SUPPORTING STUDENT TEAMS TACKLING WICKED PROBLEMS: INTRODUCING CARDS OF AMBIGUITY

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ABSTRACT

Project- and challenge-based courses in higher engineering education that address wicked problems introduce ill-defined, real-world problems to students. In these courses, they experience various forms of uncertainty and ambiguity inherent to complex problems, stemming from unclear problem definition, contradictory information, unpredictable project directions, and contradictory feedback from various supervisors. Students vary widely in how they perceive and react to ambiguity and uncertainty: some find uncertainty stimulating and creatively liberating, while others experience confusion, anxiety, and avoidance. Interviews performed with educators and students at TU Delft revealed that throughout the various phases of such projects, students frequently experienced frustration, insecurity, and overwhelm. These emotional responses strongly shape learning, yet emotional competencies are rarely addressed explicitly in engineering education. We also saw that educators often struggle with finding appropriate materials and methods to guide students through the process without over-directing. Most educators lack the pedagogical approaches needed to support the development of reflective, collaborative, and emotional competencies needed for dealing with wicked problems. To address this gap, we introduce the *Cards of Ambiguity* - a serious game designed to help student teams reflect on and discuss potential responses to ambiguous and uncertain situations. It aims to reduce negative emotions, build confidence, and normalise uncertainty as an inherent part of tackling wicked problems.

KEYWORDS

Ambiguity, Uncertainty, Complex problems, Emotions, Serious game, Standards: 3, 7, 8 and 10

INTRODUCTION

Wicked problems in project-based education

Active and experiential learning methods, such as challenge-based learning in higher engineering education (Gallagher & Savage, 2023; Lavado-Anguera et al., 2024) are advocated by the CDIO Standard 8. These approaches integrate theoretical knowledge with practical applications through relevant real-world cases and pressing societal challenges presented by external stakeholders (Guerra et al., 2017). Besides increasing students' intrinsic motivation, these active learning formats help to prepare students for professional environments by fostering the development of transversal skills (formulated in the CDIO Standard 3 and 7), such as critical thinking, problem-solving, and creativity (Sari et al., 2024, van Uum, & Pepin, 2020). Given that real-world cases often transcend the boundaries of academic disciplines, project-based educational practices facilitate contextual and inter- or transdisciplinary learning (Michel, 2009).

Tolerance of Ambiguity and Uncertainty

Complex projects central to challenge -based learning are "challenged by potential disruptions characterized by growing volatility, uncertainty, and ambiguity" (Nachbagauer, 2021). While uncertainty and ambiguity can be defined distinctly - uncertainty referring to events or trends that are difficult to predict even with sufficient information, and ambiguity relating to situations in which information is incomplete, unclear, contradictory or subject to multiple interpretations (Taskan et al., 2022) – the terms are often used interchangeably (Budner, 1962; Winkler, 2016).

Individual differences in how people interpret ambiguous situations and respond to unfamiliar or incongruent cues (often referred to as tolerance of ambiguity or uncertainty) are well-documented (Budner, 1962; Ely, 1989). Individuals with low tolerance of ambiguity and uncertainty often struggle to adapt to complex situations, displaying avoidance behaviours, rigid thinking, and a strong preference for certainty (Furnham & Ribchester, 1995). In contrast, individuals with high tolerance tend to perform better in complex problem-solving (O'Connor et al., 2018). They demonstrate greater flexibility and creativity (Tegano, 1990), effective learning in new contexts (Fenton, 2019), and a more open attitude toward diversity (Wilkinson, 2006). These associations make the facilitation of tolerance of ambiguity an appealing learning goal, particularly in challenge-based learning (Saarikoski & Rybushkina, 2019).

The term "tolerance", however, may be insufficient to capture the range of learners' responses to ambiguity. First, learners must absorb new information that may contain unknowns, hold contradictory or incomplete information without prematurely rejecting it and integrate new information into existing cognitive structures. These steps require not just simply bearing uncertainty, but accepting it and embracing it. For these reasons, we propose replacing "tolerance of uncertainty" with the broader notion of "coping with ambiguity and uncertainty."

Coping with ambiguity and uncertainty in educational settings

To introduce the aspects of uncertainty and ambiguity in challenge-based courses addressing complex problems, we draw on the conceptual model developed by Hillen and colleagues (Hillen et al., 2017). This model underscores the significance of various sources of ambiguity and uncertainty, individuals' subjective perceptions of them, and the psychological responses (covering cognitive, emotional, and behavioural responses) they elicit.

Ambiguity sources

The student-centred approach of challenge-based education inherently introduces ambiguity and uncertainty. Students may choose topics beyond the teacher's expertise, pushing educators to act less as content experts and more as process facilitators (Bohm et al., 2020). For students, ambiguity arises when project scopes are unclear, key information is missing, the available or found data are contradictory, solution paths are unfamiliar, multiple solutions exist without established best practices, or project outcomes cannot be predicted (Tao, 2024).

They can experience individual uncertainty that arises from perceived deficits in knowledge, skills, or rules needed to solve the problem (Daalhuizen et al., 2009). Low self-efficacy reduces motivation, particularly when outcomes are uncertain (Bandura, 2001; Bandura & Wessels, 1994). Task uncertainty can arise from the unpredictability of inputs and outputs within the course (Daalhuizen et al., 2009, Griffin et al., 2007). Social uncertainty arises from insufficient information exchange or limited collaboration among team members or external stakeholders (Daalhuizen et al., 2009).

Perception of ambiguity and uncertainty

How students perceptive uncertainty varies according to individuals' backgrounds, experiences, and personality traits. Cultural and educational contexts also shape these perceptions. Research on design students shows that practice and experience strengthen learners' confidence in managing uncertainty. Students reported that discussing uncertainties, gathering and reviewing information, and seeking external models, feedback, or collaboration helped them mitigate the negative effects and change the negative perception of design-related uncertainty (Tracey & Hutchinson, 2018).

Responses to uncertainty and ambiguity

Some learners experience uncertainty as liberating and appreciate the agency or freedom of choice (Anselme, 2010; Tracey & Hutchinson, 2018). Ambiguity can also foster creativity by encouraging exploration beyond conventional boundaries. Suzawa (2013) argues that ambiguity is inherent to human knowledge and should be embraced through openness.The positive cognitive responses can range from acknowledging uncertainty, feeling attracted to it, and experiencing curiosity. However, when ambiguity levels become too high or when students cannot handle unclear information, this can evoke strong negative emotions, which then prevent students from learning and making important decisions (Levy & Schiller, 2023). Negative cognitive responses encompassed denial, aversion, distrust, self-doubt, confusion, and catastrophizing. The emotional responses cover the range from comfort, enjoyment, and excitement to discomfort, stress, anxiety, fear, depression, and anger.

Some negative behavioural responses aimed to prevent the negative effects of uncertainty—such as avoiding ambiguous situations—while others sought to manage these effects once they arose, for instance by exerting control over manageable factors. Information seeking, adaptation, functional engagement, deliberation, and disclosure can be labelled as positive behavioural responses. In contrast, avoidance, dysfunction, decision paralysis, non-disclosure, resignation, and control-oriented behaviour were classified as negative responses (Hillen et al., 2017). This is in line with other studies, which highlight that wicked problems require not only cognitive skills and logical reasoning but also emotional competencies (Lönngren et al., 2023).

With this background knowledge, we were interested in how engineering students experience project- and challenge-based courses at TU Delft. We have interviewed educators and students to answer the following questions: (1.) What challenges do students encounter when working with wicked problems? (2.) How do students cope with these challenges? (3.) How do teachers support students in navigating ambiguity and uncertainty? At the end of this paper, we discuss the findings with special attention to emotions that arise during these projects and introduce the Cards of Ambiguity game, designed to support student teams in dealing with ambiguity and uncertainty during courses tackling complex problems.

METHODS

In this project we focused on how complexity, ambiguity and uncertainty manifested in courses in which students were dealing with complex problems. We conducted interviews of approximately one hour with 21 education practitioners and 9 students across various engineering programmes at TU Delft, using purposive and snowball sampling (Cohen, 2002). First, we approached 21 educators, involved in multi-, inter- and transdisciplinary project- and challenge-based courses, as they interact with a large number of students, and they have experienced diverse cognitive, behavioural, and emotional responses of students through the years. To validate the educators' experiences, we also interviewed some students who followed such courses. We stopped the student interviews when we reached data saturation. The questions were designed to gain a detailed understanding of the challenges students faced related to ambiguity, complexity, and uncertainty, as well as the emotions they experienced and how these emotions influenced their approach to tackling these challenges. The data were organised into themes that informed the initial insights and hypotheses regarding the types of competencies needed to navigate wicked problems. The research design, including participant recruitment, data collection, and data management, was approved and guided by the Human Research Ethics Committee of TU Delft (19-Feb-2025, #5081).

The interview data were analysed using a reflexive thematic analysis approach. Transcripts were read multiple times to become familiar, then coded inductively to capture patterns in how students and educators experienced complexity, uncertainty, and ambiguity. Codes were gradually clustered into broader themes through an iterative process of comparing meanings, revisiting the data, and refining interpretations. Throughout the analysis, we engaged in memo writing to reflect on emerging ideas and to remain aware of our own assumptions. To support validity, several strategies were used. First, codes and themes were checked with participants to ensure accuracy of interpretations. Second, frequent review of raw transcripts along the analysis process ensured that interpretations remained grounded in participants' words and experiences. Finally, the iterative nature of the design-based research process strengthened validity because preliminary insights could be tested and refined in later cycles of data collection and intervention development.

RESULTS

Challenges experienced during the initial phase of projects with wicked problems

At the outset of projects involving wicked problems, students often struggled to establish a workable starting point due to the complexity and ambiguity of the problem space. They found it difficult to determine what mattered when interacting with real-world constraints and competing values. Although many recognized that issues such as sustainability or futureoriented design involve intertwined technical, social, and ethical dimensions, they still found it hard to decide which aspects were relevant.

Ambiguity in problem definition further complicated the early stages. Students were also unsure what exactly the problem was. Although some were energized by abstract or controversial problems and proactively sought information, others responded with confusion and a sense of overwhelm, narrowing their attention to controllable elements and rushing to reach outcomes. Educators described this ambiguity as a confrontation with engineering identity, and students' mindsets are influenced by prior education.

"Engineering students are not so used to exploring wicked problems, because they think the world judges them on their solutions; It's their identity. And they've been taught their whole lives that there's one correct answer for everything. When it comes to less concrete things, they tend to go towards the efficient solution, which is oftentimes not the most innovative or the solution that gets to the core of the issue."

This stage was marked by frustration, confusion, and overwhelm, often leading students to rush toward simplified definitions, request detailed instructions, or label the project as vague. Many struggled to accept subjectivity and contradictory interpretations, preferring approaches that justified clear actions. Teachers, therefore, faced the challenge of offering guidance without over-specifying the task, leaving room for personalized learning.

Limited contextual understanding also shaped the early phase, especially in unfamiliar domains or projects with external partners. Students lacked insight into stakeholder priorities, constraints, and work practices, and were inexperienced in estimating timelines in real settings. Their initial ambition and confidence often diminished once they encountered unforeseen complexity. Some students avoided the human aspects of the work and focused on technical components, while others became uncertain about next steps due to the absence of a stable interpretive frame. Some teachers facilitated field visits to help promote students' contextual understanding as well as their motivation and interests in learning.

Challenges during the projects

After defining the problem, students moved into project planning and prototyping. Students noted that uncertainty manifested in this phase through unpredictable project directions, shifting requests, and conflicting disciplinary or personal constraints. Some struggled with ambiguity in communication with their peer students due to disciplinary gaps.

"There can be lots of communication challenges. Students from industrial design don't understand why something doesn't work because they don't have our technical knowledge, but we (biomedical engineering students) have a very technical mind. We focus on different things. People sometimes get confused and frustrated, and even avoid working together."

Projects also frequently unfolded in unexpected ways. Stakeholders changed their requests, and students revised their beliefs. These disruptions left many students feeling frustrated, stressed, and vulnerable. The resulting loss of orientation reduced motivation, leading some to lower their study ambitions. While some students struggled to adapt, negotiate with stakeholders, or persist in the face of uncertainty, others demonstrated proactivity, sought help, and maintained engagement despite time pressure and emotional discomfort. Both students and teachers emphasised that curiosity, positivity, and intrinsic motivation supported resilience, though educators found it challenging to foster these qualities.

Cross-disciplinary projects introduced additional difficulties when teachers and stakeholders from diverse backgrounds provided conflicting or expanding feedback. Students often felt overwhelmed and stuck with the process. Educators observed that perfectionism and low confidence hindered students' ability to navigate ambiguity. They argued that students needed to focus on the learning process rather than the perfection of outcomes.

Collaboration with peers, teachers, and stakeholders means confronting diverse professional and cultural backgrounds. When differences in working styles, expectations, or social norms were not openly communicated in the student teams, conflicts escalated, harming group dynamics and impeding learning. Unresolved tensions could affect psychological safety and student well-being. While some students embraced interpersonal differences and built strong social bonds, others avoided collaboration or felt marginalised. Both students and teachers agreed that effective collaboration is essential for engineering practice.

Challenges experienced at the end of the project

Students sometimes struggled to accept that no perfect solution exists when confronted with the inherent subjectivity and trade-offs of wicked problems. When multiple, even contradictory, outcomes were equally defendable and technically justified, students reported confusion, frustration, surprise, and dismissiveness. This often led them to seek standard answers, criticise alternative approaches, and reject divergent problem-solving paths.

Because projects could only address fragments of the broader complex problem, evaluation became more difficult to standardise. Yet students strongly desired clear rubrics to follow to achieve expected grades. Educators noted that many students sought reassurance and validation to reduce insecurity, and some complained about the perceived vagueness of assessment criteria. Emotions such as anger, frustration, and disappointment were common. Teachers attributed these reactions to limited confidence and difficulty accepting subjectivity.

Even when students produce project outputs in the short project period, they can remain uncertain about the feasibility of their solutions in practice. Many students perceived a gap between their outputs and real-world expectations, which contributed to doubts about their emerging professional competence and identity, as well as disappointment with their learning results. As mentioned by a student from Architecture:

"Sometimes, we feel frustrated, insecure, and fearful about what we can actually do. We are unsure about how our designs will be in real life."

DISCUSSION

Across all phases of project work, TU Delft students' experiences revealed that engaging with complex problems challenges their interpersonal skills, namely emotional resilience, collaborative skills, and tolerance for ambiguity. Students frequently struggled with the absence of clear problem definitions, the coexistence of multiple valid solutions, and the subjective nature of both decision-making and assessment. These difficulties were intensified by cross-disciplinary collaboration, shifting stakeholder expectations, and limited time for iteration. Emotional responses such as confusion, frustration, insecurity, and disappointment were common.

We also saw that curiosity, intrinsic motivation, and a supportive learning environment can help students engage more constructively with complexity. Educators play a crucial role in normalising ambiguity, guiding cross-disciplinary communication, and fostering psychological safety. Ultimately, our study underscores that preparing engineering students for wicked problems requires deliberate attention to the development of reflective, adaptive, collaborative and emotional competencies. This requires explicit focus on strengthening interpersonal skills and teaching students to deal with the societal context.

It is not new that students need emotional competencies in addition to cognitive skills to tackle wicked problems (Lönngren et al., 2023). Several neuroscientific studies have shown that emotion and cognition are deeply intertwined in the human mind, and the division between them may be unrealistic. Both emotion and cognition influence human behaviours, including decision-making, and vice versa (Dolan, 2002; Pessoa, 2008); they guide behaviour by partially reactivating bodily and brain states from past experiences (Niedenthal, 2007). Some neuroscientists suggest that the brain's function during decision-making relies more on emotion than on intellect (De Martino et al., 2006).

How can we support students to deal with uncertainty and ambiguity?

While students and lecturers involved in challenge-based education must deal with various types and different levels of uncertainty, which inherently result in emotional responses, hardly any course developers make dealing with uncertainty and ambiguity explicit in their course design. At TU Delft, teachers expect students to take initiative and remain engaged even when facing ambiguity, and are often left to deal with uncertain and ambiguous situations on their own. Educators at higher universities, in general are not prepared to facilitate the development of emotional competencies (Tracey & Hutchinson, 2018). "*When facing challenging tasks, there is a need for a range of cognitive and emotional skills and other qualities that go beyond what most people normally learn in schools and higher education* (Ankrah et al., 2023)".

Insights from the literature review and interviews with TU Delft teachers and students informed the design of a game intended to support student teams working on complex project-based problems. **The Cards of Ambiguity** game aims to help students build confidence and autonomy in navigating ambiguous situations while reducing negative emotions such as anxiety and frustration (Tao, 2024). By discussing their experiences with uncertain project scenarios - an exercise aligned with intellectual candour (Lazarus et al., 2023) - students reflect on past responses, explore hypothetical challenges, and identify strategies suited to their team. It is building on educators' experience with confidence-building and reflective activities. Similar experiences were found with peer reflection by Bienkowska & Lovén (2017). The game thus fosters reflection, informal active learning, perspective-taking, empathy, and collaborative problem-solving, mostly belonging to interpersonal skills. Although team-oriented, the game incorporates a competitive element to appeal to players motivated by achievement (Heeter et al., 2011).

It includes 20 problem cards, 65 solution cards derived from both the research results and the literature, and erasable cards for students to add their own challenges and responses. Fig. 1 shows an example problem card, focusing on negative emotions emerging during the project (derived from the results), and an example solution card (suggested by an educator during the interview). During play, team members select and justify a solution card they believe best addresses the drawn problem card, then collectively choose the most suitable option. A typical session consists of five rounds plus a final reflective round, taking approximately 45 minutes. Additional time allows for the use of blank cards to tailor the activity to team-specific issues. All game materials - including instructions, cards, and packaging - are available for downloading and printing under the following link (Cards of Ambiguity).

Figure 1. The cover of the Cards of Ambiguity, an example of a problem and solution card

CONCLUSION

Challenge-based learning was shown to equip students with professional competencies, such as critical thinking, teamwork, self-direction, communication, and collaboration with societal stakeholders when compared to traditional educational methods (Klaassen & De Bruin, 2022, van Uum & Pepin 2020). Several studies have acknowledged that students and teachers experience uncertainty and ambiguity during challenge-based education (Bohm, 2024), while there was little attention paid to what challenges students experience, what kind of emotions these challenges trigger and how these affect their learning. This study first introduced a framework for ambiguity, based on Hillen et al (2017), listing sources, perception and responses to uncertainty in challenge-based learning. Then we listed the challenges students experienced per project phase and highlighted the emotions they reported to be related to the challenges. Although literature highlights that some learners experience ambiguity and uncertainty in a positive way, most emotions mentioned by teachers and students were negative. Educators, in general, thought that a positive and supportive learning environment is crucial in handling these emotions.

The results, namely the issues experienced by students and the copying mechanisms educators reported and found in literature, served as a basis for the game design. We wanted to create a tool that (1.) can be used by educators without extensive training, (2.) which incorporates theoretical and evidence-based elements about uncertainty and ambiguity, and finally (3.) stimulates informal collaborative learning, shaping how students perceive and respond to ambiguous challenges. Although previous versions of the game were tested in a project-based course by student teams, the testing mostly focused on playability and game mechanisms. The extent to which students learn from each other regarding how to respond to uncertainty and ambiguity in team projects, and whether the discussion helps to reduce negative emotions, needs to be evaluated in a classroom setup.

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BIOGRAPHICAL INFORMATION

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Wenyi Chu is a PhD candidate at TU Delft. She has a background in Geo-information Science and Earth Observation, and Educational Science and Technology; she is particularly interested in the unique intersection of these fields. She is conducting educational research, amongst others, on the needs of future engineering education in terms of transdisciplinary skills.

Yiwei Tao followed the Communication Design for Innovation MSc track at TU Delft. Her graduation project focused on tolerating ambiguity, and she created the first prototype for a serious game to support student teams in dealing with wicked problems.

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