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Intellectual journeys in different directions: Engineering and social science students' expanding understanding of the role of engineering

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Abstract. Engineering and social science students can be said to belong to different thought collectives, with certain concepts and capabilities being considered core and others being considered more peripheral. In the interdisciplinary context we studied, engineering and social science students had the common object of learning of expanding their understanding of engineering but from different starting points. We aimed to identify what conceptions of engineering the course brought forth among the students taking the course. To achieve this, we employed a qualitative research approach, phenomenography, with a focus on different ways of experiencing something. Through iterative analysis of interview and written self-reflection data, four qualitatively different categories of description were identified for the engineering and social science students, respectively. Our identified categories of description represent potential positions along intellectual journeys as the students move closer to the other discipline, which also means moving further into a liminal space.

Keywords: engineering; engineering students; social science students; interdisciplinary course; phenomenography

1. Introduction

I have come to realise that social science students are often given the tools to deconstruct an issue, but have no ability to directly apply it in the real world. Working with engineers has most definitively created and developed this balance. [Reflection 14]

The above quote from a sociology student participating in the interdisciplinary, critically-oriented course on engineering reported on in this study captures the sense that engineering and social science students have often been taught to think quite differently, engineers to solve problems, and social scientists to ask questions. It is this value of broad interdisciplinary collaboration (Bertel et al. 2022; Klein 2010) that frames our paper.

The traditional approach to teaching engineering problem-solving, where students are limited to finding purely technical solutions, is widely critiqued as inadequate preparation for understanding and solving the engineering challenges of the twenty-first century (Bertel et al. 2022; Martin et al. 2022; Riley 2008; Trevelyan 2010; Williams 2002). There is increasing acceptance of the need for graduate engineers to frame technical requirements within their social, economic, and environmental context. This need is recognised by professional engineering accreditation bodies, employers, and international organisations, such as UNESCO, which published the Global Report on Engineering in 2010 (UNESCO 2010).

There is also a clear recognition that problems are rarely confined within disciplinary boundaries (Jacob 2015; Williams 2002). Consequently, engineers need not only to learn new interdisciplinary approaches to problem-solving that incorporate thinking from disciplines usually associated with the social sciences and humanities but also realise the value of collaboration with professionals from these disciplines (Lattuca, Knight, and Bergom 2013; Patel, Pang, and Salameh 2015; Shankar et al. 2017). In terms of terminology, similarly to Frodeman and Mitcham (2007, 506), we use ‘interdisciplinarity’ in a generic sense to cover inter-, multi-, cross-, trans-, and other extradisciplinary formations.’

Discussions about bringing humanities and social science (HSS) content into engineering are nothing new. For example, in the United States throughout the last century, there has been an ongoing culture-versus-utility debate around the role of HSS content in engineering education, with engineering faculty generally coming down on the side of utility, and despite early calls for better integration, segregation has endured between professional (STEM courses) and general education (HSS courses) (Leydens and Schneider 2009). In Liberal Arts colleges, there is a very different approach, as students do a generalist foundation and only select to study engineering in their second year. They get a lot more opportunity to take courses from other disciplines. However, even in this context, students may not know how to blend these disciplines in a meaningful way, and they can remain in separate and distinct frames of reference in the students’ minds. This HSS-STEM separation seems to have existed in other national contexts as well, for example, in France, where, according to Roby (2024, 98), a ‘technocratic identity’ has ‘made it difficult to integrate academic HSS, as a tool for understanding social realities, into engineering education.’ Roby sees potential in interdisciplinarity for HSS integration, but concludes that this might be easier at newer academic institutions than older, more traditional ones. There is also recognition of other barriers to overcome in order to move to a more interdisciplinary mode for engineering education (Ashby and Exter 2019; de Ruiter et al. 2023; Graham 2018; Richter and Parette 2009).

In practice, it does not appear to be that common to bring engineering students together with students from the humanities and social sciences (HSS) in the same course or programme, especially not in a context where they can discuss their different perceptions. In their review of interdisciplinary engineering education initiatives, Van den Beemt et al. (2020), when looking at course design in terms of including students from different disciplines or simply importing knowledge and skills, found 16 cases with students from a single discipline of engineering and 37 cases with students from different engineering disciplines or engineering and non-engineering disciplines. Of the latter category, fewer than ten cases included engineering and HSS students together. Bringing together students from vastly different disciplines is likely non-trivial. Many years ago, more specifically back in 1935, Ludwik Fleck ([1935] 1979) argued that stable *thought collectives* form around organised social groups (such as professional engineers or social scientists), and that *thought styles* of such collectives become fixed and formalised in structure if the group is large and lasts long enough. The longer the thought style has existed, the more certain it appears, which might cause communication and collaboration challenges across disciplines. When two different thought styles collide, according to Fleck, ‘[t]he alien way of thought seems like mysticism. The questions it rejects will often be regarded as the most important ones, its problems as often unimportant or meaningless trivialities’ ([1935] 1979, 109). This reads like a description of *broad interdisciplinarity*, which ‘occurs between disciplines with little or no compatibility [in terms of methods, paradigms, and epistemologies], such as sciences and humanities’ (Klein 2010, 18). The spectrum between narrow and broad interdisciplinarity

(Klein 2010) can be thought of as corresponding to different cognitive distances between disciplines (Sonnenberg-Klein and Coyle 2024). Most engineering subdisciplines would have a relatively small cognitive distance between them, while the distance to business studies would be a bit larger, and the distance to sociology would be significantly larger.

When considering learning in an interdisciplinary context, *boundary crossing* (Akkerman 2011; Akkerman and Bakker 2011) is a useful concept as it addresses learning at and across disciplinary borders and practices (Fortuin et al. 2024). Akkerman and Bakker (2011) introduced four learning mechanisms—identification, coordination, reflection and transformation—which Fortuin et al. (2024) consider ‘essential heavers for learning across boundaries’ (215). For students to successfully work together, they need to both develop a better understanding of the other discipline(s) and move beyond the boundaries of their own disciplinary practices. If the goal is to enable engineering and social science students working together to consider possible future alternative practices situated in interdisciplinary collaboration to meet the challenges of tomorrow, an important aspect is the development of a somewhat nuanced understanding of engineering, which includes a critical awareness of fundamental aspects of the current dominant engineering common sense (Riley 2008). While engineering students have a lived experience of engineering education, they often do not get the opportunity to develop a critical perspective on their education and future professional practice. In fact, Cech (2013) has suggested the prevalence of a culture of disengagement among engineering students and that their public welfare concerns decline significantly over the course of their education. So, for many engineering students, developing a critical perspective might prove challenging, as one of the participants of our study put it:

This course has had a huge effect on my way of thinking. Big time! ... It really messed with my head. Sometimes I was scared to go to class because I didn't want to think about stuff ... I feel now that I look at things from a different perspective or CAN ... (SIGH) this course... [Interviewee 13]

Social science students, on the other hand, are often more used to applying a critical perspective to unpack the common sense and power relations for a particular concept or context, but are likely to have a hazier understanding of concepts of engineering. According to Waltemathe and Hemminger (2017), humanities and social science education often lacks opportunities for students to develop a more advanced understanding of technology and, consequently, ‘[t]heir awareness and thus their competence to rationally engage with science and technology is lacking.’ Still, according to Hitt, Banzaert, and Pierrakos (2023), efforts have increased to provide opportunities in this direction. In contemporary culture, one generally tends to talk more about technology than engineering (Williams 2002). To some extent, this has been true even in the field of Science and Technology Studies (STS), where engineering and engineers, until more recently, have been relatively invisible as a focus of inquiry (Downey 2009; Downey and Lucena 2009). This potential haziness regarding engineering might prove a bit of a challenge for social science students, as one of the sociology students participating in our study put it:

A good majority of us, and myself, really have no idea in terms [of] talking about engineering. I was going into this course and ... actually had no knowledge of engineering. So I was nervous. [Interviewee 8]

One way of framing these challenging and potentially perspective-shifting learning experiences is that students move further into a *liminal space* (Meyer and Land 2005). A liminal space is characterised by flux, transition and transformation, and in the context of the

course reported on in this study, offered the students a conceptual space where they were safe to remain confused and to explore different ways of seeing and understanding the world. In a previous study, we explored this liminal space by mapping students' conceptions of social justice (Kabo and Baillie 2009). While analysing interviews with students, articulations about how the course impacted their ideas about engineering were identified and found significant. Consequently, this study aimed to map out the liminal space in terms of what conceptions of engineering the course brought forth among the students taking the course. Accordingly, we formulated the following research question:

What are potential shifts in perspective on engineering among engineering and social science students, respectively, participating in an interdisciplinary, critically-oriented course addressing the nature and possible practices of engineering?

To address our research question, we employed a qualitative research approach, phenomenography, with a focus on different ways of experiencing something (Marton and Booth 1997). Through iterative analysis of interview and written self-reflection data, four qualitatively different categories of description were identified for the engineering and social science students, respectively. In our minds, one way to summarise and interpret the findings is as potential *intellectual journeys* in different directions in terms of thinking about engineering. We use intellectual journeys to capture the conceptual movement involved in developing one's thinking. This terminology came to us as we were making sense of our combined outcome space, and we acknowledge drawing on Paulo Freire's ([1970] 2003) concept of conscientização—the process of developing a critical consciousness—and the German-Scandinavian Bildung tradition, especially Wolfgang Klafki's Critical-hermeneutic Bildung (Sjöström and Eilks 2020). It is important to note that the implication is not that one direction is better than the other, as both the engineering and social science students expanded their understanding (in different ways) as they moved closer to each other.

2. Research context: The Engineering and Social Justice course

The Engineering and Social Justice course was originally developed and co-taught by an engineering educator and a sociologist at a North American university in 2005. In this initial class, the two professors taught the course concurrently and were both present in the classroom at the same time. This was an important element of the course as students could see professors in a state of 'not knowing', which aided their ability to ask questions that might otherwise seem ignorant to those from the other discipline. For this research, two classes were studied, one per year for two years. Both classes followed the same format and were taught by the same engineering professor, but two different sociology professors (the course co-creator being on sabbatical in 2008).

The course was taken as an elective by students from engineering (several fields, such as civil, chemical, electrical, geological, mechanical, mining and engineering physics) and the social sciences (mainly sociology and developmental studies) in their second to fourth year. Students' reasons for choosing the course included prior positive experience with one of the professors, needing the specific type of course credit and the schedule fit, finding the concept of social justice in general and/or in relation to engineering interesting and/or important, wanting an interdisciplinary course, or just thought the course looked interesting when reading about it. For many of the students, the course was likely their first experience of broader interdisciplinary study and collaboration.

The two main approaches of the course were the deconstruction of the ‘common sense’ of current engineering practices and the creation of alternative practices that are non-oppressive, non-capitalist, and ecologically sustainable. The main aim was to enable both engineering and social science students to consider the current and potential alternative future of engineering through a lens of social justice. The course started by exploring basic definitions of social justice and engineering and introducing students to the key concepts related to the social construction of technology (how society shapes technology) and technological determinism (how technology shapes society). The dominant engineering paradigm of technological and capitalist rationality was explored and critiqued from its rise during the Industrial Revolution to its current phase of neoliberal globalisation. Towards the latter part of the course, alternative paradigms were explored through a series of lenses, such as anarchism and feminism. Table 1 gives a more detailed overview of topics covered, and Table 2 lists the course learning objectives.

Table 1. goes here.

Table 2. goes here.

Over a twelve-week period, the class met once a week for a three-hour session. Each session was split into two parts, usually focusing on different topics and readings, with one of the instructors taking the lead for respective sections. After a short introduction to the topic at hand, sometimes by a guest speaker, the floor opened up for class discussion. These seminar-style discussions were the main dynamic of the classroom through which the week’s topics were explored, but at times this was mixed with small group exercises.

In addition to participating in the discussions, the students engaged with the course themes by writing two critical response essays. From the instructors’ point of view, the essays were of crucial importance to the development of the students’ thinking. Both instructors gave feedback to each student on both essays. The students’ progress was discussed by the two instructors, and interventions were created to facilitate learning in difficult areas. For example, in one of the courses focused on in this study, it was decided to alter the focus of the second after the first essay. In this new and slightly revised assignment, the engineering students were asked to ‘only deconstruct’ and the social science students to ‘stop deconstructing and to create alternatives’.

A final, important component of the course was a community-based group project in which the students worked in interdisciplinary teams to respond to real community problems. Potential projects were identified by the instructors and presented to the students, who could choose what they wanted to work on but were encouraged to form teams consisting of both engineering and social science students for a total team size of 3-6 persons. Examples over the years have included working with local Indigenous/mining conflicts, co-developing culturally appropriate engineering course materials for local Indigenous school students, developing an access ramp for a local shop, and creating a bike shopping trolley for a local green bike campaign. Towards the end of the course, the teams had to deliver a written report, give an oral presentation to the rest of the class, and individually submit critical self-reflections on their group projects. Due to the structure of their programmes, many social science students had no or little prior experience with project work, while most engineering students had worked on projects but not together with social science students.

3. Methodological approach

In this section, we discuss some aspects of the qualitative research methodology used in this study, *phenomenography*, which is distinct from *phenomenology*, another qualitative research methodology. Studies employing *phenomenography* seek to uncover the range of conceptions that exist within a particular group of individuals in relation to a particular concept, with the assumption that it is possible to describe these in a number of qualitatively different categories of description (Marton and Booth 1997). For example, Dringenberg and Purzer (2018) explored the experiences of first-year engineering students working on ill-structured problems in teams, Täks et al. (2014) explored engineering students' experiences in studying entrepreneurship, and in their seminal study, Marton and Säljö (1976a; 1976b) explored how students approached their learning (deep and surface approaches). Key concepts and methods in the *phenomenographic* research process are illustrated in Figure 1 and are described more fully in the sections below. For each section, we first describe the ideas or practice in general and then how these were put into practice in this particular study.

Figure 1 goes here.

3.1 Data collection

Key to all *phenomenographic* studies is the focus on differences or variation, rather than similarities, among different ways of experiencing or understanding a phenomenon in the world. The objective is not to characterise individual subjects' experiences of a given phenomenon but the collective experience of a select group. According to Marton and Booth (1997) data at the collective level are particularly robust compared with data relating to individuals, since (1) it is possible that individuals only express some of the different ways, or fragments of ways, of experiencing a particular phenomenon, and (2) categories of description, and even their fragments, are distributed across individuals. In practice, data are drawn from individuals to form a common pool of meaning from which categories of description are constructed on the collective level. During *phenomenographic* data collection, the aim is to maximise the variation both in terms of the individuals data are drawn from and the range of articulations from each individual. Thus, it is usual practice to select a theoretical sample of subjects to cover the group according to a predetermined plan and have a well-prepared guide for semi-structured interviews, a common data collection method in *phenomenography*.

For this study, data were collected in two distinct steps corresponding to two yearly iterations of the Engineering and Social Justice course. Since Baillie was the teacher and examiner for the course, she did not participate in any data collection or analysis before course grades had been assigned. During both iterations of the course, Kabo took part as a participant-observer during the classroom seminars to become familiar with the course context and the students, and allowing the students to become familiar with him. Kabo participated in classroom discussions but not in other course components, such as the student group projects. At the start of the course, the students were informed of Kabo's doctoral project, his presence in the course, and that he had no impact on the evaluation of their performance in the course.

During the first iteration of the course studied, Kabo interviewed fourteen students about their learning experiences in the course. Drawing on the *phenomenographic* principle to maximise the variation, students were invited to participate in the interviews mainly based on their discipline of study and observed engagement in the classroom. Participation was voluntary, and written informed consent was used. The interviews were conducted in-person

during the course, lasted 30-80 minutes, were recorded, transcribed verbatim and anonymised. Eight students were interviewed twice (five engineers and three social scientists). Since the focus for this study—students' potential shifts in perspective on engineering due to the course—accidentally emerged from the collected data, the interview design had not been set up to maximise the range of articulations from each individual concerning this topic. Consequently, we found that we had interesting but insufficient data for a comprehensive analysis. The following year, after the course had concluded and grades had been assigned, writing in the form of critical self-reflections on their group projects was collected from the 30 students taking the course, who had been informed about the study at the start of the course. In these self-reflections, the students had, in up to 1500 words, to critically examine their group, their project and their contribution to the work. The choice of collecting these self-reflections was pragmatic as conducting more student interviews was not feasible within the remaining timeframe of Kabo's doctoral project. After being anonymised, the critical self-reflections were pooled together with the interview transcripts from the previous year. In total, data were collected from 28 different engineering students (3 female and 25 male) and 16 different social science students (13 female and 3 male), who were all in their early twenties and in their second to fourth year of university studies. A more detailed breakdown of informant characteristics can be found in Table 3. The data we ended up with were somewhat fragmented in nature, and the phenomenographic focus on the collective level became an asset during the data analysis.

Table 3 goes here.

3.2 Data analysis

A phenomenographic analysis aims to produce an outcome space consisting of a system of categories of description, which are distinguished from one another in terms of the presence or absence of certain critical aspects of the object of study and are logically related to one another. The focus on establishing logical relationships between qualitatively different ways of experiencing something is a strength phenomenography has over an approach like thematic analysis. Marton and Booth (1997) explain how interview transcripts (or other written texts) are analysed within phenomenography:

The researcher has to establish a perspective with boundaries within which she is maximally open to variation... The analysis starts by searching for extracts from the data that might be pertinent to the perspective, and inspecting them against [...] two contexts: [...] [1] in the context of other extracts drawn from all interviews that touch upon the same and related themes; [2] in the context of the individual interview. [...] This process repeated will lead to vaguely [discerned] structure through and across the data that our researcher/learner can develop, sharpen, and return to again and again from first one perspective and then another until there is clarity [in the form of a system of categories of description]. (133)

So, the data analysis is an inductive and iterative process, where the researchers try to put brackets around their conceptions of the object of study to minimise the effect of their own biases. One way of reducing researcher biases is to work in iterations with one or several colleagues and construct the categories together. Even when a researcher does the analysis alone, iteration is key to a robust outcome space. The main point is to let the data speak and let the categories of description and their organisation emerge from the data without input from external sources and frameworks. Working this way helps to give trustworthiness to the

findings. Often, the relationship between categories will be hierarchical, with higher categories corresponding to more complex, complete, and/or useful conceptions of the concept. In addition, the more complex categories often encompass the less complex categories.

In this study, the collected data were analysed with respect to the following issues: how the students perceived engineering (and engineers) and what aspects they highlighted, as well as how the course influenced these perceptions. All written and spoken statements relevant to these issues were collected and read through several times to identify relevant themes. Kabo did the initial read-through of the research material, identification of relevant statements and first thematic clustering. This initial analysis was then discussed with and iterated upon together with Baillie. As seen in the research findings section, most selected quotes explicitly reference the course's influence or one of its components, such as the group project. Thus, we argue that we can say something about the perceived impact of the course from the students' point of view. However, our purpose with this study was not to evaluate or prove the possible success of the course (for that, another methodology would be more appropriate), but rather we were interested in what aspects of engineering the course brought forth in the conceptions held by students taking the course.

During this phase of the analysis, it quickly became apparent that the course highlighted very different aspects of engineering among the engineering and social science students, which is unsurprising as the two groups were bound to start from different positions. The emerging themes through several iterations were formalised into outcome spaces for the respective student groups, with categories of description representing different aspects of engineering brought forth by the course in the conceptions held by students. Initially, we had seven categories of description for the engineering students and two for the social science students (Kabo 2010), but with further analysis, these could either be consolidated or differentiated until we ended up with four categories of description for each student group. For the engineering students, the organising principle reflected a shift in focus from engineering problems to engineering practice, which we interpreted as progression in critical thinking in relation to engineering. For the social science students, the organising principle reflected a shift in focus from engineers as group and individuals to the potential of the engineering profession, which we interpreted as a progression in appreciation of engineering. However, this hierarchy is not based on the degree of positive attitude but on nuances in understanding. In addition, the different categories for each student group do build upon each other. For example, we find it difficult to imagine that a social science student would see any positive potential in engineering without first moving past holding only negative stereotypes of engineers.

Preliminary versions of the two separate outcome spaces have previously been published separately (Baillie, Kabo, and Reader 2013; Kabo and Baillie 2014). For this paper, we wanted to bring the two outcome spaces together, which involved an additional deductive step. For this, we drew upon Fleck's ([1935] 1979) idea of *thought collectives*. We argue that engineering and social science students can be said to belong to different thought collectives, with certain concepts and capabilities being considered core and others being considered more peripheral. In the interdisciplinary context we studied, the two student groups had the common object of learning (Lo 2012) of expanding their understanding of engineering, but from different starting points. We think our findings become comprehensive when interpreted as possible intellectual journeys in different directions in terms of thinking about engineering for engineering and social science students. Our identified categories of description represent

potential positions along these intellectual journeys as the students move closer to the other discipline, which also means moving further into a liminal space (Meyer and Land 2005).

4. Research findings: Students' expanding understanding of the role of engineering

In this section, we present outcome spaces capturing the possible expanding understanding of the role of engineering among the engineering and social science students taking part in the Engineering and Social Justice course. Taken together, our findings can be interpreted as intellectual journeys in different directions in terms of thinking about engineering. A visual summary of a combined outcome space highlighting the main focus for each category of description can be found in Figure 2. For engineering students, four categories of description—problem solving, problem framing, underlying assumptions, and embracing uncertainty—reflect a progression in critical thinking in relation to engineering and a shift in focus from problems to practice. This progression is likely due to an expanding understanding and valuation of the ways of thinking usually associated with the social sciences and humanities. So, in a sense, (some) engineers moved closer to the social sciences students, which is indicated in Figure 2 by the right-facing arrow. For social science students, four categories of description—stereotypes, beyond stereotypes, appreciation, and positive potential—reflect a progression in appreciation of engineering and a shift in focus from individual engineers to the craft and field of engineering. This progression is likely due to an expanding understanding and valuation of engineering and engineers. So similarly, to the engineers (some) social scientists took steps to lessen the distance between the disciplines, which is indicated in Figure 2 by the left-facing arrow. Here, it is important to note that our findings should not be interpreted as student learning happening in a purely sequential and linear way, moving from category of description to category of description. For an individual student, the process will likely involve much backtracking and oscillation between categories, which is characteristic of a liminal space.

Figure 2 goes here.

Below we present the categories of description, first for the engineering students and then for the social science students. The different categories of description are illustrated by representative statements from individual students from either interview (I#) or written reflection (R#), of which the former have been lightly edited to improve readability (i.e., by removing utterances that do not add meaning, such as filler words).

4.1. Engineering students: A progression in critical thinking in relation to engineering

The first two categories of description reflect a narrower focus on engineering problems, while the final two categories reflect a broader focus on engineering practice.

4.1.1. Category E1: Starting to question solutions to problems (problem-solving focus)

Some engineering students spoke of the impact of the course in terms of problem-solving. The problems, issues, and topics the students encountered in the Engineering and Social Justice course were by no means well-structured. Some students described how they had to rethink their ideas about problem-solving:

I14: [The course] taught me that my opinions and my ideas don't necessarily have to be right or wrong as they very often are measured and considered in engineering—right answer, wrong answer—and it's just very weird to think

‘oh! here’s an idea and that’s all it is,’ it’s just an idea, it’s not an answer or right or wrong or ... you could judge it accordingly.

R9: This course has opened my eyes in making me see that there are many different views in the world and that there are no universal solutions or methods when dealing with a problem.

While these students were starting to expand their problem-solving horizons, for example, moving away from right/wrong answers and universal solutions, often they were still stuck in a mostly technical paradigm when trying to deal with problems where social dimensions were important:

R1: I found the project to be a tremendous learning experience. To be perfectly honest, when I first tried to do some work I was completely at a loss for how to proceed. I looked at material from other design projects I’ve done and tried to emulate the same process, but in a lot of ways I found it breaking down. Some of the concepts just didn’t apply to projects of a social nature and even the ones that did seemed not to get me anywhere useful.

The students were starting to open up to more ill-structured problems with many possible solutions, but still, the problems were more or less taken for granted, and the focus was on the solution.

4.1.2. Category E2: Starting to question the actual problems (problem framing focus)

Some engineering students spoke of the impact of the course in terms of starting to move beyond considering not only the solutions but also the actual problems themselves, as well as asking questions along the lines of ‘Why are we doing this? For whom? Who benefits?’ Problem definition becomes central when dealing with the problems, issues, and topics the students came into contact with in the Engineering and Social Justice course. Some students described how they were starting to realise this and that they needed to ask new questions, especially when working in their community-based group projects:

R13: In the engineering curriculum we are programmed to determine an answer and we are not always asked to question the situation at hand. In general, the questions of why this task is being performed and who it is affecting are simply not asked. I feel as if this class has helped me to be more critical of different situations I face, and I found that this class was very informative and eye-opening.

R3: When brainstorming ideas for a product design for our project I couldn’t simply suggest, for example, a chair, as I would normally do in a brainstorming session. I had to stop, think, and deconstruct my suggestion before suggesting it to the group. I had to think: Who the chair was for? Was it useful for [people in country A]? Was there a market? Would [certain marginalized group] benefit from a chair? This differed completely from an engineering brainstorming session where I would suggest anything as long as it could be physically manufactured in an engineering context.

The critical aspect of this category of description is that the students are starting to shift their focus to the problem or task at hand and its surrounding context, and ask broader questions,

which might then lead to new and more fundamental questions about engineering.

4.1.3. Category E3: Starting to question underlying assumptions of engineering

Some engineering students spoke of the impact of the course in terms of starting to ask questions concerning the assumptions and common sense underlying engineering education and practice. When starting to ask broader questions, some students realised that they had to dig deeper, which for some led to reflection on the limits and restrictions of the conventional thought style of engineering problem solving they had been trained for:

R11: Knowing the underlying social cause of the problem changes the way in which the problem can be dealt with. Critical examination of social causes rather than a focus on only technical problems is something I never considered before, although now that I think about it, it appears to be in fact much more important than the technological factors alone. ... [The project] has changed my perspective on social issues and has led me to believe that the engineering approach to problem solving taught at [University A] is generally not the most comprehensive and is severely lacking in social considerations when working in the 'real world' outside of school.

Others, when digging deeper, started to reflect on the heavy, and often unreflected, emphasis put on profit and economic dimensions in connection with engineering practice:

R4: I always assumed that we had to design a product that would be marketable, but it wasn't until I started to see its connections to Neo-Liberalism theory that I did think of any faults of this goal.

I9: I think that it might be one of the most important things for an engineer to consider the true bottom line and [that] it's not just about the money. And to think about what the social implications and the environmental implications are and how there are gains and losses from all of them.

However, some students identified a tension between these new insights and what they perceived as common priorities in the industry. One student offered the following hypothetical example:

I13: Say I had three barrels of contaminated oil or something that cost \$5000 a piece to get rid of, or a site that I'm working on that is running into contaminated soil, or you contaminate the soil. A company doesn't want you to report that, they rather you bury the oil 10 meters underground and know that it will never be found for 500 years or more. Whereas from a social aspect now you will want to make sure the barrels go somewhere to get processed and make sure they get released back into the environment without an impact. Before in terms of profit it's a big margin there.

This student also articulated a perceived potential personal cost by assuming this kind of perspective or position:

I13: I feel now that I look at things from a different perspective or CAN ... I feel I'm going to think more socially about making certain decisions. But I

think it could have an impact on my success within a company ... (SIGH) this course... **[Interviewer: A bit scary...?]** Yeah, most definitely!

The critical aspect of this category of description is that the students are starting to express a much broader perspective that goes beyond the problems to be solved to questions about common assumptions informing engineering practice. The focus is on the underpinnings of engineering. Here, students might start to rethink prioritising technical and economic dimensions over social and ecological dimensions. This kind of reflection might give rise to uncertainty and concerns regarding students' future professional identity and practice. This can indeed be a very troublesome process as one starts to adopt a new and transformed view. However, this process could also open up new possibilities for some students.

4.1.4. Category E4: Embracing the uncertainty rising from a critical perspective

Some engineering students spoke of the impact of the course in terms of starting to accept and, also, value the uncertainty and confusion caused by questioning their education, future profession and even themselves. Their focus turned from common sense ways of thinking in engineering to themselves as engineers:

R1: I now find myself critiquing the society I live in on a daily basis. When I read or hear something, especially in my classes, I find myself critiquing it from the many perspectives we discussed in class. It always surprises me but also comforts me as I understand that I'm being slightly less ignorant than before.

For some students, this process of critique did not necessarily directly lead to increased clarity, but to the world appearing more complex and confusing than before and a growing realisation that most issues in the world are not engineering issues. However, in the end, this was seen as a good thing and highlights the need for reflexivity:

I7: I think the lasting impression is going to be that I need to do a lot of thinking about what I'm going to do after I graduate. And I think as of most of these issues that aren't engineering issues, where you walk out and say 'Okay, one plus one equals two.' You walk out of it feeling like you knew less than you did when you walked in and you have to do more research and you have to think about the issues more. So I do feel I'm going to walk out of it feeling, personally, that I need to think hard about what I'm going to do after I graduate, but I also think I'm going, just in general, to feel like the world is more confusing than I thought it was. **[Interviewer: So less wise and more confused?]** Yeah, but I mean in a good way.

Some students further emphasised the need for this kind of reflexivity together with humility and being open to critique in order to be able to find appropriate holistic 'solutions' that also take social and human dimensions into consideration:

R7: [The communication skills gained from the project] have allowed me to slowly begin to dismantle my own 'ivory tower of engineering' and to begin to fully engage with the issues I am examining on a much more holistic level. ... By stripping myself of the prestige of engineering I make myself vulnerable to critique as well. I consider this vulnerability to be central to a socially just design process. As flawless as the technical minutiae of a project

might be, no design will ever be perfect in four dimensions. The design process must then incorporate a reflexivity that allows for it to change with time and conditions, be they social, physical or otherwise.

In short, students start to embrace the uncertainty rising from a critical perspective by realising its potential and necessity for coming up with real new alternatives and for change. In contrast to the preceding category of description, they are more comfortable with confusion until a potential way forward emerges. Here, we want to stress that the idea is not for students to critique existing good practices but to develop the skills of critique so that taken-for-granted assumptions can be questioned and appropriate choices made about the future. For example, if students assume that technology equates to advancement, then they might ignore the problems of the environmental impact of those technologies.

4.2. Social science students: A progression in appreciation of engineering

The first two categories of description reflect a narrower focus on the engineers themselves, while the final two categories reflect a broader focus on the engineering profession.

4.2.1. Category S1: Stereotypes due to no (or negative) idea of what engineering is

Some social science students spoke of views they held of engineering and engineers before taking part in the course:

R18: I remember when I first came into this class, I had no idea of what ‘engineering’ actually was, beyond the chants we sang about engineers who should ‘go build a bridge and jump off it.’

I8: I thought that all engineers wouldn’t be able to have any critical thinking skills or be able to reflect because they ... go to class, sit in lectures, take notes, read a text book, study it, memorise it, and write it out, so they never question materials so that they wouldn’t have those critical thinking skills as individuals.

I10: I used to think that engineers had no social skills, but this course has proved otherwise.

These statements clearly illustrate previously held views centred around stereotypes about engineers, arising from a lack of or naïve knowledge of engineering.

4.2.2. Category S2: Seeing beyond stereotypes about engineers and engineering

Some social science students reported more nuanced views of engineering due to participating in the course—they did not see engineers as one uniform group but rather as a collection of individuals, some with positive potential. However, this broadened understanding did not always lead to increased clarity about what it is that engineers do:

R18: In some ways, my definition of what engineers do has become even more confused, but in others I’ve grasped the breadth of knowledge and expertise that engineers bring to their own field of study, which happens to be as or nearly as widespread as the liberal arts programmes. Along with this diversity, I have also begun to recognise the difference among each engineer

I've gotten the chance to know—it turns out they aren't just one big group of partying, conservative, clones after all!

One aspect that appears to be central to several of the social science students was getting to know and work with the engineering students as individual people:

I8: I did have preconceived notions about your typical male engineering [student], sort of not very considerate, very much just in with the work that they were doing, and more boyish and immature, but it's not true. The guys that I worked with were critical thinkers, they were gentlemen, they were socially conscious. They weren't perfect by any means, but they were complete, they were really kind, really amazing people and I think that it was really important for me to sort of break down to work with them and get to know them past my classmates and as friends and, yeah, I think they were amazing.

The interaction with the engineering students helped to challenge preconceived notions, which is an important first step toward grasping any positive potential engineering has to offer:

I10: I think a lot of people [engineering students] are very well spoken and come across as extremely socially intelligent people so ... a lot of my preconceptions have definitely been taken away which is probably a good thing.

Working with engineering students in a constructive manner during the course offered the social science students an opportunity to break down (negative) stereotypes about engineers and engineering.

4.2.3. Category S3: Appreciating engineering—wanting to know more about 'these things'

Some social science students reported their appreciation of 'the art of engineering':

R6: One of my proudest moments of the project was when I could stand in front of our entire class and discuss the intricacies of load-bearing walls and feel (somewhat) legitimate doing so! This project has definitively sparked an interest in wanting to learn more about 'these things,' as well as a new appreciation for the art of engineering (who knew you needed cement to hold a post in the ground!?).

This category of description focuses on 'doing engineering' rather than the engineers themselves. In addition, the category highlights a more personal perspective on engineering knowledge in terms of confidence and desire to know more.

5.2.4. Category S4: The realisation that engineering holds positive potential for the creation of alternatives

Some social science students reported seeing the value of working together with engineers and becoming more aware of the positive potential of engineering:

R14: Participating in this class this semester has definitively been an eye opening experience. I came to the class thinking I knew what 'social justice'

was and how it should be approached. However, I have come to realise that social science students are often given the tools to deconstruct an issue, but have no ability to directly apply it in the real world. Working with engineers has most definitively created and developed this balance. Overall, this class has taught me not only to think but to think and act.

One characteristic appreciated by the social scientists was the engineering students' ability to take action in order to get something concrete done:

R2: ... during this idea generation stage I realised that there will never be a perfect option, however unlike in sociology where one can simply deconstruct—engineers are trained to construct. Therefore I had to force myself from rejecting every idea that was suggested and try to decide on one that seemed like the 'best' option.

Other students focused more on awareness of the positive aspects and potential of engineering in general:

I10: Before I was very critical, sort of talked from a perspective that everything is bad, science [and engineering] is bad. All they want to do is take over the world and earn lots of money. ... [The course has] made me more aware that there are positive aspects within that as well that can be very helpful and very useful. I mean there are a lot of things that technology does for us that is very useful, it just a matter of not always taking it for granted or just accepting everything that we are sort of presented with as necessary so...

This category represents a much more complex perspective than the previous three. The social science students start to acknowledge the complementary knowledge and skills engineers can bring to the creation of viable alternatives to current practices. The progression between the four categories of description can be likened to the shape of an hourglass, where the students start with a generalising perspective, then move on to a more narrow but individual perspective, and finally, end up with a general and nuanced perspective.

5. Concluding discussion: Intellectual journeys in different directions

The two outcome spaces shown above complement one another and suggest the possibility for movement toward increased capability for interdisciplinary collaboration between engineers and social scientists in the future. In addition, the two outcome spaces also reflect the two main themes of the course: the deconstruction of the 'common sense' of current engineering practices and the creation of alternative practices. In some sense, the first theme is a prerequisite for engaging with the second theme in a more profound manner. We would argue that one needs to become aware of the assumptions one holds about something, such as engineering practice, before one can really consider any radically different alternatives. Engineering students are often not trained to ask these kinds of questions, and while engineers are expected to manage uncertainty in relation to technical problem solving, they are less used to managing uncertainty in relation to, for example, social aspects. Social science students, on the other hand, are often used to asking these kinds of questions but often lack adequate knowledge of engineering to do a proper deconstruction of it and thus open up toward seeing the positive potential of engineering in creating constructive alternatives to current practices in order to meet the challenges of tomorrow. Thus, both engineering and social science students need to develop their thinking and knowledge along

new pathways and in new directions in order to facilitate future interdisciplinary collaboration.

It is also important to note that this difference in trajectories is inevitable, considering the varying disciplinary preparation of the students, but also because in one case, engineers are considering new perceptions in their own profession, and in the other case, social scientists are considering new perceptions of others. Furthermore, and rather interestingly, our findings can be interpreted as the engineers mostly starting with a positive view of engineering, which became much more nuanced and uncertain and, in some cases, negative. On the other hand, social scientists can be interpreted to have often started with a rather negative view and moved to a more positive one, as they started to work with engineering students and experienced their intellect and values. Engineers had to reflect upon their own ‘identity’ as professional engineers, whereas social scientists had to consider engineers as human beings, often for the first time, not just anonymous professionals creating ‘technology’. Applying a critical perspective to one’s education and future profession might lead to a clash with the engineering identities perpetuated by many engineering education programmes and institutions (Berge, Silfver, and Danielsson 2019; Morgan, Davis, and López 2020). Engineering identity has been studied extensively (Morelock 2017) and could be one way to extend the discussion of our findings, but it is beyond the scope of this paper.

While the empirical and analytical focus of this paper has been the potential shifts in perspective on engineering among the students participating in the Engineering and Social Justice course, and not on their broader experiences of this educational context, we have some insight from a previous publication of ours (Kabo, Day, and Baillie 2009). Given that studies of interdisciplinary courses combining engineering and humanities and social sciences students appear to be somewhat uncommon (Van den Beemt et al. 2020), we thought it might be worth to share what two students had to say about this mixing of students (Kabo, Day, and Baillie 2009, 133-134):

I14 [engineering]: I loved that there was a mix ... I would love to see more interaction between engineers and sociologists, but again I wouldn’t want that sort of thing imposed, ... but I wanted more of it to happen just because it was so interesting. When we were working with [sociology student] ... she was the only non-engineer in the group and ... she just thought of things very different than we do and I really liked that and would have liked to see more of that.

R12 [developmental studies]: The most valuable aspect of the course was the opportunity to interact with other students coming from very different backgrounds, especially the engineering students. I found the in-class discussions very interesting, especially as students with different perspectives tried to understand each other and communicate their interpretations of subject matter. ... the opportunity to work together and question our assumptions of what we think we know.

While this is only two voices, the sentiment is also reflected in some of our selected quotes for this current study, especially in Category S4—they say something about the students’ appreciation of the interdisciplinary mix. Still, while the course contained a mix of disciplines in terms of student composition and encouraged some collaboration across disciplines (in the form of community-based group projects), the students appeared to be quite firmly situated in their different thought collectives. For example, in their critical project self-reflections, some students wrote about how they had divided the work up along

disciplinary lines to use the time effectively. This is not surprising as the students were taking several disciplinary courses in parallel with this course, and the time period was only twelve weeks in total. Our findings point to—at least partial—expansion beyond these disciplinary thought collectives and to an approach to supporting the passing of thresholds towards a broader, boundary-crossing, interdisciplinary space of learning.

After the initial iteration of the Engineering and Social Justice course focused on in this study, the course had a second iteration at an Australian university, which included further developments by an anthropologist, and then the third iteration at a US-based institution. The core idea and approach of the course have remained intact across its various iterations, but with constant iterative improvements. A few observations based on the author/instructor's (Baillie's) experiences over the past 20 years are worth noting:

Course intensity: The Australian version of the course moved to an intensive mode of learning, with one full day per week, which enabled deeper student discussions (Male et al. 2015). The intensity of the sessions enabled the students to better see the difference in ways of thinking in action and made them better able to question terminology or concepts that they did not understand as they could delve into it for longer periods of time. The instructor has observed that the more intensive the class, the more students were able to focus on just this topic, and the easier it was to help them get out of standard mindsets.

Passage of time: It is also noted that each time a course is taught within the same institution it becomes a little easier to help students through the thresholds. This is notable particularly where engineering students hold a bias that studying the social impact is not important, and social scientists have a bias that engineering students are not interested in positive social impact. The 'word of mouth' through the student body that this is a useful course, that this course 'changed my perspectives' aids in their perceptions at the start of each course.

University context: In a liberal arts college, such as in the US, it is certainly easier to teach this course than at universities where students do not have the opportunity to study from many different disciplines outside their own. However, it is the author's experience that this is not always the case. A more important factor is that other instructors/courses from the *same school* also help to reinforce the lessons learnt. This has been the case at the University of San Diego Integrated Engineering programme where students of the sustainability concentration have been the most successful yet at passing through the thresholds as the whole Department focusses on sociotechnical studies. Another critical factor is that engineering students and social science students need the opportunity to discuss *together* in small groups in the classroom, engage in groupwork, and be explicitly asked to reflect on their perceptions, in order for these thresholds to be passed. Being together in a large lecture does not suffice.

It is still incredibly rare to find learning opportunities for engineering and social scientists to work together at undergraduate level and to critique and question their own positions through a critical pedagogical approach. This has been fully explored by Baillie and Kadetz (2024) in their recent book 'Reimagining Engineering Education: Health. Justice. Sustainability.', where they consider the capabilities that students need to develop by learning from other disciplines if they are to become just and sustainable engineers. In the book they note that this has been achieved well at the master level (including the Master of Science in Engineering, Sustainability and Health founded and directed by Baillie—open to students of any discipline and taught by professors of many) but not yet at undergraduate level.

In later versions of the course, a learning journal has been used to enable students to reflect on their learning inside the course and out, in relation to the themes of the course, and to explore their understanding in whatever creative style they preferred. The students' learning trajectories are then mapped using ideas from initial work of ours, which assumes students take a journey through certain 'thresholds' and into a 'liminal space' (Kabo and Baillie 2009). The research from these early studies was used to develop an assessment tool that enabled the instructors to see where the students were on their learning trajectory (Baillie and Male 2019). Students submit their writings each week and engage in exercises in the classroom which help them learn to identify where each other's work is on a pathway through the liminal space. This gives them rich feedback and enables them to concretize what the course aims are and how to achieve them.

The categories of description identified in our approach can inform course development and assessment approaches in future courses which bring social science and engineering students together to learn in an interdisciplinary, boundary crossing way. This could be done by developing an assessment tool based on the categories of description as done by Baillie and Male (2019). The threshold that students would be passing through would be more explicitly related to the particular passage that engineers and social scientists pass through as shown in Figure 2 above. Teaching strategies which support and specifically target social science and engineering students at each stage of their journey along that passage could inform curriculum development. Focussing on these points of variation, spending more class time on troublesome thresholds and less time on other areas which students do not find tricky, is a classic way of applying threshold concept research into practice.

As final remarks, our take-home message regarding engineering students is not that they also need to become social scientists, but that they will gain from understanding the value of the analysis that social scientists can provide. Similarly, social science students can benefit from obtaining a better understanding of engineering and its possible potential. Both groups need to realize the importance of collaboration across the disciplines on more intangible global problems. In short, we need to help students expand or move beyond their disciplinary thought collectives.

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Ethical approval statement

At the time of the data collection, the project was reviewed and approved by the General Research Ethics Board at Queen's University, Canada.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Additional information

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Table 1. Overview of topics covered in the 2009 iteration of the course.

Week	Topic
	Part I: Introduction to Key Concepts
1	Introduction to Critical Theorizations of Technological Practices and the Information Revolution
2	Science and Technology Studies: technological determinism, technophilia, social construction and technophobia. Field Research Methods.
	Part II: Analyzing the Dominant Paradigm
3	Historical Context: European ‘Enlightenment’, the Industrial Revolution, Modern capitalism. Field Research Methods.
4	Current Context: Postmodern capitalism, neoliberalism, globalization.
5	The division of Labour in Engineering practice today; labour as commodity
	Part III: Critical Perspectives and Alternatives
6	Rights, Justice, Freedom & Ethics: Towards Just and Sustainable Human Communities
7	Working Within: The State and State Policy
8	Working on the margins: Co-ops and Recovered Factories
9	Working outside: Delinked Communities, indigenous struggles
10	Dealing with oppression within progressive movements and spaces: race, gender, ability, etc.
11 & 12	Student Presentations

Table 2. The 2008-2009 course learning objectives.

By the end of this course students will be able to ...

- Demonstrate the historical context of engineering in relation to the Industrial Revolution
- Demonstrate an ability to think critically and reflexively not only about engineering practices in the abstract, but about your own work in this course.
- Challenge current 'common sense' views of engineering practice
- Assess different views of the relationship between science, technology and society
- Differentiate between rights, justice, freedom and ethics and illustrate their relation to engineering practice
- Identify the role of labour in engineering practice
- Characterize the relationship between state policy and technology
- Describe feminist perspectives on technology
- Analyze the relationship between technology and racialization
- Critique Neoliberalism, Globalization and the role of engineering
- Evaluate Participative design practices
- Compare and contrast radical and traditional sustainability practices
- Synthesize data from different sources
- Work together with other students to develop a consistent argument
- Represent multiple viewpoints in a coherent report and presentation
- Demonstrate the application of critical theory to engineering practice/theory
- Demonstrate the ability to write clearly and concisely with adequate grammar
- Demonstrate good presentation skills
- Demonstrate good debating/negotiating skills

Table 3. Breakdown of informant characteristics.

Class iteration		2008*	2009*	All	Mix of disciplines
Engineering	Male	11 [of 19]	14	25	A mix of engineering disciplines, such as civil, chemical, electrical, geological, mechanical, mining and engineering physics; year 2-4 [of 4].
	Female	0 [of 1]	3	3	
	Total	11 [of 20]	17	28	
Social science	Male	0 [of 1]	3	3	Mainly sociology and developmental studies, one or two from history and environmental studies; year 2-4 [of 4].
	Female	3 [of 5]	10	13	
	Total	3 [of 6]	13	16	
Everyone	Male	11 [of 20]	17	28	*Number of interviewees [out of everyone] from the 2008 class and collected self-reflections from the entire 2009 class.
	Female	3 [of 6]	13	16	
	Total	14 [of 26]	30	44	

Figures

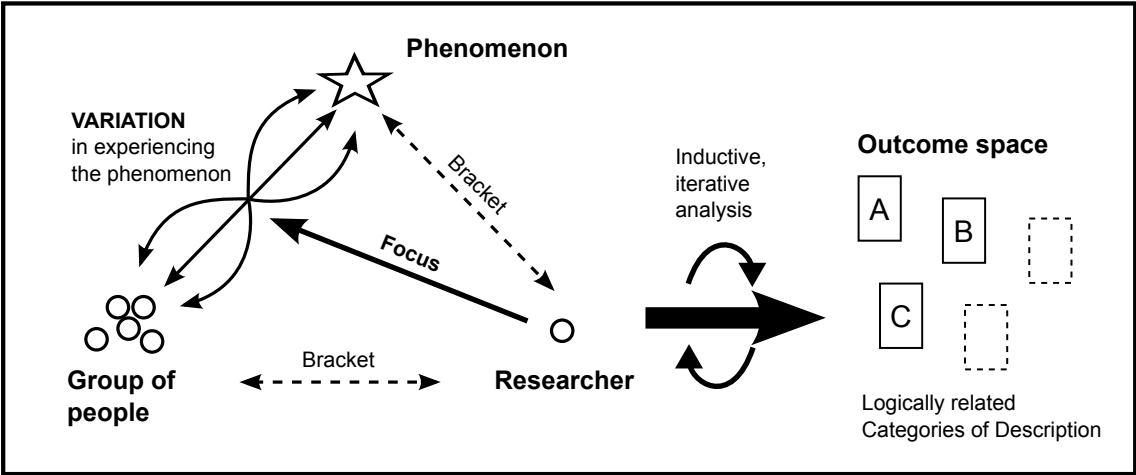


Figure 1. The key concepts and methods in the phenomenographic research process. (Adawi and Kabo 2012). Reprinted with permission.

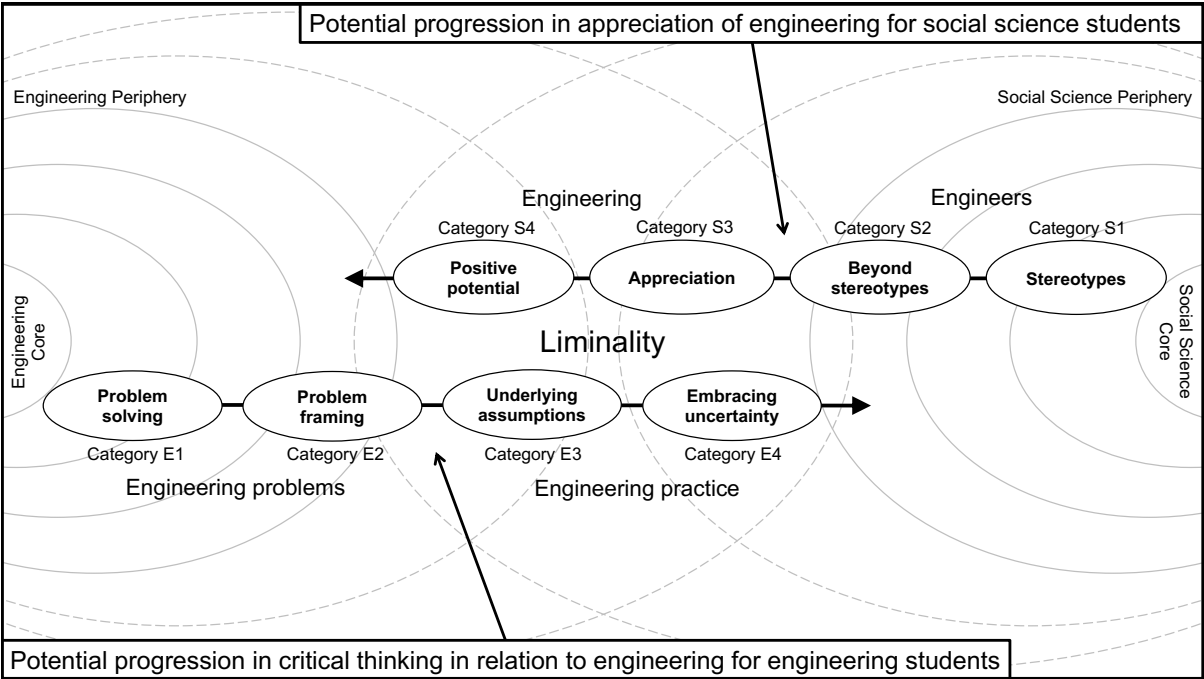


Figure 2. Engineering and social science students' respective expanding understanding of the role of engineering, conceptualised as intellectual journeys in different directions, bringing them closer to one another through a series of categories of description of increasing complexity.

Figure captions

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