developer' to prevent unintended harm.

These reflections reveal students' emphasis of integrity, transparency, inclusivity, and caution as guiding principles in their engineering practice.

D. Attitude toward power relations

In week 10, students were more aware of the complex power dynamics involved in engineering and technological innovation, particularly the tensions between serving public interests and meeting corporate expectations. Dirk acknowledged the potential for such a conflict in industries like Brain-on-Chip, noting that 'management has a conflict of interest between the customers, the patients, and the shareholders, the ones who have the power to fire them.' His observation shows the ethical dilemmas that arise when financial imperatives compete with privacy and user protection.

The potential for misrepresentation in research is another concern. Bart warns that Brain-on-Chip researchers 'are in a position of power; they need to avoid the danger of giving a too promising impression of the research.' His statement highlights the responsibility of researchers to present accurate findings, ensuring that public perception and policy decisions are based on realistic expectations. Ralf adds that volunteers may not fully comprehend 'what is the extent of data that they will potentially be giving out,' emphasizing the need for transparency in emerging fields where the implications of data collection remain unclear.

Hendrik extends this discussion to biobank management, where financial pressures can influence ethical decision-making. He explained that 'biobanks have high costs to preserve and maintain their samples, and this often drives biobanks to go commercial. However, a commercial position brings in the outside influence of stakeholders,' shifting power toward profit-driven interests rather than donor rights. According to him, this dynamic 'puts stakeholders and owners in a position of benefactor and decision maker, while the donor becomes the ethical risk taker.'

Through these reflections, students show a growing awareness of the ethical complexities associated with technological power structures. They started to recognize that while engineers and researchers wield significant influence, this power must be exercised with transparency and responsibility to ensure technological advancements prioritize societal well-being.

E. Attitude toward professional identity

Prompted by the reflective assignment inviting them to consider at the 10-week course mark how the project they worked on is important for their future as individuals, citizens, or engineers, students grappled with defining their professional identity, balancing their roles as future employees with their responsibilities as community members. This duality becomes apparent as they confront ethical dilemmas in Brain-on-Chip technology and anticipate similar challenges in their careers.

Arthur reflected on this balance, emphasizing that 'as a citizen, I believe that in any engineering domain, ethics should be considered, especially in a society living through hard times.' He argues that engineering 'should never be advanced without an ethical approach since we all know what dangers could appear.' His reflection reveals a deep concern for ensuring that technological solutions do not exacerbate societal issues.

The tension between corporate interests and user vulnerability comes into play when students make sense of their professional identity. Monica explored neuromarketing in her project, recognizing its benefits for companies while acknowledging its potential harm to users. She states: 'for companies, it's going to be very beneficial, but at the same time, for users, it might not be as useful, because they'll be in a way vulnerable to companies and influenced by companies.' Her insights highlight the ethical dilemmas engineers must navigate, balancing profitability with user well-being.

Most students recognized how ethical decision-making can shape their professional development. For example, Alex reflects that the course provided him with 'the tools to assess my personal choices differently' as a future engineer. These perspectives illustrate a growing awareness among students of the multifaceted role of engineers, and how these roles intersect with dimensions of responsibility and power relations.

VI. CONCLUSION AND RECOMENDATIONS

Microethics is the prevalent way of teaching engineering ethics and educators are seeking ways to complement it with macroethical activities fostering students' broad understanding of ethics ([25]; [2]). As engineering projects increasingly involve diverse stakeholders and impact various aspects of society, the ability to navigate complex ethical landscapes becomes paramount. By situating ethics within real-world sociotechnical challenges, this study aligns with recent calls for embedding ethics in the curriculum in ways that are more experiential, reflective, and interdisciplinary [26].

This study contributes to the literature on teaching ethics via real-life projects, by presenting a first-year 10-week Challenge Based Learning course on Ethics and Data Analytics in the context of the development of Brain-on-Chip technology. It employed a narrative approach to analyze data collected via reflections and final course essays, with the aim of understanding students' attitudes towards ethics and their emerging macroethical orientation, as well as identifying the course components that may facilitate it.

The study makes two contributions:

First, at the theory level, the study strived to reflect on what is understood by macroethics and disambiguated the concept with examples from the literature. It differentiated between five macroethical attitudes that can be expressed toward responsibility, technological innovation, values, professional identity, and power relations.

Second, the study provides an example of teaching engineering ethics and data analytics via CBL, in a course dedicated to the development of Brain-on-Chip technologies where a university research team took the role of educational partner. The findings suggest that upon course completion, students displayed a nuanced understanding of ethics, representative of a macroethical orientation. Students recognized the societal impact of their work, exhibited technoskepticism, and critically reflected on ethical dilemmas arising from their engagement with Brain-on-Chip technology. Importantly, they acknowledged their agency as future engineers and the necessity of balancing corporate, societal, and user-centered interests.

Students' attitudes toward ethics have been underexplored in the context of CBL and emerging technologies like Brain-on-Chip, thus highlighting the potential of this pedagogical approach to broaden ethics instruction.

For educators, this study suggests several key recommendations. First, integrating real-life sociotechnical challenges into engineering curricula enhances students' ethical engagement. Partnering with internal or external stakeholders, such as research groups, companies, or policy bodies, provides students with tangible ethical contexts. Second, ethics instruction should extend beyond abstract discussions to include methodologies such as value mapping, stakeholder and risk analysis, and foresight exercises, encouraging students to anticipate long-term ethical consequences. Finally, interdisciplinary teaching teams can provide diverse perspectives, reinforcing the complex nature of ethical decision-making in engineering.

While students mentioned that being involved in a 'real-life' project related to the development of a technology by a research group prompted them to consider with more care the impact and risks of their work, it is not possible to pinpoint exactly which CBL components contributed to this view. A limitation of the study is thus the limited data on the connection between specific CBL course components and students' emerging views. Further research is needed to explore the specific impact of CBL course components as well as the long-term impact of CBL interventions on students as they progress through their degree. Additionally, investigating how these findings are relevant for courses exploring other recent technological developments would provide valuable insights into the broader applicability of the educational strategies identified in this study. Future studies could also examine the impact on student attitudes of specific teaching activities, such as value mapping, stakeholder analysis, or participatory engagement, to enhance and facilitate their adoption.

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