Naviagte Ambiguity: Supporting Tolerance of Ambiguity Development in Problem-Based Learning Environmentsat TU Delft

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Master Thesis Report

Supporting Tolerance of Ambiguity Development in Problem-Based Learning Environment at TU Delft

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Preface

This graduation project marks the end of my master's journey and the beginning of a new chapter in my life. I am glad I chose this topic—or perhaps the topic chose me—allowing me to prepare myself for the real-life challenges ahead. Delving deeper into the concepts of ambiguity and tolerance of ambiguity, and listening to different perspectives from others, I have developed an interest in the topic. The most fascinating part is that ambiguity is an inseparable part of life.

My journey in the Netherlands, in Delft, and with all people I've met here has truly shaped my life. I would like to express my heartfelt gratitude to everyone who supported me along this journey, with special thanks to several people who helped me a lot in this project.

First and foremost, I want to thank my supervisors for their invaluable guidance and feedback throughout this process. A special thanks to Éva for giving me the opportunity to explore transdisciplinary skills, for your timely support, and for providing me with the freedom to explore and pursue my ideas. Thank you, Caroline, for offering suggestions and guiding me to align my work with my own interests. Your questions always guided me to be specific about the choices I made. Thank you Nina, your vast knowledge about uncertainty was incredibly inspiring, and our discussions sparked a deeper passion in me for the topic. This thesis is itself a perfect example of ambiguity, and I am grateful to my supervisors for helping me develop tolerance for it along the way.

Also, I would also like to thank all the participants in my study. Your time spent filling out surveys, engaging in discussions and participating in the game test session was instrumental in making this project possible.

Finally, I have to thank my family and friends in China, as well as my "family" in Delft. I promised 胡若琳 that I would definitely include you in my report, as you were always there (in my earphones) for me, brainstorming ideas whenever I felt overwhelmed and didn't know where my project was heading. There's also a special place in Delft where I've found a sense of belonging—where I met new friends, socialized comfortably, and enjoyed fantastic food. A big thank-you to Bo for helping me find participants for my study. And last but not least, if I've forgotten anyone, thank you, Leo.

Wish everyone a happy life,

Demi, also known as 陶-艸

Executive Summary

The ability to navigate ambiguity has become increasingly essential in today's workplaces. However, while many encounter ambiguous situations, not everyone feels comfortable in making decisions in such contexts. To be well-prepared for the future workplace, university graduates need skills to effectively manage ambiguity. How individuals experience and respond to ambiguous situations reflects their tolerance of ambiguity (TOA), which represents a person's natural tendency to react to perceived ambiguity with varying levels of comfort and adaptability. Students with low TOA may exhibit rigid thinking, reduced creativity, and heightened anxiety. Therefore, supporting students in developing TOA is critical, and teachers have a key role in facilitating this process. For this project, Delft University of Technology was selected as a higher education case, specifically problem-based learning (PBL) courses as the project focus.

The project employs a design-based research methodology, integrating both quantitative and qualitative methods to examine current practices at TU Delft. Analysis revealed two central challenges: (1) teachers need a closer familiarity with students to provide tailored guidance, and (2) teachers expect students to take action and engage, even when faced with ambiguous situations.

To facilitate teachers in fostering higher levels of TOA in students, an educational tool called "Piece-by-piece game" was designed. It is a puzzle-inspired game that encourages students to discuss the challenges they encounter and explore approaches for addressing them. The game aimed to serve as a way for teachers to become familiar with students and equip students with various approaches to navigate ambiguity, while creating a supportive environment for students to openly discuss challenges they face.

The concept was validated in a pilot session with Communication Design for Innovation (CDI) students at TU Delft. Results indicated that the Piece-by-Piece Game can increase participants' tolerance of ambiguity and effectively support open communication to discuss challenges and exchange ideas. Participants also found it inspiring and acknowledged its potential for long-term and general use.

This project serves as a foundation for raising educators' awareness of TOA development. While promising, further evaluation is necessary to assess the game's effectiveness across diverse student groups. Future research can build on these preliminary insights to refine teaching strategies for PBL. Additionally, the game itself could be experimented in class or problem-solving context in the future.

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Introduction

1.1 Tolerance of ambiguity is needed for university graduates

The only constant is change. In a rapidly evolving and unpredictable world, fueled by rapid technological advancements and increased global cooperation, exchange, and communication, today's professionals are required to navigate complex and uncertain environments more than ever. The evolving demands of the workplace mean that university graduates must be fully equipped, not only with job-specific knowledge but also with the "job-neutral" skills to tackle a growing array of open, complex, dynamic, and networked problems in their careers (Peschl et al., 2021).

One of the essential "future skills" in this context is tolerance of ambiguity (TOA). Identified as a critical skill for the future of work (Ehlers & Kellermann, 2019; Future Fit Academy, 2020), TOA provides individuals with the "ability to act successfully on complex problems in a future unknown context," (Ehlers, 2020) making it invaluable for staying relevant, adaptable, and competent. TOA helps graduates face the ill-defined nature of problems that carry creative potential, equipping them to consider a broader range of options and solutions (Runco, 2023).

1.2 Why should higher education care?

While TOA is considered an individual difference variable, it is not solely innate but can be developed and enhanced through targeted interventions (Saarikoski & Rybushkina, 2019). Therefore, the central problem arises: why is it imperative for higher education institutions to include the development of TOA among their students? The answer lies in the evolving nature of the workforce and the demands of the modern world. Employers increasingly seek graduates who possess not only technical expertise but also the ability to navigate complexity, communicate across disciplines, and innovate in ambiguous environments. By integrating TOA development into the higher education curriculum, institutions can better prepare students for the challenges they will face in their future careers.

At its core, education is characterized by a preoccupation with the future (Dishon & Gilead, 2020) and education should be geared towards preparing graduates for their lives as professionals in their future career. Higher education is the stage where students begin to engage deeply with complexity, starting specialising discipline-specific knowledge and tackling real-world professional problems that don't have straightforward answers. This environment offers a unique opportunity to cultivate TOA through specialized learning experiences such as research projects, problem-based learning, and interdisciplinary teamwork.

Furthermore, fostering TOA aligns with the broader goals of higher education, which include promoting critical thinking, problem-solving, and lifelong learning. In an era where the pace of change is accelerating, students must be equipped with the skills and mindset to adapt and thrive in a rapidly evolving landscape. Therefore, addressing the need to prepare students with TOA is not only essential for their individual success but also for the continued relevance and effectiveness of higher education in meeting the needs of society and the global economy. By prioritizing TOA development, institutions can empower students to become agile, adaptable, and effective contributors to the complex challenges of the 21st century.

To prepare students to become comfortable in dealing with ambiguity, students need practice and guidance in solving complex, open-ended problems (Douglas et al., 2015). Without adequate exposure to ambiguity, students may struggle to cope with uncertainty in professional settings, adversely affecting their decision-making abilities and resilience. Individuals who are intolerant of ambiguity tend to view it as a psychological threat and may resort to avoidance strategies, such as ignoring the situation or opting for premature closure, thereby limiting their consideration of alternative possibilities (McLain et al., 2015). This avoidance can lead to rigid thinking, decreased creativity, and heightened anxiety (Furnham & Ribchester, 1995). In contrast, graduates equipped with TOA are better positioned to adapt to shifting circumstances, think creatively about complex issues, and collaborate with diverse teams—qualities that are increasingly valued in modern work environments (Botke, 2021).

1.3 Knowledge gap and research contribution

While previous studies have focused on how students navigate ambiguity in PBL (Bohm et al., 2023), less attention has been given to how teachers can support students in developing TOA. Since teachers play an essential role in the learning process as guides and facilitators, understanding how teachers can help students approach ambiguous situations and identifying their needs in doing so is important. This study aims to explore how teachers can support the development of TOA in PBL environments, addressing a gap in the literature and can be a starting point for curriculum designers to consider incorporating TOA into their programs to better prepare university students for the complexities and uncertainties of future technological and professional landscapes.

By understanding the current states of TOA development in higher education, specifically at TU Delft, this research is hoped to provide insights for educators, researchers, and program designers. Identifying the needs of educators can enable targeted interventions. In line with this, a practical educational tool, the Piece-by-Piece game, has been developed to help teachers support students' TOA in PBL courses. This tool aims to foster open communication, creating a safe environment for students to discuss their difficulties openly and allowing teachers to understand the challenges students face. By encouraging students to take action in ambiguous situations, the tool empowers them with a greater sense of ownership in their learning process.

1.4 Scope and research question

The study was conducted at Delft University of Technology, involving teachers across various faculties and disciplines who have experience in problem-based learning courses.

PBL is a student-centered educational approach where students actively construct their own knowledge through hands-on learning, independent or collaborative work, and interaction with their environment, in line with the constructivist approach. In this setting, the teacher takes on the role of a "guide on the side," directing and supporting students as they navigate the learning process. PBL provides a good opportunity for students to engage with real-world situations, gaining practical experience that can foster their tolerance of ambiguity.

With this in mind, the research question guiding the study is:

How can teachers support students' Tolerance of Ambiguity development in problem-based learning at TU Delft?

To address this, two sub-research questions were also defined:

(1) How do teachers perceive and address tolerance of ambiguity development in problem-based learning, and what challenges do they encounter?
(2) What educational tool can facilitate the development of tolerance of ambiguity in students participating in problem-based learning courses?

1.5 Report structure

This study employs a design-based research approach as the guiding methodology, which is commonly used to develop and refine educational interventions through iterative cycles of design, implementation, and analysis (Anderson & Shattuck, 2012). This research focuses on the initial design and validation phase. The study adopted the Double Diamond process (Design Council, 2023) to investigate how educators at TU Delft can support the development of tolerance of ambiguity in problem-based learning courses and based on the insights, an educational tool was developed.

The study consists of two main stages: problem identification and solution development. Each phase addresses specific sub-research questions that contribute to the overarching aim of the study. In the first diamond, a survey and interviews were conducted and analyzed to identify the problem, which guided the design direction. The second diamond encompasses concept development and validation of the game design.

The structure of the report is illustrated in Figure 1.

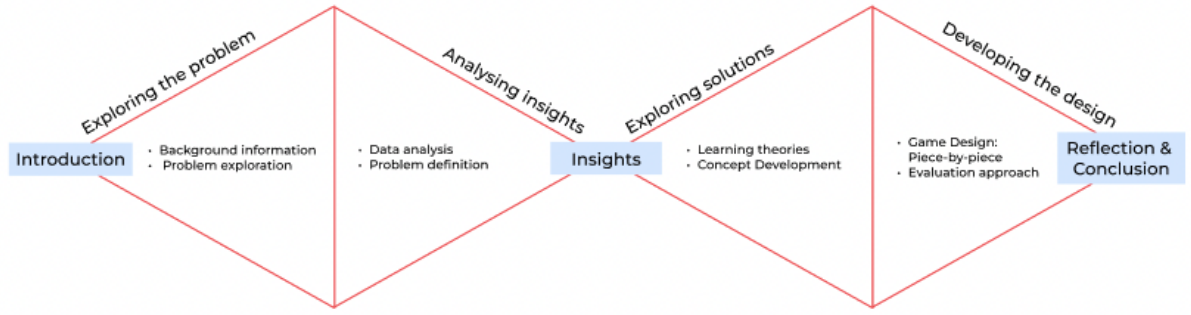

Figure 1. Report structure

The initial discovery phase involves **Chapter 2**, which provides background information to introduce tolerance of ambiguity and problem-based learning as the study context, setting the stage for the problem exploration. **Chapter 3** introduces a survey and interviews conducted to gather perspectives from TU Delft teachers.

The second phase includes **Chapter 4**, which focuses on data analysis to present findings from the survey and interview analysis. By synthesizing insights, key findings emerge. **Chapter 5** defines the essence of the problem that needs to be solved, leading into the design exploration in the second diamond.

Building on these key insights, **Chapter 6** reviews learning theories that resonate with the key findings from the first diamond and uses these identified theories to guide the design for developing TOA. **Chapter 7** details the concept development process and the design of the educational tool, the Piece-by-Piece game.

To validate the game design, a pilot test session was hosted at the Faculty of Applied Sciences, where participants from the CDI master's program played the game together and provided feedback. This process is described in **Chapter 8: Validation**. Finally, **Chapter 9: Discussion** reflects on the overall process, the impact of the design, and any limitations identified during the study.

2

Theoretical Framework

In the initial stages of this study, a comprehensive literature review was conducted to establish a theoretical foundation for understanding tolerance of ambiguity. This chapter explores the concepts of ambiguity and tolerance of ambiguity, as well as teaching strategies relevant to these topics, particularly within the context of problem-based learning.

2.1 Keyword selection and literature search

To explore the literature on tolerance of ambiguity in higher education, especially in engineering, several keywords were selected for searching: "ambiguity," "tolerance of ambiguity/uncertainty," "deal/cope/foster/develop/manage/improve/enhance/improve," "problem-based (learning)," and "higher education/(higher) engineering education." The search started by keywords combination, and was further expanded through citation tracking and snowballing in academic databases like the TU Delft repository, Web of Science, and Scopus.

Deciding on these keywords required careful consideration, given the close relationship between ambiguity and uncertainty. My preliminary research revealed that while there are distinct differences between these concepts in the context of problem-solving, tolerance of ambiguity and tolerance of uncertainty are often used interchangeably in the literature.

According to Schrader et al. (1993), ambiguity arises from a lack of clarity regarding the relevant variables and their relationships, making it common in real-world problem-solving. In contrast, uncertainty refers to situations where possible outcomes are identified but where information on their probabilities is lacking. This distinction suggests that, in real-world settings, decision-making and problem-solving are often shaped more by ambiguity than by uncertainty, as future outcomes are not always clearly defined or identifiable.

When it comes to tolerance of ambiguity and tolerance of uncertainty, Grenier et al. (2005) propose a time-based distinction: TOA pertains to present-oriented, ambiguous features, whereas TOU relates to uncertainty about future outcomes. However, Hillen et al. (2017) argue that the rationale for this time-based division is unclear and may reflect historical or disciplinary biases rather than a robust theoretical distinction. Moreover, Hillen emphasises the substantial overlap between TOA and TOU literature.

In the context of this study—problem-based courses, both TOA and TOU are pertinent as they relate to students' abilities to navigate complex, unclear situations. Developing these competencies allows students to enhance their problem-solving strategies and

decision-making processes. This study thus focuses on the overlapping aspects of these terms, particularly their shared cognitive processes, as individuals respond to ambiguous or uncertain situations with a set of cognitive, emotional, and behavioral reactions (Grenier et al., 2005). Accordingly, both TOA and TOU have been included in the literature search.

2.2 What is ambiguity?

Most studies have defined ambiguity as a characteristic of the problems (Douglas et al., 2022). Some emerging terms including "wicked problems" (Rittel & Webber, 1973), "ill-structured problems", and the concept of "Volatile, Uncertain, Complex, and Ambiguous (VUCA)" (Schick et al., 2017) have framed ambiguity in problems. Ambiguity typically arises in complex, indeterminate situations where necessary information is missing, and the available choices are not clearly defined (Cernega et al., 2024), or in new, intricate, or conflicting contexts or when there are gaps or errors in learning and applying knowledge (Lakhana, 2012). Beyond difficulties, ambiguity also represents possibilities for freedom of choice, enabling individuals to navigate between various alternatives and create order in chaos by making a choice, thereby enabling them to progress through problem-solving steps (Salikhova et al., 2019).

This dual nature of ambiguity—its potential to both support and challenge learners—plays an essential role in the learning process. On the positive side, ambiguity offers students creative freedom and space for exploration, pushing them to experiment and think beyond conventional boundaries. Suzawa (2013) suggests that ambiguity is intrinsic to human knowledge; people should embrace it by staying open to new ideas and avoiding narrow thinking. However, when ambiguity levels become too high, or when students are not prepared, it can evoke strong negative emotions, such as fear, anxiety and frustration, which then prevent students from making the cognitive gains necessary to become effective problem solvers (Douglas et al., 2022).

Individual differences also influence how students respond to ambiguity. Some are source-focused, seeking to avoid or alter ambiguous situations, while others are consequence-focused, aiming to mitigate or manage the effects of ambiguity (Hillen et al., 2017). Students can encounter what Douglas et al. (2015) calls "points of ambiguity," moments when they feel unsure about what to do next, due to various factors in problem-solving. Table 1 lists possible factors contributing to ambiguity found in the literature. Additionally, open-ended problems, with their lack of clear constraints, can add to students' ambiguity, as they must navigate without well-defined limits (Douglas et al., 2015).

2.3 What is tolerance of ambiguity?

Building upon the concept of ambiguity, tolerance of ambiguity emerged as a way to clarify and describe how people interact with ambiguous situations (Salikhova et al., 2019). Ambiguity itself is defined as a perception—shaped by the information we receive about a particular stimulus—that highlights uncertainty or multiple interpretations. TOA, in turn, represents an individual's stable tendency to respond to perceived ambiguity, with varying levels of comfort and adaptability (McLain et al., 2015). For individuals in fields where ambiguity is a constant, understanding the determinants and consequences of TOA is especially important, as it can directly impact both personal development and task performance (Salikhova et al., 2019).

Historically, TOA was viewed primarily as a stable personality trait (Furnham & Marks, 2013), implying a consistent response to ambiguity across different situations. Early studies framed TOA as a general disposition, suggesting that people either tended to tolerate ambiguity or not, regardless of the context. However, subsequent research began exploring the possibility that people's responses to ambiguity could vary depending on the situation (Durrheim & Foster, 1997).

This led to a subset of contemporary researchers who view TOA as a dynamic, malleable cognitive process rather than an immutable characteristic (Lakhana, 2012). In this perspective, TOA is seen as a dependent variable that can change with intervention, especially in educational settings where students can develop this capacity over time. With this in mind, TOA is considered in this study as a learning construct—an ability that can be nurtured and enhanced through targeted interventions.

To support students in tolerating ambiguity, it's important to understand what TOA means for them and how it influences their learning experience. Research indicates that students' capacity to tolerate ambiguity affects their resilience, engagement, and academic performance (Yu et al., 2022; Tynan, 2020). Students with high TOA often embrace ambiguous situations, finding them ripe with potential for growth and innovation. Others, who may be less comfortable with ambiguity, manage it by gathering information to reduce uncertainty to manageable levels, thus still benefiting from the experience. In contrast, some students may attempt to ignore ambiguity by focusing on more concrete elements, while others feel overwhelmed, which can hinder their engagement.

To examine TOA within an educational setting, this study uses an adapted version of the Uncertainty Tolerance conceptual model developed by Hillen et al. (2017). This model defines Uncertainty Tolerance as *"the set of negative and positive psychological responses—cognitive, emotional, and behavioral—provoked by the conscious awareness of ignorance about particular aspects of the world."* The UT model is multi-dimensional and integrative, encompassing psychological responses, needs, motivations, and goals across disciplines. Unlike prior approaches that may narrowly address specific facets of uncertainty, the model offers a flexible, comprehensive framework, making it particularly relevant across disciplines.

In Hillen's UT model, ambiguity is viewed as a subordinate construct, representing one of the primary sources of uncertainty. Ambiguity refers to the lack of reliability, credibility, or adequacy in information, while uncertainty serves as the overarching construct, encompassing metacognitive awareness of ignorance related to an object or phenomenon. Alongside ambiguity, two other major sources of uncertainty—probability and complexity—are identified. Probability refers to the inherent unpredictability or randomness of future events, known as 'aleatory' or 'first-order' uncertainty, while complexity reflects the difficulty in understanding phenomena due to their multiple components, causal determinants, or effects. When individuals become consciously aware of these sources—probability, ambiguity, and complexity—they experience uncertainty, triggering a range of psychological responses.

Given that ambiguity is a primary source of uncertainty, it can trigger similar cognitive, emotional, and behavioral reactions as other forms of uncertainty. Therefore, Hillen's UT model provides a relevant foundation to guide the development of a TOA model, as it helps us understand the spectrum of responses individuals may have when encountering ambiguous situations. This study makes a minor adaptation to Hillen's UT framework to

focus specifically on ambiguity in problem-solving contexts. Here, the framework serves as a guide to understanding how students respond to ambiguity and which responses are most relevant in an educational environment. The adapted framework divides TOA into three main components: (1) **Ambiguity Component** - refers to specific sources of ambiguity; (2) **Perceptions**; and (3) **Tolerance Component -** refers to specific response to ambiguity, and can be divided into three categories.

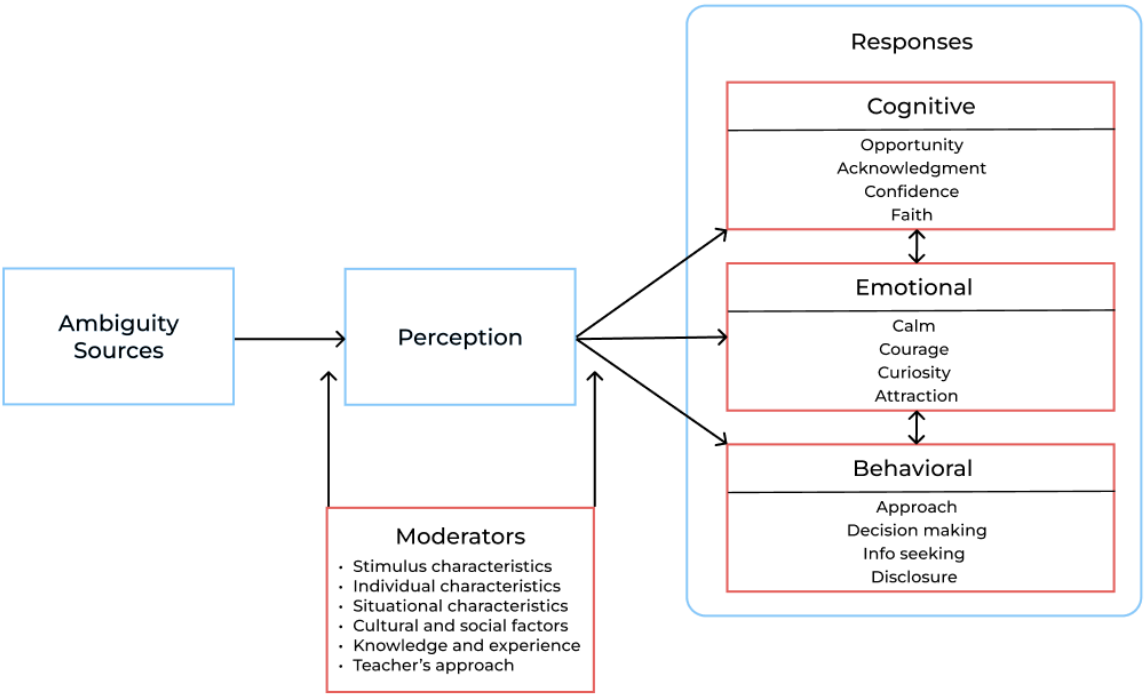

Figure 2. Tolerance of ambiguity model adapted from Hillen et al. (2017)

(1) Ambiguity Component

The ambiguity component refers to sources of ambiguity that originate from the problem itself. Table 1 presents the sources commonly identified in engineering problems, based on the literature.

Sources	Description	Citation
Unclear or changing scope	Ambiguity arises when the boundaries of a problem are not clearly defined or keep changing, making it difficult to fully understand what is being asked or required.	Douglas et al., 2022; Bohm et al., 2023
Missing information / knowledge gap	When essential information or understanding is lacking, individuals face ambiguity in decision-making and problem-solving due to incomplete knowledge.	Douglas et al., 2022; Hillen et al., 2017; Brugnach et al., 2008

Conflicting or imprecise information	Ambiguity occurs when information is unclear, inconsistent, or erroneous, forcing individuals to reconcile differing or inaccurate data.	Hillen et al., 2017; Bozic et al., 2018; Boelt et al., 2022
Unknown path to a solution	Ambiguity is present when the steps to reach a solution are unclear, leaving individuals uncertain about how to proceed with solving a problem.	Douglas et al., 2022; Dubikovsky, 2017
Multiple possible solutions	Some problems, such as "wicked problem," have no one correct answer, leading to ambiguity as individuals must navigate multiple viable solutions.	Douglas et al., 2022; Bozic et al., 2018
Unknown result	When the outcome or consequences of a solution are uncertain or unpredictable, ambiguity is heightened, as individuals cannot be sure of the impact of their decisions.	Dubikovsky, 2017; Lazarus et al., 2023

Table 1. Ambiguity components

(2) Perceptions

To respond to ambiguous situations, individuals first need to perceive the elements of ambiguity—this perception then activates the tolerance component, or their responses to ambiguity. This conscious perception is a form of metacognitive awareness, where learners recognize that the situation includes aspects of ambiguity requiring adaptive strategies.

However, some students may not fully perceive ambiguity due to reliance on familiar aspects within a new situation. These students might recognize familiar elements in the new phenomenon, but their attention may not extend to unfamiliar or conflicting aspects that challenge their current understanding. As Merenluoto and Lehtinen (2004) note, a moderate grasp of familiar processes can lower sensitivity to potential conflicts, leading to dependence on routine methods that may not meet the demands of the task. While low sensitivity to ambiguity doesn't always result in overtly negative responses, it can indicate a lower TOA due to a limited capacity to recognize novel or conflicting information. In contrast, learners with high TOA remain open to novel or conflicting information, allowing their sensitivity to ambiguity to grow throughout the learning process.

(3) Tolerance Component

Tolerance component refers to specific response to ambiguity, and can be divided into three types (Hillen et al., 2017). While the original model includes a range of responses from negative to positive, this study emphasizes positive responses to better align with classroom learning objectives. Although negative responses to ambiguity are not inherently harmful, positive responses implicate higher level of TOA. Additionally, response aspects have been carefully adapted to fit the unique dynamics of PBL, ensuring the model's relevance to higher education.

Response type	Response aspect	Description
Conitive responses	Opportunity	View ambiguity as an opportunity for growth
	Acknowledgement	Aware and recognise that ambiguity is an implicit part of the course
	Confidence	Feel empowered and have confidence in navigating ambiguous circumstances
	Faith	Self-assure in abilities to manage when presented with ambiguous stimuli
Emotional responses	Calm	Exhibit openness and acceptance, showing a composed response to ambiguity
	Courage	Do not fear being held accountable for the limits of their knowledge
	Curiosity	Cultivate a sense of curiosity and excitement when faced with ambiguity
	Attraction	Experience joy and fulfillment from overcoming challenges associated with ambiguity
Behavioural responses	Approach	adopt proactive strategies to engage with ambiguous situations
	Decision making	Make informed decisions even when faced with ambiguous information
	Info seeking	Actively seek out additional information to reduce ambiguity
	Disclosure	Openly share their uncertainties and seek feedback

Table 2. Tolerance component: list of positive responses to perceived ambiguity

2.4 Why problem-based learning?

Building on the concept of ambiguity and its role in learning, it becomes clear that approaches exposing students to open-ended challenges can help develop TOA. While ambiguity appears in traditional classrooms, such as when students encounter imprecise concepts, PBL provides even richer and more frequent opportunities for ambiguous encounters.

This study focuses on problem-based learning environments because, compared to traditional lecture-based instruction, student-centered approaches like PBL have been shown to be more effective in cultivating critical transdisciplinary skills necessary for addressing complex, real-world problems (Bozic et al., 2018). PBL's emphasis on real-world problems, independent exploration, and iterative learning aligns with the goals of building students' resilience to ambiguity.

Research indicates that PBL contributes positively to the development of students' tolerance of ambiguity. The literature provides several studies that underscore PBL's effectiveness in fostering TOA. For instance, Banning (2003) examines the effect of the "case method" on management students' abilities to navigate the "complex nature of business decision making". In the case method, students read, analyze, and discuss written versions of real events, inherently full of ambiguous cues. And the results showed that "case teaching may increase TOA in students by providing guided practice in decoding ambiguous cues that are embedded in the social and decision contexts of the case narrative". Similarly, Taajamaa et al. (2014) found that students initially resisted ambiguity in PBL, preferring more structured guidance. However, many students later recognized the value of learning to manage ambiguity. Douglas et al. (2015, 2022) suggested that, unlike professionals who accept ambiguity as natural, students often see it as an obstacle and suggested that students need practice and guidance in solving complex, open-ended problems in order to become comfortable in dealing with ambiguity. It is implicit that students feeling of ambiguity as an obstacle may due to limited exposure.

There is a considerable lack of clarity regarding the concept of problem-based learning as the label "PBL" is used to cover a variety of educational practices, ranging from problem-oriented lectures to fully open experiential learning environments that provide students with extreme freedom (De Graaf & Kolmos, 2003). There are also other types of instructional strategies that are similar to problem-based learning, such as case-based learning, project-based learning, inquiry-based learning and challenge-based learning, .

For example, Savery (2006) summarises that case-based and project-based learning are all learner-centered instructional strategies that are similar to problem-based learning, while in these approaches, the expected outcomes and goals are clearly defined, making it less need or incentive for learners to set their own parameters. And Savery also introduced the inquiry-based learning as a similar approach to problem-based learning which focused on questioning, critical thinking, and problem solving and the primary difference with PBL is the role of the tutor where in IBL, the tutor is both a facilitator of learning and a provider of information, and a tutor in PBL don't provide information but only supports the process. Gallagher and Savage (2023) found the key defining features of challenge-based learning are global themes, real-world challenges, collaboration between students, academic and extra-academic actors, technology, flexibility, multidisciplinarity and discipline specificity, creativity and innovation, and the use of a challenge.

Given that many participants may not be familiar with the precise definitions of PBL or its differences from these related approaches, a list of PBL characteristics was included in the survey. Participants were then asked to self-assess whether their course could be classified as PBL. The characteristics valued in this research include (Savery, 2006): (1) the role of the tutor as a facilitator of learning, (2) the responsibility of learners to be self-directed and self-regulated in their learning, and (3) the design of ill-structured instructional problems as a driving force for inquiry.

3

Problem exploration

Building on the theoretical foundation established in Chapter 2, this chapter introduces the development of the survey and interview questions, detailing the methods used for their design and outlining the data analysis procedures. Chapters 3, 4, and 5 collectively aim to examine the current state of tolerance of ambiguity development at TU Delft, providing a deeper understanding of the problem context. The goal is to address sub-research question 1: How do teachers perceive and address tolerance of ambiguity in problem-based learning, and what challenges do they encounter?

3.1 Ethical conduct

Ethical integrity was a central priority throughout this study. The study and plans for data collection and analysis were approved by the Human Research Ethics Committee (HREC) in TU Delft.

Informed consent was obtained from all participants, including survey respondents and interviewees, before data collection began. Participants were fully informed about the purpose of the research, the voluntary nature of their participation, and their right to withdraw at any time without penalty. The study ensured confidentiality by anonymizing all data. Unique identifiers were assigned to participants to maintain anonymity in the analysis and reporting stages.

All collected data were securely stored on SURF Drive, accessible only to authorized members of the research team. Audio and video recordings of interviews were deleted once transcriptions were finalized, further safeguarding participants' privacy.

3.2 Survey design and analysis

The survey was conducted using the scientific survey platform Qualtrics (https://www.qualtrics.com/) and remained open for 3.5 months, from mid June to the end of September. Unfortunately, this period coincided with the summer break at the university, necessitating two rounds of distribution. In the first round, conducted before the summer break, the survey was emailed to program coordinators in each faculty, who then forwarded it to their staff. In the second round, after the summer break, posters promoting the survey were placed in each faculty and in the teaching lab where educators frequently gather. Finally, the survey receives 40 responses in total.

The survey comprised three parts:

- **Understanding of TOA**: This section is based on the Tolerance of ambiguity model proposed in Chapter 2.3 to understand how educators perceive this skill and which aspects they value most in the classroom setting.
- **Teaching Strategies**: This section explored the strategies educators use to support TOA development, drawing on strategies identified in the literature review, to see if how effective do educators think about these strategies.
- **Challenges**: This section identified challenges educators face when attempting to incorporate TOA development into their teaching, also informed by literature review.

The survey contains multiple questions and open questions. It took approximately 15-20 minutes to complete the survey. The full questionnaire can be found in Appendix B.

To minimize the risk of identifying participants, the survey only collects general geographic information, such as the faculty and discipline the participant is involved in. All responses are collected through an anonymous link or QR code, ensuring that no IP addresses are tracked. While some participants provided their email addresses to express interest in further involvement, which could potentially allow for identification, we took steps to ensure this did not pose a privacy risk in any published results. Only aggregated data is presented in any reports.

The survey, designed to gather people's attitudes on the existing information, was primarily analyzed using descriptive statistics and frequency analysis. Initially, the raw data were cleaned to remove incomplete responses. However, two incomplete responses were included in the analysis, as they were more than 50% complete (with progress at 60% and 76%, respectively) and due to the small sample size. Therefore, there were 23 responses analysed. The analysis and visualization were conducted using the Tableau platform.

In the first part of the survey, the goal was to find statistical evidence regarding which aspects of tolerance of ambiguity were most valued by educators in the classroom. Responses were analyzed both individually and grouped by response type to uncover any patterns in the data. Descriptive statistics were used to summarize central tendencies and variances, while frequency analysis helped to highlight how often certain responses occurred, providing insight into the most prominent views among participants.

For the Likert scale questions, responses were scored from 1 to 5, with values corresponding to intensity or likelihood (e.g., "1" representing "extremely unlikely," "not effectively at all," or "never," and "5" representing "extremely likely," "extremely effectively," or "definitely yes"). The results were averaged to reveal central tendencies, and distribution patterns were also examined to showcase the spread of responses.

For multiple-choice questions, frequency analysis was employed to determine how often specific answers were selected. This allowed for the identification of common trends and the preferences of educators in relation to the TOA aspects covered in the survey.

3.3 Interview design and analysis

The survey options were drawn from existing literature, but it was not specifically designed to capture additional strategies and challenges unique to TU Delft's context. Although participants had the chance to suggest other strategies and challenges in open-ended

questions, the format didn't allow them enough time or space to provide detailed responses. One participant noted, *"There are probably some more, but I do not have time to find or formulate them now."* To address this limitation, qualitative interviews were conducted with educators actively involved in problem-based courses. The aim of these interviews was to gain a deeper understanding of the unique strategies and challenges these educators experience, providing context-specific insights that the survey alone could not capture.

A total of 6 in-depth, semi-structured interviews were conducted. The semi-structured format was chosen for its flexibility, allowing for deeper insights to emerge from the interviewee's responses while still maintaining a focused discussion. Of the 6 interviewees, three were selected because they expressed interest in further involvement after participating in the survey, while the remaining were approached directly.

To ensure consistency and thoroughness, an interview protocol was established in advance. This protocol included guidelines for obtaining informed consent, providing an introductory overview to each participant, and a set of prepared interview questions. The interview guide can be found in Appendix C.

Interviews were conducted both in person and online, with Microsoft Teams (https://teams.microsoft.com) used to record all sessions. Draft transcriptions were generated by the app automatically and later manually cleaned and coded. Audio or video recordings were securely stored in SURF Drive and were deleted once fully transcribed. For analysis, transcripts were anonymized, with serial numbers used in place of any identifiable information for internal reference.

The interview, designed to gain exploratory information, were analyzed using Atlas.ti, a software tool that facilitated the organization and management of the interview data and the corresponding codes. The data were analyzed thematically to identify underlying themes and refine the initial theoretical framework. A combination of deductive and inductive coding approaches were employed. Deductive coding involved applying pre-existing codes derived from the theoretical framework and literature, while inductive coding allowed for the generation of new codes based on insights emerging directly from the interview data.

The transcripts, initially auto-generated by Microsoft Teams, were thoroughly checked and refined. During this process, I read through the transcripts multiple times to gain familiarity with the data and identify preliminary insights. Before coding, I incorporated codes identified in the literature review phase, particularly those related to ambiguity sources, student responses, teaching strategies, and teacher challenges—categories that were also reflected in the survey design. This provided a foundation for predefined themes such as "ambiguity sources," "teaching strategies," and "teaching challenges."

In the first round of coding, I applied these predefined codes to relevant portions of the text, while also generating new codes based on the interview content. Codes such as "observation," "reflection," "rubric," and "decision-making" emerged during this phase and did not immediately fit into any predefined themes. I then grouped the codes, retaining the original themes and creating several new, broader categories, including "student-related issues" and "student problems."

In the second round of coding, I reviewed and refined the codes and themes, merging similar ones and creating new themes to ensure each group accurately reflected the data. I revisited the transcripts to confirm that the themes captured the key points raised by participants and made necessary adjustments.

After finalizing the themes, I gave them clear names. In total, I identified five overarching themes: *Ambiguity Sources, Student Responses to Ambiguity, Student-related issues, Teaching Strategies*, and *Teacher Challenges*. These themes encompassed 11 sub-themes and a total of 54 distinct codes.

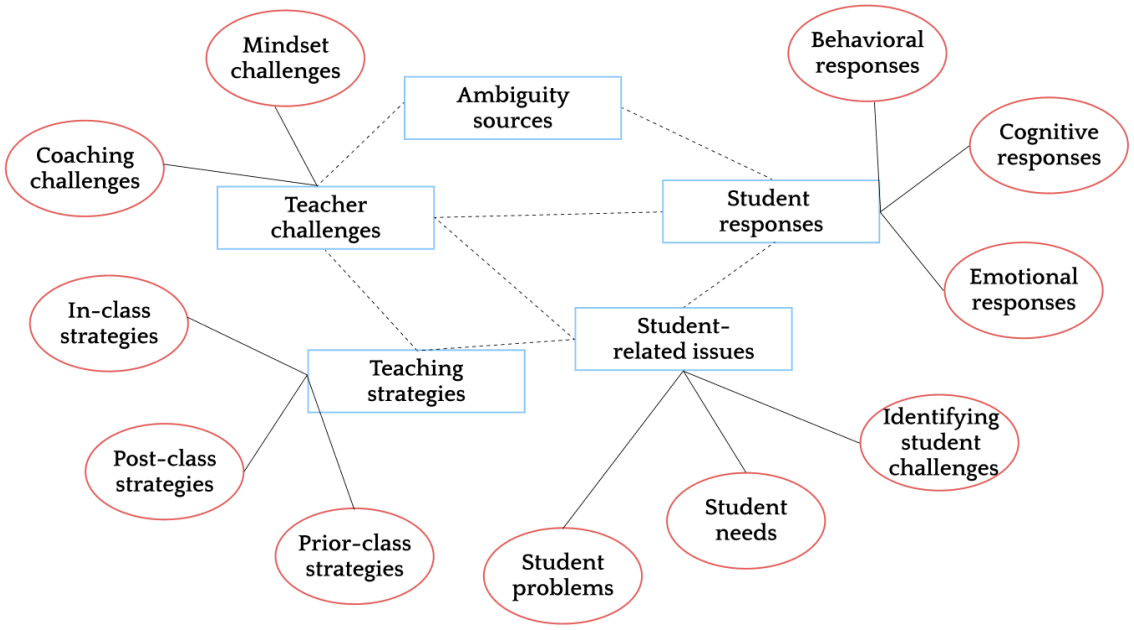

Figure 3. Themes and sub-themes identified from the analysis of interview transcripts

4

Data Analysis

This chapter presents the results of the survey and interviews conducted among TU Delft educators.

4.1 Survey results

Demographic data

The survey received 40 responses in total. Since the scope of the study is problem-based learning, after explaining our definition for PBL, participants who think they are not familiar with this type of course left the survey, 6 responses end here. There are 13 participants who didn't finish the survey. However, considering finish progress and duration, 2 uncompleted responses were included in the analysis. Therefore, there are 23 responses remained.

Faculty	**Participants count**
Aerospace Engineering (AE)	1
Applied Sciences (AS)	6
Architecture and the Built Environment (A+BE)	2
Civil Engineering and Geosciences (CEG)	1
Electrical Engineering, Mathematics, & Computer Science (EEMCS)	2
Industrial Design Engineering (IDE)	6
Mechanical Engineering (ME)	3
Technology, Policy and Management (TPM)	2
	23 (Total)

Table 3. Survey participants

Among the participants, the majority are relatively new to PBL courses, with 9 out of 23 reporting only 1-2 courses of experience. Notably, one participant initially indicated no experience in PBL; however, in the following question regarding the differences between PBL and similar courses, they described experience in a comparable course format.

Participants demonstrated limited familiarity with the term "Tolerance of Ambiguity." Over 50% reported never having heard of it, while 4 out of 23 participants had heard the term but were unsure of its actual meaning. Only 30% of participants expressed a strong understanding of the concept.

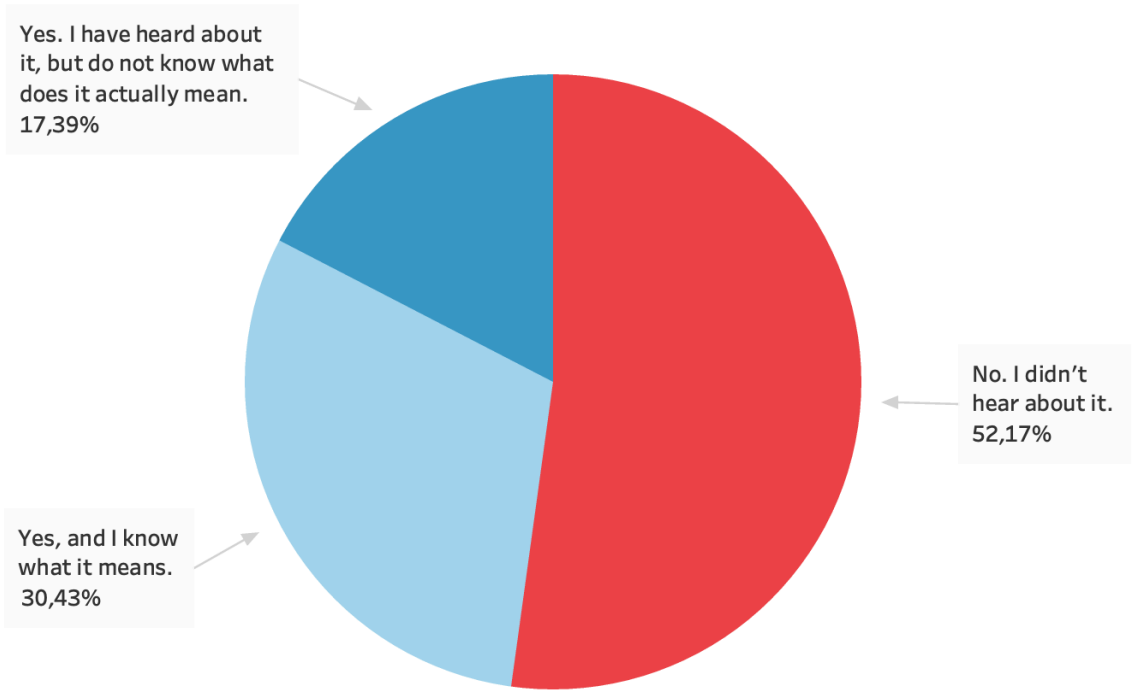

Figure 4. Participants' familiarity with the term tolerance of ambiguity (N=23)

Regarding the necessity of developing TOA and whether PBL is an ideal environment to foster students' TOA, most people believe that it is important to develop TOA (21/23) and PBL approach can help increase students' TOA (16/23). Worth mentioning, although the majority see the need to develop TOA and should be integrated into PBL courses, there is one participant clearly stated disagreement.

In the ranking question, participants were asked to rank the identified sources of ambiguity on a scale from 1 to 9, with 1 representing the most common source and 9 the least common source within their discipline. A lower average score indicates that the source is more frequently encountered. The results align closely with the findings from the interviews. For example, **multiple possible solutions** and an **unknown path to a solution** emerged as the most common sources of ambiguity, consistent with the qualitative data gathered from interviews.

Interestingly, **unclear or changing scope** ranked highly in the survey, even though none of the participants explicitly mentioned it during the interviews. Conversely, **unknown result** was ranked the lowest in the survey, yet it was discussed by 50% of participants during the interviews. This discrepancy suggests that while participants may recognize certain sources of ambiguity, like unclear scope, as significant when responding to a structured survey, these factors might not be as readily discussed in conversational contexts. On the other hand, the frequent mention of **unknown result** in interviews, despite its low survey ranking, suggests that participants might perceive this source differently in a more fast-thinking, dialogical context.

Understanding of TOA

As introduced in the theoretical framework, there are three main types of responses people have when facing ambiguity, which are further divided into 12 aspects. The following questions were asked regarding these 12 aspects.

First, participants were asked, "Which aspects do you believe students should exhibit when facing ambiguity?" This question reflects teachers' expectations and their understanding of a high level of TOA or the ideal outcomes. *Confidence* and *acknowledgment* received 18 votes each, placing them in first, and *decision-making* and *curiosity* followed closely with 16 votes each, securing second place.

When analyzing responses by category, behavioral responses received the highest overall vote count (59), followed by cognitive responses (54), and emotional responses (48). Despite behavioral responses receiving the most votes overall, the two highest-rated aspects, *acknowledgment* and *confidence*, were both cognitive. This suggests that while actions (behavioral responses) are highly valued, particular cognitive aspects such as *acknowledgment* and *confidence* are considered especially important. In contrast, other cognitive aspects, such as *faith* (8 votes) and *opportunity* (10 votes), were less valued. Similarly, while emotional responses received fewer overall votes, *curiosity* (16 votes) emerged as one of the top three aspects overall, showing the varying importance of individual aspects within each response type.

When asked which aspects they believe are important to support in PBL, participants once again ranked *acknowledgment* highest with 21 votes, a result 31% higher than the next three aspects—*disclosure*, *confidence*, and *approach*, each with 16 votes. When grouped by response type, behavioral responses once again garnered the most votes (57), followed closely by cognitive responses (55), with emotional responses receiving the fewest votes (47). As in the previous question, *acknowledgment* in the cognitive category was ranked highest, while *faith* in the same category received the fewest votes.

Participants were next asked to reflect on their experience supporting these aspects in previous PBL courses and their willingness to support them in future courses. Both questions used a Likert scale format, with "never" and "extremely unlikely" score 1, and "very often" and "extremely likely" score 5.

In terms of past experience, *acknowledgment* received the highest average score (mean = 3.96), followed by *approach* (mean = 3.86), with *confidence* and *information-seeking* tied for third place (mean = 3.73). Notably, *acknowledgment* had a combined majority selecting 'very often' or 'often' (9 votes each). For *approach*, the 'often' option was the most frequent response (12 votes), a pattern also seen in *confidence* and *information seeking*, with 9 and 10 votes in the 'often' category, respectively.

Looking to the future, participants expressed an increased willingness to support *confidence* (mean = 4.18), *acknowledgment* (mean = 4.14), and *approach* (mean = 4.05). Interestingly, the average scores for these aspects in future support were approximately 7% higher than those for past support, indicating a stronger inclination toward providing support. The number of respondents selecting positive options also increased compared to the previous question. Additionally, aspects such as *attraction*, *courage*, *faith*, and

opportunity, which previously received more middle-range responses, saw a shift toward higher levels of support in the future.

		Q10		Q11	
Behavioural	Approach	13	59	16	57
	Decision Making	16		14	
	Disclosure	15		16	
	Information Seeking	15		11	
Cognitive	Acknowledgement	18	54	21	55
	Confidence	18		16	
	Faith	8		8	
	Opportunity	10		10	
Emotional	Attraction	9	48	10	47
	Calm	13		11	
	Courage	10		12	
	Curiosity	16		14	

Table 4. Survey response summarise for Q10. "Which aspects do you believe students should exhibit when facing ambiguity?" and Q11 "Which aspects of Tolerance of Ambiguity do you believe are important for educators to support in problem-based courses?"

One aspect that stands out is *disclosure*, which displayed significant variance between the two sets of questions. While participants ranked *disclosure* third in terms of teachers' expectations of how students should face ambiguity and second in importance for support in PBL courses, it ranked much lower in terms of actual support provided in previous courses (11th) and projected support in future courses (8th). This discrepancy leads to a discussion that, although *disclosure* is recognized as important in theory, it is not consistently prioritized in practice.

Across all four questions, a consistent pattern emerged in terms of the most valued aspects. *Acknowledgment* and *confidence* consistently ranked in the top three, with *approach* appearing in the top three in three of the four questions. When grouped into response types, behavioral responses consistently received the most votes, followed by cognitive responses, and emotional responses received the fewest votes. This trend suggests that while emotional responses are not considered unimportant in problem-solving contexts, they are generally given less attention compared to cognitive and behavioral responses.

Furthermore, even within a single response type, different aspects are valued differently. For example, *acknowledgment* and *confidence* are highly prioritized within the cognitive category, while aspects like *faith* and *opportunity* are not. And in the emotional category,

through the other three aspects, *attraction, calm,* and *courage* have fewer votes, curiosity ranked in the first half among all aspects. This indicates that response types should not be treated as homogeneous groups, as certain aspects within each category are perceived as more relevant than others.

Teaching strategies

In the second part of the survey, participants were asked about teaching strategies they have used in relation to TOA development in PBL, how effective they found these strategies and if they will adopt these strategies in future teaching practices. These strategies, drawn from various disciplines, were either directly linked to TOA development or aligned with general PBL practices, with a total of 12 strategies listed.

Regarding how often teachers employed these strategies, *giving compliments* ranked first with a mean score of 4.00. It was followed by *challenging students' preconceptions by encouraging exploration of possibilities outside their current frame of reference* (mean = 3.81), and *motivating students to be explicit about the methods they use* (mean = 3.76). The responses were predominantly clustered around the 'often' option, with 11, 9, and 8 votes for these three strategies, respectively.

In terms of perceived effectiveness, *challenging students' preconceptions by encouraging exploration of possibilities* ranked first with a mean of 3.90. This was followed by two strategies tied for second place with mean scores of 3.76: *motivating students to be explicit about the methods they use* and *sharing personal experiences of ambiguity similar to those faced by learners and explaining how they were managed*.

When asked which strategies they were most likely to use in the future, the results suggest three distinct tiers of strategies based on participant preferences: (1) The first tier includes the highly valued *motivating students to be explicit* strategy which received the most votes (17), approximately 30% higher than the strategies tied for second place; (2) The second tier includes six strategies with 11-13 votes, which are also recommended for classroom use; (3) The third tier, containing the other five strategies with 5-10 votes, may require further testing or validation to prove their effectiveness in TOA development.

A few interesting trends emerged from the data. *Letting students visualize the ambiguity they face* was the least-used strategy in previous practice (mean = 2.48), yet it appeared in the second group of strategies participants expressed willingness to try in the future. *Highlighting the development of TOA as part of the learning goal* ranked in the middle for past use (mean = 3.19), but jumped to second place (13 votes) for future adoption. Conversely, *sharing personal experiences of ambiguity* was ranked mid-range in terms of past use (mean = 3.57) and second for effectiveness (mean = 3.76), yet dropped to 11th place (8 votes) for future use.

Some patterns emerged consistently across all questions. *Motivating students to be explicit about the methods they use* ranked in the top three in all three questions (past use, effectiveness, and future use). Similarly, *challenging students' preconceptions* and *giving compliments* appeared in the top three for two of the three questions. On the other hand, *motivating students to quickly choose a direction* consistently ranked last across all three questions, and *suggesting exercises to narrow down ideas* was also among the least

favored, suggesting these strategies may be less useful for fostering TOA development in problem-solving contexts.

In addition to the strategies listed in the survey, some participants highlighted reflection as a valuable tool. Two participants specifically mentioned self-reflection, collective reflection, and peer feedback as useful strategies.

These findings provide an overview of how TU Delft teachers currently support the development of TOA and highlight the strategies they favor. While not all strategies may be applicable to every classroom, they offer reference points for teachers designing problem-based learning courses or those seeking to emphasize TOA as a transdisciplinary skill in their courses. Additionally, by sharing the survey, we hope participants have gained deeper insights into how to better support students and refined their own approaches accordingly. During the survey period, we received feedback from teachers who expressed interest in the topic and indicated they would like to adopt some of the strategies mentioned, as the survey options presented them with new possibilities to explore.

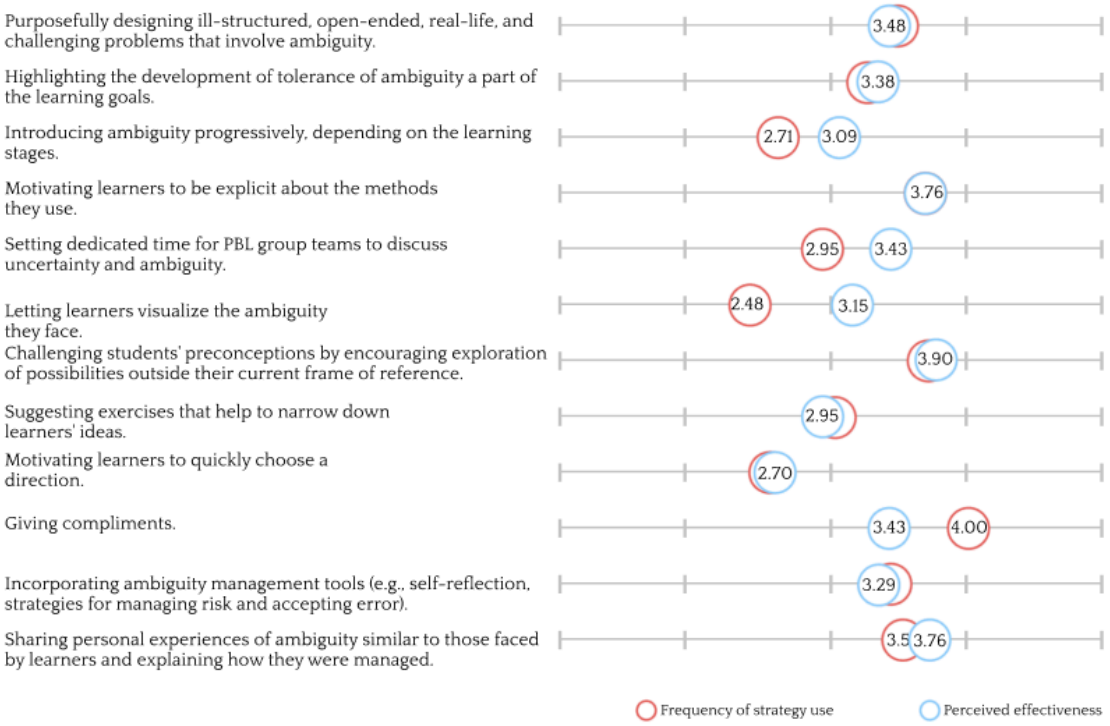

Figure 5. Summary of teaching strategies Q16, Q17 (N=21)

Challenges

In the final part of the survey, participants were asked about the challenges they face when integrating TOA development into PBL courses. The options presented were drawn from literature on both TOA development and PBL in general, with 10 challenges listed.

The most significant challenge identified was *the need to adjust strategies to facilitate each unique PBL group*, with a mean score of 3.63 and 13 participants responding positively to this option. The second most frequently cited challenge was *encountering resistance from learners when it comes to divergent or convergent thinking* (mean = 3.21), with 8

participants selecting this as a challenge. All other options had mean scores of 3 or lower, indicating that a majority of participants either did not perceive these as challenges or had mixed experiences. One participant noted, "The challenges are manageable and shouldn't be avoided." Notably, the option "I feel anxious about dealing with ambiguity" received only negative feedback, showing that teachers' anxiety around ambiguity was not an issue for participants.

Additionally, participants shared other challenges they encountered, including *"over-arching assessment criteria and rubrics that tend to over constrain and create checklists of activities students see as the 'right' way to approach the problem," "The infrastructure at TU Delft is not very suitable for PBL sessions: too many lecture halls, to few project rooms."* and managing students' varying paces in learning to handle ambiguity. Another challenge mentioned was *"resistance from the more conservative fraction of teachers."* In the survey, one respondent clearly expressed their reluctance to include TOA development in their courses, viewing it as more of a psychological issue rather than a skill, and preferring to focus on practical discipline-specific skills. This dissenting perspective adds richness to the findings and highlights the diversity of opinions on the role of TOA in education.

4.2 Interview results

Demographic data

The six interviewees represented diverse academic faculties, with 2 participants from Applied Sciences, 2 from Industrial Design Engineering, 1 from Architecture, and 1 from Aerospace Engineering. Their experiences with problem-based learning courses varied significantly, ranging from involvement in 2 courses to over 15 years of experience in the field. This breadth of experience covered all educational levels—bachelor's, master's, and PhD—offering insights into how ambiguity in problem-based learning manifests differently across these stages. Finally, there were five themes and 11 sub-themes were identified, and a total of 54 distinct codes.

Difficulties experienced by students

Regardless of sources rooted in the problems, students perceive ambiguity mostly when they are making decisions [P1, P2, P3, P4, P5]. The challenge students face in making decisions is they constantly question whether their choices are the right ones amidst competing priorities and limited information. As P4 stated: "*There are so many problems, you can't solve it all. So you need to prioritize, and you need to identify them*."

One problem mentioned by participants most is that students tend to focus on a perceived solution [P4, P5, P6]. This is acceptable since assumptions, hypotheses, and personas are popular methods being used widely and many teachers also include this in their classes. However, the challenge for having an assumption is that the assumption is what you imagine, and it's not 100% correct. This happens because students are not fully engaged with the problem, with the context or situation. "*When uncertainty is very high, it's very hard to formulate a hypothesis about the thing that you don't know yet.*" [P6]

Another problem students face is that they focus too much on the result than the learning process [P3, P4, P5]. This might has something to do with grade pressure, since students

want to have good grades and they believe if they follow whatever teachers say they can get a good grade. However, in real-life situations, there are not many instructions, guidelines to follow, they should set boundaries and clarify themselves [P4, P5]. This mind restrains them from letting go of their ideas and avoids iteration [P2, P4]. "*They often mistakenly view their initial idea as the best one and work in a straight line from that first idea to the end*". This might be because giving up initial ideas and thinking of new possibilities means the time spent before are wasted [P6]. So the participant mentioned that teachers only evaluate students' end result based on the actual time they have worked on the final idea instead of the whole semester so that students feel "*that they can actually kill something they don't believe in anymore*".

To relief the grade pressure, a course focusing on skill development can be non-examinitive and just to be a pass-fail course [P3, P6], so that students can only focus on the process itself, because "*if something is truly ambiguous and people are working on different aspects of it. It's hard to compare them*".

Problems in PBL

Three sources of problems are mentioned in interviews, namely teacher-provided problems [P3, P5], student-generated problems [P1, P4, P6], and externally sourced problems [P2]. For the problems given by educators, some participants mentioned that they would like to make the problem ill-defined just like real-world complex problems on purpose. P5 introduced: "*I'd like to provide ambiguity by giving sort of requirements or boundary conditions at a higher level, subject to interpretation*." And when collaborating with case owners, accessibility is a primary consideration, not only the case should be accessible to student to explore to get involved with the context, but also case owners should be accessible by students, to occasionally interact with students and provide feedback, letting students know that they are on the right direction [P2]. When it comes to students thinking about what problems they want to solve, it looks like students have more freedom, however, it also causes some challenges, including broad focus/cliche problem and reversed cause-effect to have the problem based on their perceived solution [P4, P6].

Team element

In the courses mentioned by participants, students either work individually or in teams and the differences between these two working styles show a pattern that team support is beneficial for students to go through ambiguity since they can support each other [P5]. Team mates sometimes can represent teachers' role to support each other. Working in a team makes it possible for team members to share their struggles, support each other and compensate each other for their omissions, since everyone has blind spot [P1, P4, P5], which can relieve teachers' pressure. However, sometimes team elements can also create challenge especially when the team size becomes bigger, such as more than 5 people, this might be because when there are too many people in the team, it is a challenge for every student to participate in the problem equally. Both P2 and P3 mentioned that they use different team size in different problem solving stages, smaller teams containing 2 students in exploring the problem or engaging with the context and grow the team to 4 or 5 students when working on the solution.

Sometimes the "*choice is made by political fight, where the strongest voice might win.*" [P2] or a team member "*monopolize making the decision where they recognizes all of the*

challenges with the ambiguity, and then sets up the boundary conditions and communicates to the rest of the team, so then it becomes a non-ambiguous project to the rest of the team from their perspective." Participants also hold different views when facing this challenge: P2 thinks it is okay to leave the process to students themselves while P5 would like to intervene and make the problem ambiguous again to all team members. Not all students are willing to work in teams, once a student wasn't comfortable working in a team, maybe an easier solution for this kind of student is to just let them work on their own [P3].

Scaffolding

As discussed in the Literature Review, scaffolding is a common approach used in problem-based learning environments. In the interviews, all participants except P4 referenced methods related to scaffolding, with a total of 12 quotes highlighting its use. Participants consistently emphasized the importance of equipping students with the necessary knowledge and skills before allowing them to independently tackle problems.

The necessity of scaffolding is to provide students with guidance, supplementing for knowledge gap or missing information, and help to reduce the perception of ambiguity. And it is flexible, where students are given support but retain the freedom to navigate the learning process independently, just as P3 noted: "*What I found really important, and what is already implemented, is a form of scaffolding. I provide structure, but the structure is there for students to choose whether to follow or not. At least it gives them a bit more guidance in the process*."

Although the aim is that students can set boundaries and requirements themselves to navigate ambiguity [P2, P4, P5], there are also some aspects that teachers can certainly step in to help. These aspects are typically around lack of experience, for example, poor time management [P4, P6] ("*...that to give him a problem, he will spend more time defining the question. Give him one hour, he will spend 59 minutes defining the problem and one minute solving the problem*"); wrong focus [P1, P3, P4] ("*They were overly concerned with minor details ... I believe it's the teacher's responsibility to guide them to set certain things aside and don't need to worry about*"), lack capacities [P6] ("*There are people that cannot really push it forward because they don't have the skills, capacities – to make that converging step*"). There is nothing to blame for lack of experience, since students can gradually overcome these ambiguities with time and experience. And during these start problems, a certain guidance just like what mentioned in scaffolding can help release the confusion, to set a certain time for each phase as reference, clearly stated requirements, and prepare students with necessary skills with lecture.

Students ownership

One key finding is that participants value students as owners of their learning [P2, P3, P4, P5, P6]. As a result, even if the problem is given by the teacher, it is still part of the fixed but remained free part for students to explore [P3]; and for problems decided by students, they have total freedom to choose based on their interest and knowledge [P4]. Although sometimes students are not used to such freedom and constantly seek teachers' confirmation on the goal of the problem [P4]. This might be caused by grade pressure, since students want to implement what teachers want them to, but in that sense, they are just "following steps" and not fully realise why they are doing this, which is an important

part in their learning [P3, P4, P5]. P2 also emphasises that students should lead the discussion when meeting with teachers. Participants showed that teachers shouldn't have any expectation on what students will get [P2, P5]. Participants also use various methods to help students with this issue: P2 and P4 give conflicting ideas about students' choice so that students need to balance and make their own decision, and "*support students regardless of which idea they choose*" [P1]; P5 and P6 give an obvious wrong direction so that students know it's time to decide themselves or sometimes they are just "can't find the words, the moment they hear the word, they know it's what they don't want to do"; P3 and P5 promote students to think outside the box by continuously asking "what if" questions rather than giving suggestion so that students feel that "*they are coming to the answer themselves*"; similarly, P6 uses the same asking question to "*show the contours of what a decision could look like*" and emphasise the magic of visualising what a less ambiguous situation looks like. This high level ambiguity might cause anxiety [P2], it is also possible that students can be "*surprised at what they have been able to achieve when being motivated*." [P6]

Learning by failing

Sometimes students might underestimate or oversimplify a problem and the ambiguity behind it [P1], this might due to lack of knowledge or for students with high confidence with their abilities. "*If the students' knowledge isn't deep enough, they might not understand the subtleties teachers are pointing out*." So the method using by P1 is letting students try themselves and probably they will see the ambiguous point.

Similarly, P3 and P5 also emphasize the value of learning by failing. They adopt the method of encouraging students to first try themselves, and if doesn't work out, teachers can have a discussion regarding their failure after then. The point of making errors and failing is to let students reflect on it, drawing knowledge and learning out of that, and try a different route.

In this sense, atmosphere plays an important role in making students aren't afraid to come to teachers and share when things don't work [P5]. "*I think creating the atmosphere where students are not afraid to ask questions and they know it's not a bad thing if they don't get the right question right away, they can just try again*." [P3]

Atmosphere

P3 mentioned methods used in previous courses including, creating a living-room like classroom for coaching, and breaks with food and drinks also creates a friendly atmosphere for students to reflect and share and not only focus on the content.

Talking about atmosphere, P1 showed concerns about when teachers can't balance high-level content with ensuring a solid foundation. Sometimes the expert blindness creates ambiguity since they assume students know things they may not and don't realize students face that ambiguity [P1,P3]. "*And when this happens, students are often too intimidated to ask questions, so they just carry on with these undefined concepts*." P3 mentioned a way to alleviate this by making learning lines and knowing what previous courses were teaching and then showing the relation to the new problem, linking to other courses.

Ways to identify students' struggle with ambiguity

One thing that stands out in the literature review stage is before teachers can help students with ambiguity, teachers need to find out that students are struggling with ambiguity. Two popular methods mentioned by participants are observing [P1, P2, P5, P6] and knowing from time spent for certain tasks by students [P1, P3, P4, P6]. Observation was mentioned mostly in the coaching session where teachers look into how students work as a team and the methods they use in the process. P1 also use non-verbal cues from students who are reluctant to express their frustration openly and try to engage them in discussion to understand their challenges.

The challenge for using observation is the class size, since if there are too many students or student teams, it is difficult for teachers to engage with every student or student team. *"The key thing is the observation. I also teach very large bachelor courses of like 450 students, I couldn't give ambiguous things there. There's no way because I know so many students would get, um, be completely lost and I would have no way of identifying who. There's just too many people to observe."*

Time is an objective measurement for students' TOA since if a student spends longer time on a specific task compared to others, it means this students is obviously facing some difficulties. P3 gives students a timing per step, and tell students that *"although there are variation, if it takes you twice as long and you are still struggling, then please ask and we will come help you out."* Besides, some students have problems with time management [P4], they might spend too much time on exploring the problem and only use little time for the solution, this is also not ideal for problem-solving. This method with time element requires teachers to be involved with students' process deeply, so they need to meet on a daily or weekly basis. All participants value the meaning of meeting with students regularly, and half of them also notice the constraint of teachers' time and availability [P3, P5, P6]. This is usually a limit on how many students in the class, because in theory, every student needs dedicated time with a coach to get regular feedback and encouragement, so more students in class means the need for more coaches.

What do teachers think students have developed TOA?

In the TOA framework, higher TOA means responding to ambiguous situations as positive. But how do teachers think about the outcome? As a teacher, what do they want students to improve and react to ambiguity?

Four participants [P1, P3, P4, P5, P6] mentioned from behaviour angle, to *"take next steps", "assess all options they have one by one and make a decision", "they annoyed by that (ambiguity) and they went through", "they have the light bulb go off in their head and they go and try"*, "*be able at some point to not walk around in circles*". Three participants [P1, P3, P4] mentioned from an emotional angle, to "*minimize students' negative emotions*", "*remain calm*", and "*frustration together with relief*". Regarding cognitive angle, participants mentioned it together with behavioural responses. P5 expects students to be "*aware and find their own way through it (ambiguity)*". And P4 and P6 don't care if students like ambiguity or not, or even they complain about that, but expect students to make the decisions.

Teachers also get frustrated when they tried every method but it still doesn't work for students [P1, P6]. *"I don't have a measure or something. But intuitively, sometimes I just... yeah, I give up."*

However, every effort has its own coming, things might click in the future. Participants [P1, P3, P4] hold the view that even if some methods can' help students at this point, doesn't mean it's ineffective; it might work later under different circumstances. "*After, like, 7 years, you don't remember the exact content in class, but you remember the way you apply it or the way you approach a problem.*" Especially for skills like tolerance of ambiguity, normally it's a skill gained gradually with experience instead of a quick change/improvement.

Challenges experienced by teachers

All participants except P4 mentioned students' characteristics and challenges to **adjust their method based on the situation** with totally 12 quotes. Meeting regularly and observation are highly related to this challenge. During regular meetings, teachers observe how they approach the situation, answering their questions. Sometimes there are students reluctant to "*express their frustration openly*", then a safe enviornment is needed; or "*they are very confident and have many ideas, I usually listen more and inform if there are oversimplifications.*" [P1] There are universal design for learning where teachers have already "*make it easier for a specific task or group*", but a desire to "*adpat with minimal efforts to make it more approachable for any student*", because "*solve what is minor for teachers might what is big for a student*" [P3].

This is also related to the nature of problem-based learning environments, which can be **a large time investment** for teachers [P3, P5, P6] since every student or student team should have that regular meeting with teachers to get feedback and encouragement. Students can benefit a lot from teachers being approachable to ask questions, so there is a need to "*figure out a way which makes it work for students and teachers without, like, too much extra effort*". When there are not many students in the class, it is all good, but when there are more students, to make every student or student team have time to interact with teachers, maybe extra teachers are needed [P6].

And because every student might experience different types of ambiguity and respond differently. There are not many general forms to deal with ambiguity [P6], and even if there are some, the general suggestions are "*hard for students to learn about the process to make that knowledge transfer themselves*" [P1, P6]. Students need concrete, and tailored suggestions [P6]. This requires teachers to **empathize with students**, to contextualize themselves with students' case [P2, P3, P4, P6]. Knowing students well can help since after certain time and meeting regularly, teachers have the chance to know students' characteristics and their progress, thus can provide tailored suggestions [P2, P6]. Or a kind of teacher course as highlighted by P3 "*What helps them is if, like, a teacher does...follow a course for their own, like, professionalisation, finding themselves being in the side of the student – that really helps.*" The hinder for empathize can be **teacher blindness** [P1, P3], where teachers have too much experience and they can't even notice this might not be familiar to students as well. "*When this happens, students are often too afraid to ask questions, so they just carry on with these undefined concepts.*" What helps with this is that teachers know well about students' level. P3 also mentioned the faculty is restructuring the programme that "*first-year courses start from scratch in the sense of not expect students*

to know anything, so need to help them out with not only the content but also the approach and the way how to work together, for example." And for the later courses, teachers can resume the approaches that students already learnt to make it easier and more relatable. The idea behind is to "*make learning lines and know what previous courses were teaching*".

When supporting students, teachers should be open to various perspectives, **divorce themselves from any expectations** of what students will produce [P2, P3, P5]. The challenge is that even if teachers or case owners already have a pre-existing idea, there should be space for students to "*explore many different solutions within the context*".

"*It's a maturation process for teachers not focusing on the content and acknowledging that the students struggle with the process*." [P3, P4, P5] Not only students shouldn't only pay attention to results, teachers should also adopt this mindset, otherwise how can teachers show students not to. Teachers' beliefs will influence students'.

Result and answer are not that important because there won't be a perfect solution [P3, P4, P5, P6], everything changes; and as technology development, simply focusing steps to get answers is obsolete because computers can do much more faster and better than humen [P4, P5]. What matters is the why behind these steps [p3, P5], "*what other approaches are there? How can you choose between them?*"

5

Problem definition

Key findings will be highlighted in this chapter, providing insights into the current state of tolerance of ambiguity development in the context of problem-based learning. The aim is to synthesize the data collected, setting the stage for a deeper understanding of the challenges and opportunities identified.

5.1 Teachers' Expectations for Students' Responses to Ambiguity

From the interviews, it's clear that students exhibit varied responses to ambiguity. Teachers observe a range: some students embrace ambiguity, enthusiastically exploring and learning from it, while others struggle, especially those who were unfamiliar with open-ended situations. A recurring difficulty teachers noted is that students often fail to prioritize which aspects of a problem to address, sometimes fixating on perceived solutions. This fixation can be problematic, especially when these solutions are based on incomplete or imagined information. Another common response is that students tend to seek the fastest route to a good grade, often without a solid understanding of why they are approaching the problem in a specific way.

These responses, while potentially reducing students' perceived ambiguity, ultimately conflict with core learning objectives. A crucial finding emerging from both survey and interview data is that perception serves as the foundation for developing ambiguity management capabilities. The survey results highlighted acknowledgment as one of the most valued aspects in teachers' perceptions and expectations of TOA. This aligns with interview findings where teachers consistently emphasized the importance of students being "aware" of the ambiguity they encounter, regardless of their comfort level, and developing personalized strategies for navigation.

In the framework selected for analysing tolerance of ambiguity, Hillen et al. (2017) categorisd people's responses into three categories - behavioural, cognitive, and emotional. When analyzing responses indicated by partipants, an interesting pattern emerges. While the survey data indicated that behavioral responses were most valued overall, the highest-ranked individual aspects—acknowledgment and confidence—fell within the cognitive domain. This finding was corroborated by interview data, where all six participants emphasized the importance of concrete action in successful ambiguity engagement. This means that when students face ambiguous situations, teachers expect them to take steps forward rather than remain stuck.

These insights suggest that while it's helpful to categorize responses into behavioral, emotional, and cognitive types, teachers do not treat each category equally. Certain aspects, such as acknowledgment and confidence, hold more weight, while others—like attraction

or faith —are less emphasized. Ultimately, teachers hope for students to take initiative and persist through ambiguous situations, developing the resilience to move forward even when the path is unclear.

- Students needs - ownership, learning by failing (lead to what strategies help with this)
- How teachers identify student difficulty (can also lead teacher coaching challenge)

5.2 Teaching Strategies for Fostering Ambiguity Tolerance

Building on teachers' expectations for how students should ideally respond to ambiguity (5.1), this section explores specific strategies teachers use to foster these desired responses. Some strategies specifically target TOA development, while others align with broader PBL principles but are intentionally adapted to support TOA.

According to survey data, the top three favored teaching strategies are *motivating students to make their methods explicit, challenging preconceptions, and offering positive feedback*. Less favored strategies include *pushing students to quickly decide on a direction* and *suggesting exercises that narrow down ideas*. It shows that teachers favored strategies that encourage students to be divergent thinker, this might because diverging happens before convegring, although both thinking methods are important, students need to be divergent and then can come to the convergent stage.

In line with these survey findings, interviewees also highlighted the effectiveness of questioning. Through questioning, teachers encourage students to reason their decisions, think out of box, and feel empowered of generating their own ideas and solutions. This approach not only strengthens student ownership of the learning process but also aligns with the principles of problem-based learning, which emphasizes student-centered, guidance-based, and process-oriented education (Savery, 2006). Interviewees explained that intentional questioning allows students to independently explore, as seen in strategies like offering freedom to tackle problems independently [P3], nudging them with questions rather than answers [P3, P5, P6], and empowering students to take control of their learning [P2]. This aligns with Taajamaa et al. (2014), who advocate the need to support students by being there, making the right questions and also by simply encouraging the students to go forward despite the ill-defined situation; without such support, too much responsibility may fall solely on the students.

Intentional questioning is also widely recognized in the literature as a technique for building ambiguity tolerance, serving multiple purposes: (1) connecting theory to practice and ensuring comprehension (Rowan et al., 2007); (2) prompting students to critically reflect on their thoughts in relation to real-world applications (Lazarus et al., 2023); and (3) highlighting overlooked aspects of the learning process (Nel et al., 2008).

Other strategies cited in both surveys and interviews include *purposefully designing ill-structured, open-ended, real-life problems that incorporate ambiguity*. Three main sources of problems emerged in interviews: teacher-provided, student-generated, and externally sourced. For teacher-provided problems, participants P3 and P5 noted that ambiguity is often intentionally built into the problem design to simulate real-world complexities. P2 uses a strategy to collaborate with an external case owner, allowing

students to get involved in an ongoing project. When it comes to students considering what problems they want to solve, it appears that they have more freedom; however, this also causes some challenges, including a broad focus or cliché problems and a reversed cause-effect relationship where the problem is based on their perceived solution [P4, P6].

Progressive introduction of ambiguity is another key strategy proposed in the literature specifically for addressing ambiguity, but it can also be categorized as part of the broader scaffolding strategy. This approach is necessary because Douglas et al. (2015) found that a lack of content knowledge is the most common factor responsible for ambiguity. Five out of six participants highlighted the necessity of providing students with structured guidance, particularly in the early stages of problem-solving. P3 mentioned that they provide a manual at first to guide students through the steps, and in the end, students solve a question without guidance. As Awati & Nikolova (2022) suggest, this kind of step-by-step strategy, which starts with rational decision-making and gradually introduces problems of increasing ambiguity, is crucial for helping students become accustomed to ambiguous problems. Additionally, the suggestion to "challenge learners to build their uncertainty tolerance over time" can enhance learners' uncertainty tolerance, as mentioned by Stephens & Lazarus (2024) in their tips for educators to help increase healthcare learners' uncertainty tolerance.

In addition to the strategies listed in the survey, interview participants emphasized the importance of creating a supportive atmosphere and safe environment where students feel comfortable trying new things, even if it means failing. Failure is an inevitable part of solving open-ended problems (Taajamaa et al., 2014; Feng et al., 2024). Bohm et al. (2023) highlight that accepting the possibility of failure and ambiguity is a crucial skill for students facing uncertainty. This perspective is reflected in the approaches of participants P1, P3, and P5, who encourage students to explore, experiment, and learn from their mistakes. However, despite the importance of learning through failure, some students initially fear making mistakes, underscoring the need for teachers to cultivate a safe environment. Many studies highlight the significance of creating a psychologically safe and supportive learning space (Bozic et al., 2018; Stephens & Lazarus, 2024; Yaccob et al., 2023), yet few provide clear strategies for teachers to achieve this.

During the interviews, P3 shared their approach of transforming the classroom into a living-room-like space to foster a sense of familiarity. This comfortable setting helps reduce students' anxiety, encouraging them to ask questions and take risks, even if they might fail. P3 also highlighted the value of taking breaks, a strategy supported by Bohm et al. (2023), which found that students view breaks as an effective way to manage uncertainty. Beyond the physical environment, P3 stressed the importance of establishing continuity in learning across courses. This ensures that teachers are aware of what has been covered in previous classes, preventing students from feeling lost or intimidated by gaps in their knowledge. Some programs at TU Delft are already making efforts to restructure curricula to create clear learning pathways that support a smooth transition for students.

The team plays a crucial role in problem-based learning courses, as most projects are completed in groups. Interview participants noted that students often work either individually or in teams, and the benefits of teamwork in navigating ambiguity are evident. Team members can support each other, which aligns with existing literature that highlights how learning teams can collectively manage uncertainty, reduce discomfort, and leverage

diverse perspectives to identify knowns that help manage unknowns (Stephens & Lazarus, 2024).

However, the functioning of teams can present challenges. While it is ideal for every student to experience ambiguity to develop tolerance, some individuals with strong insights and persuasive skills may dominate the team discussions, potentially sidelining quieter members. This imbalance can limit opportunities for all students to engage with ambiguity effectively. To address this issue, teachers must intervene during key moments, which Lehman et al. (2006) refer to as "teachable moments." These critical instances allow educators to guide the learning process, ensuring that all students—regardless of their confidence or vocalness—have the chance to develop the skills necessary to navigate ambiguity.

5.3 Teacher Challenges in Supporting Ambiguity Tolerance

I also tried to understand what challenges have teachers faced to step deeper into the problem. The most significant challenge identified in the survey was *the need to adjust strategies to facilitate each unique PBL group,* this was also the key challenges stated by interviewees to provide tailored guidance since general strategies for handling ambiguity are often insufficient [P6]. Teachers must have a deep understanding of their students' individual needs [P6], which requires familiarity with their personal characteristics and progress [P2]. This is consistent with Goh (2014) who stated that *"good facilitation is not about methods, but about possessing an astute awareness of the unique learning situations in the classroom"* and responding appropriately to create learning opportunities. Because of these, time investment was a recurring theme in the interviews.

Similar findings emerged in the interviews, where participants referred to this as empathizing with students, highlighting the idea that teachers may struggle with their own blind spots when guiding students to deal with ambiguity. P1 and P3 described how experienced teachers can sometimes overlook the fact that students may not be familiar with certain concepts, leading students to continue with undefined ideas out of fear of asking questions. P1 also suggested that professional development courses placing teachers in the student's position could help them empathize with the frustrations and challenges students face, thereby improving their ability to support students through ambiguity. But the point is for teachers to realize what are the students' knowledge stages.

A related question that sparked my interest was *how do teachers recognize when students are struggling with ambiguity*. There were limited evidence found in the literature about a good answer. Most interview participants [P1, P2, P5, P6] mentioned that they regularly observe and ask students questions to better understand their difficulties, which requires teachers to draw on their own experience. This method is also showed its efficiency from Bohm et al. (2023) study that talking about uncertainty help students to gain better understanding of uncertainty. Another concrete indicator of student struggles is the time they spend on specific tasks [P1, P3, P4, P6]. If a student takes significantly longer than expected, it's a clear sign that something is amiss, prompting a conversation to identify what went wrong. Interestingly, it's not always the ambiguity of the task itself causing delays—students might be overwhelmed by other courses or commitments. In these cases, time management becomes crucial. If ambiguity is the issue, students should be

encouraged to seek help from their teachers after a reasonable period instead of trying to figure everything out on their own [P3].

5.4 The Essence

The analysis revealed two central challenges: (1) teachers need a closer familiarity with students to provide tailored guidance, and (2) teachers expect students to take action and engage, even when faced with ambiguous situations.

The first challenge reveals the importance of open communication between teachers and students. Effective communication allows teachers to understand the specific challenges students are facing, which is essential for providing targeted support. By discussing students' progress and approaches to tasks, teachers gain insight into areas where students may be struggling and can offer personalized guidance, making it easier for students to feel understood and supported. This open communication fosters empathy, helping teachers connect with students on a deeper level.

The second challenge arises from the students' perspective: when facing ambiguity, students may hesitate to take action due to uncertainty about how to proceed. Addressing this requires equipping students with approaches for navigating ambiguity and helping them recognize actionable steps they can take to move forward. Teachers and peers can support this by providing new perspectives on challenges and show empathy. By creating a safe environment where students feel comfortable expressing their uncertainties, they are encouraged to reflect and explore alternative approaches—ultimately helping them become more confident in handling ambiguity.

6

Learning theories

This chapter reviews some learning theories relevant with the study. The key findings from the first diamond of the research also mapped these learning theories to identify any connections and then guide the design of interventions. The focus will be on how these theories can inform practical approaches in the context of PBL. Chapters 6, 7 and 8 collectively aim to design an educational tool that facilitates teachers and students in the learning process. The goal is to address sub-research question 2: *What educational tool can facilitate the development of tolerance of ambiguity in students participating in problem-based courses?*

6.1 Experiential learning

When reviewing the learning process for problem-based learning (PBL), experiential learning emerges as a highly relevant approach because both are grounded in constructivist learning theory. Experiential learning is the process of learning by doing and learning by reflecting. It emphasize the combination of experiences and reflection. Kolb (1984) has described experiential learning as a four-stage cycle (Figure 6). The main idea behind the cycle is that effective learning occurs through a continuous cycle of experience, reflection, conceptualization, and experimentation.

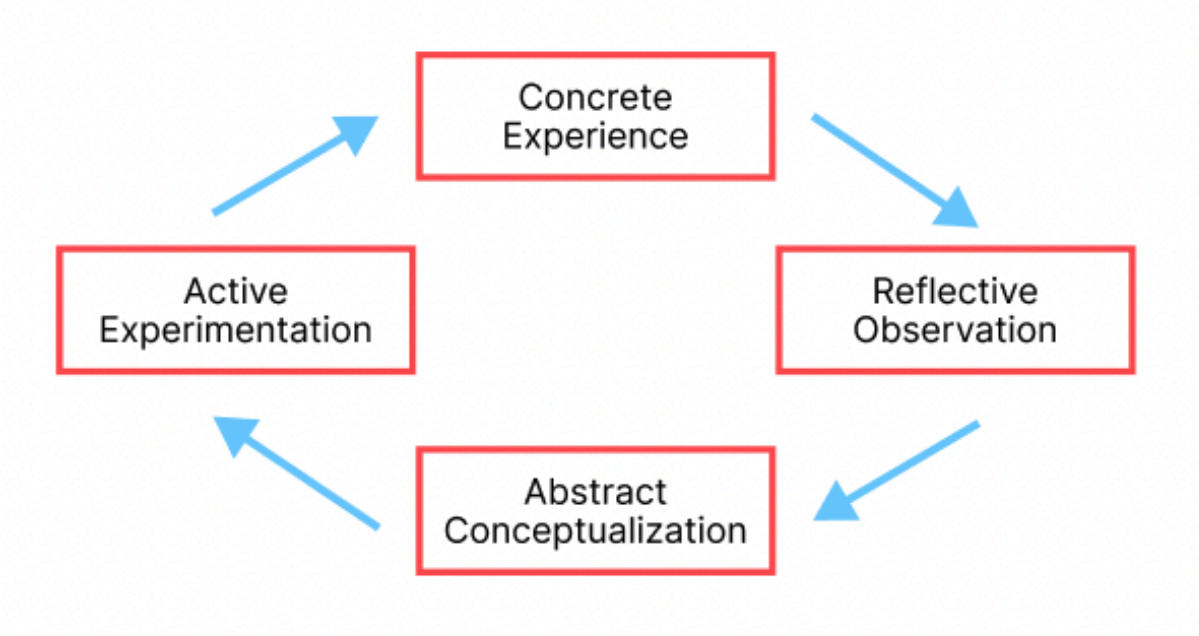

Figure 6. Kolb's learning cycle (Kolb, 1984)

Suggested by experiential learning, reflection is an integral element in the learning process. The problem-based learning environment provides students with concrete experience to encounter ambiguity. Followed by it, reflective observation of this new experience is needed. In the interviews, participants also recognise the importance of reflection in class [P3]. However, a structured reflection process is currently missing, leaving students to reflect independently on their learning journey [P3].

Given the focus of this design on navigating ambiguity, structured reflection guidance can support students more effectively. Guiding questions, for instance, can help students reflect more deeply by encouraging them to think critically about specific ideas and experiences and to consider new perspectives. After reflection, teachers can further support students through the next stage, abstract conceptualization, by helping them develop personalized strategies for dealing with ambiguity. These strategies can then serve as valuable tools for students to apply in future courses or ambiguous real-world scenarios, promoting their ongoing development and confidence in handling uncertainty.

6.2 Self-determination theory

The second theory examined is Self-Determination Theory, which emphasizes the importance of understanding student motivation to foster self-directed, lifelong learners. According to SDT, students have an inherent tendency to explore, grow, and develop (Ryan & Deci, 2017). How, then, can educators nurture this natural interest?

SDT proposes that people have three basic psychological needs—autonomy, competence, and relatedness—that are interconnected and equally essential (Ryan & Deci, 2017):

- **Autonomy**: The desire for one's goals and actions to be self-chosen and volitional.
- **Competence**: The desire to experience mastery and feel effective in one's actions.
- **Relatedness**: The desire to belong and feel connected to others.

The environment should be able to support these basic psychological needs. It is conceivable that when students experience satisfaction of their basic needs for autonomy, competence and relatedness, they may be more likely not only to develop academically but also to develop adaptively towards ambiguity. Research supports a link between meeting these psychological needs and increased tolerance for ambiguity. For example, in a study of third-year medical students, satisfaction of the need for competence was significantly related to tolerance of ambiguity (Babenko & Lee, 2022). Then the findings were mapped onto the three psychological needs to identify any relevant connections within the higher engineering educational context.

1. Autonomy

In the interviews, participants emphasize student ownership of their learning process, revealing the connection with autonomy, defined as the desire for goals and actions to be self-chosen and volitional. Participants highlight the importance of supporting students in becoming more independent thinkers, not only letting them feel that they are the subject of the ideas, but also encouraging students to clarify their choices, letting them be aware of why these choices have been made.

Similarly, TOA as a skill, its development should fulfill the psychological need for autonomy, which requires that students explore and develop their own way of navigating ambiguity. Because according to Hillen's framework (2017), students' response may vary based on the perception and the way they deal with ambiguity can also vary.

2. Competence

Problem-based learning environment set a good foundation to fulfill students' need for competence since in this type of course, students will complete a problem-solving process and at the end of the course, there will be a tangible outcome for students to see their achievements and how their actions lead to this result. Teacher in this process, is to prepare students with necessary skills and tools to take actions and help students look back to see why these actions are effective. In the development of TOA, after each experience of going through an ambiguous situation, students empower themselves with competence, which can lead them to be confident in the future situations.

3. Relatedness

Team element, meeting regularly and atmosphere with teachers are highly relevant with the need for relatedness.

Working in a team enables students to support each other: teammates are facing the ambiguous situation at the same time, they can relate to each other, knowing others have a similar frustration as them relax some of the tension; or seeing others playing with ambiguity and multi[ple possibilities, students can learn from each other. Peer support and shared experiences in navigating ambiguity contribute to a sense of belonging, which reduces feelings of isolation that can often accompany uncertain tasks. As students feel more connected to both their peers and instructors, they become more comfortable with ambiguity, recognizing that their contributions are appreciated regardless of the clarity or certainty of the solutions they propose.

Meeting regularly with teachers allows students to get formative feedback and encouragement. The compliment and a feeling of working/going in the right direction gives students motivation to continue and take next steps. Then there is a point for teacher to be careful, is to let students feel values when they are behind the schedule or going to a dead end. Sometimes students feel even more ambiguity after working for a long time and tried every method, it is important for teachers to give meaning to their tries.

Atmosphere is connected to relatedness because it provides a safe environment for students to feel supported and valued within their learning environment, they are more likely to embrace ambiguity and take risks without the fear of negative judgement. This sense of psychological safety empower students with confidence and resilience. In problem-based learning, ambiguity often triggers anxiety and discomfort because students may feel vulnerable when they are unsure of the correct answers or pathways. However, when students know that their efforts are valued, irrespective of whether they succeed or fail, they are more willing to experiment with different solutions and engage deeply with ambiguous tasks. This feeling of being supported by peers and teachers fosters a growth mindset, where students see ambiguity as an opportunity for learning rather than something to be feared.

6.3 Self-efficacy

When reviewing the self-determination theory, I feel like the competence need is highly related to self-efficacy, which refers to an individual's confidence in their ability to achieve specific goals (Bandura & Wessels, 1997). Low self-efficacy is often associated with reduced motivation and a decreased willingness to take action. And when ambiguity surrounds a task or decision, individuals tend to experience negative attitudes, which further diminish their self-efficacy. This relationship is especially pronounced in those with low tolerance of ambiguity, as they often feel they lack control over both the environment and the task at hand (Budner, 1962).

Endres et al. (2009) further explored this link, finding that ambiguity tolerance directly impacts self-efficacy. Individuals with higher TOA are better able to accurately assess their own abilities, even in complex and uncertain situations. Thus, those who are more tolerant of ambiguity often exhibit stronger self-efficacy, as they are better equipped to manage uncertainty and perceive their capabilities realistically.

Interestingly, while there is clear evidence that TOA influences self-efficacy, the reverse relationship—that self-efficacy supports the development of TOA—has not been widely explored. However, it is reasonable to suggest that self-efficacy plays a role in fostering ambiguity tolerance. In problem-solving contexts, for instance, an ideal scenario for a student with high TOA is the ability to recognize ambiguity and, despite feeling uncomfortable or confused, still take decisive action to move forward. This perseverance in the face of uncertainty is closely tied to perceived self-efficacy.

To explore potential connections, findings were mapped to Bandura's four key sources of self-efficacy (1994). These factors collectively shape individuals' self-efficacy perceptions and may, in turn, impact their ability to tolerate and navigate ambiguity.

1. Mastery experience

In the interviews, several participants [P1, P3, P5] emphasized the importance of allowing students to explore and experience minor setbacks in a safe environment. While not advocating for complete failure, these small setbacks can be constructive, as students know they can seek help from teachers or teaching assistants. With guidance and support, students learn to persist through difficult moments. The experience of navigating challenges and ultimately succeeding helps them feel more resilient, as they realize they can recover from failure and grow stronger from adversity.

Teachers' encouragement and positive feedback also play a significant role in boosting students' confidence. When students believe they have the ability to succeed, they are more likely to persevere in the face of difficulties and quickly bounce back from setbacks. This process not only builds their self-efficacy but also fosters a mindset of persistence and resilience in the learning environment.

2. Vicarious experience

Observing people similar to oneself succeed through sustained effort enhances the belief that one, too, can master the skills needed to succeed. Teachers, team members, and fellow students serve as important social models. Research shows that intellectual candor (Lazarus et al., 2023), closely related to vicarious experience, plays a crucial role in the

learning process. Intellectual candor refers to the open sharing of personal experiences, typically by those in positions of authority, such as teachers (Molloy & Bearman, 2019). In the context of ambiguity, teachers who share their personal experiences of uncertainty, along with strategies they used to manage it, provide students with relatable and valuable guidance.

In teamwork settings, students can support one another during ambiguous learning situations [P5]. For instance, one student might be particularly adept at identifying ambiguity and guiding the team's approach, while another may contribute creative ideas when the group is feeling stuck. Additionally, seeing other teams perform well during presentations can motivate students [P6], as peers in the same classroom are perceived as highly relatable models. This shared experience fosters a sense of connection and encourages students to believe that they, too, are capable of overcoming challenges.

3. Social persuasion

Encouragement and positive feedback from teachers and peers are forms of social persuasion that can significantly boost students' belief in themselves. However, for this feedback to be effective and credible, teachers must be familiar with their students and their progress [P2]. Tailored feedback, based on a deep understanding of the student, makes encouragement more convincing. General strategies for dealing with ambiguity may not work for everyone [P6], so personalized support is crucial.

When students struggle with self-doubt, teachers can remind them of their past successes, highlighting that they already possess the capabilities to tackle the current challenges. In addition to boosting self-belief, teachers can create learning environments that set students up for success by gradually increasing complexity and avoiding situations where frequent failure is likely. This is where scaffolding becomes essential—providing students with the knowledge, skills, and guidance they need to manage ambiguity, with the option to follow structured support or navigate independently.

By focusing on the learning process rather than purely the results, teachers send a clear message that success is measured by growth and improvement, not by outperforming others. This approach helps students see progress as an achievement in itself, which is particularly valuable in ambiguous and challenging tasks.

4. Emotional and physiological states

In the learning context, stress is frequently caused by time constraints, fear of failure, and grade pressure, as highlighted in the interviews.

Time constraints are a common source of stress when students face ambiguity. One participant noted, *"If you have five vague solution ideas next to each other, how are you going to decide on things that aren't determined yet, and you don't have time to wait? That's a big part of the uncertainty."* Another mentioned, *"The best thing to reduce uncertainty for students is to have more time on their projects."* However, students often juggle multiple classes and may not have the luxury of dedicating enough time to a single project, exacerbating their stress levels.

Fear of failure and grade pressure are closely linked in this learning environment. Students may invest weeks into a particular idea only to realize that it doesn't add value, leaving them feeling as though their efforts have been wasted. The prospect of starting over adds further stress, especially when they need to meet the same high standards within a shorter timeframe to achieve a good grade.

So, how can this stress be alleviated? One approach mentioned in the interviews is for teachers to focus their evaluations primarily on the final solution, rather than judging the students' work throughout the entire semester [P6]. Additionally, teachers emphasize the progress students make, focusing on how much they've improved from their original activity rather than solely on the final outcome [P3, P5]. This shift in focus helps reduce pressure and allows students to see value in their growth, even when they encounter setbacks.

7

Concept development

Following the theoretical guidance provided in Chapter 6, this chapter details the concept development process for the educational tool, the Piece-by-Piece game. It will outline the design requirements, the development process, and provide a detailed overview of the game itself.

7.1 Design requirement

In this section, in order to formulate a definitive design solution, an analysis of the design requirements was conducted.

The primary requirement is to develop greater sensitivity to ambiguity by recognizing its sources and the value of fostering tolerance of ambiguity. The aim is to encourage students to engage with ambiguous situations rather than oversimplifying or avoiding them. Additionally, the design should inspire students to discover their own methods for navigating ambiguity, which aligns with the principle of autonomy. This autonomy is essential for fostering independent thinking and problem-solving, encouraging students to take ownership of their learning journey in ambiguous situations. Another critical requirement is to enable reflection. The design must support students in clarifying their actions and reasoning during the learning process, helping them understand their choices and responses to ambiguity.

Insights gathered from surveys and interviews also emphasize the need to encourage students to take action and move forward rather than becoming stuck in ambiguity. Additionally, it highlights the importance of providing teachers with a way to gain insight into their students' learning progress. The design should enable teachers to observe and understand where students are in their learning process, allowing them to offer better-targeted support and guidance. This ensures that teachers are actively involved in developing students' skills and progress. Moreover, the design should avoid requiring a significant time investment. It should seamlessly integrate into existing classroom routines, providing an efficient tool that does not overwhelm either students or teachers.

Considering the project goals and research context, the design must also be relevant to problem-based learning. It should benefit both students and teachers, as skill development in PBL environments requires collaboration between the two. Additionally, the design solution should not be a one-time product but should be designed for long-term use. The solution should also be open-ended, allowing for adaptation to different learning environments and needs, ensuring flexibility across diverse educational contexts.

7.2 Concept development

Taking into account the aforementioned requirements, I embarked on several rounds of iterative design to explore what educational tool would be most effective in supporting students.

The choice of the target user—students or teachers—was a critical consideration. While this study primarily focused on teachers' perspectives, the two key challenges highlighted by the results are heavily related with students: (1) teachers need a closer familiarity with students to provide tailored guidance, and (2) teachers expect students to take action and actively engage with ambiguity. In both cases, students play the central, active role in addressing these challenges. Furthermore, since problem-based learning is fundamentally a student-centered approach, designing a tool that directly empowers students aligns with the pedagogical philosophy of enabling learners to navigate ambiguity independently. By focusing on students, the design can address their needs while indirectly supporting teachers in their role as facilitators.

Thus the primary objective of the concept became clear: to create a safe and supportive environment that enables open communication and inspires students to discover their own methods for navigating ambiguity. In the context of problem-solving, behavioral responses to perceived ambiguity emerged as particularly valuable. Rather than solely aiming to increase tolerance for ambiguity through the intervention itself, I focused on equipping students with various approaches and encouraging them to take actionable steps in ambiguous scenarios.

The concept is designed as dedicated time for students to explore independently, making it suitable for repeated use. To foster students' acknowledgment of ambiguity and confidence in their abilities, recalling successful experiences and engaging in reflective practices would be essential.

Drawing inspiration from puzzle-solving, which mirrors the experience of navigating ambiguity—where progress is not always linear and often requires trial, error, and reflection—I recognized that a puzzle-based game could serve as an effective medium.

Through several iterations of prototypes, the concept ultimately solidified as a team-oriented game, with teachers serving as facilitators and observers. This decision was influenced by the collaborative nature of problem-based learning, where students typically work in teams. Implementing a team activity allows members to collectively discuss, share, and inspire one another. The game aims to alleviate the pressure associated with ambiguity and add fun in the learning process.

Elements of open communication and student ownership can also be integrated into the game design. Participants will collaboratively construct solutions to ambiguous challenges while reasoning through problems and solutions. The puzzle format enables players to externalize their thinking, clearly laying out problems and potential solutions while visualizing the interplay between ambiguity and resolution. Serving as a catalyst for discussion, the game encourages teams to propose innovative ideas aimed at addressing ambiguity in future problem-solving scenarios, with a strong focus on identifying their own methodologies for navigating uncertainty.

There were three main goals for this game:

- Recognize ambiguity as a natural aspect of the problem-solving process.
- Facilitate discussions that promote knowledge sharing and learning from diverse perspectives.
- Feel more comfortable with ambiguity as participants explore multiple approaches.

7.3 The concept in detail: Piece by Piece Game

The finalised concept was created as the "Piece by Piece Game". The aim of the game is to create an open and supportive environment where students can discuss the difficulties and challenges they encounter in problem-solving, with particular attention to ambiguity. Through collective discussion, students will think critically about how to overcome these challenges and navigate ambiguity effectively. The game also provides a way for teachers to identify where students are struggling, offering insights into their problem-solving progress. This enables teachers to provide more targeted support and guidance. It also encourages students to reflect on and clarify their own methods for navigating ambiguity, fostering the development of their own strategies. Ultimately, the game is designed to help students build confidence and independence in managing ambiguity. As a side effect, the game hopes to reduce negative emotions, such as anxiety and frustration, that can arise when facing ambiguity.

The game is designed to play in a classroom setting for each problem-based groups with group member, but it can also play in general scenarios. Below we talk about the classroom setting as example. The duration of the game depends on the size of the team and the team of students, but an standard duration is around 30 minutes. The ideal participant composition for the game involves 3-6 individuals. Teams work together on one shared puzzle board, putting pieces together by connecting raised and recessed parts on the pieces, which represents for approaches and ambiguity sources. Teacher will be a observer and facilitator for the game, occasionally provide guidance or introducing new problems and solutions if the game reaches a standstill. The game provides clear instructions and rules for the game, enabling both teachers and students to effectively understand the rules and follow the steps.

Game setup and mechanics

When playing this game in class, students will be divided into groups of 3-6 and each group get a puzzle board, a central area where participants will place their puzzle pieces. This board serves as the visual representation of the various approaches and ambiguity sources discussed throughout the game. This can be a A1 size white paper and students sit around the puzzle board. It helps to organize the gameplay, showing the connections and facilitating collaborative thinking.

There will be 4 types of pieces to use.

- **Dual Pieces:** These pieces contain both a prewritten problem (labeled blue) and a prewritten solution (labeled red). They provide a foundation for discussion, allowing participants to connect existing problems with established solutions.
- **Problem Pieces:** These pieces include only prewritten problems related to ambiguity. They encourage participants to fill in the solutions during the game, enabling customization and creativity as they identify solutions collaboratively.

- **Solution Pieces:** These pieces contain only prewritten solutions for navigating ambiguity. At the start of the game, each participant receives one solution piece. Participants write down their biggest current problem or a problem they need advice on, transforming this solution piece into a "**mystery piece**." The mystery piece then become the same as a dual piece, can be played like any other piece, at any time during the game. This adds a personal element to the game, allowing participants to actively engage with their own challenges and seek solutions from the group.
- **Blank Pieces:** Empty pieces that participants can use at any point during the game. They provide flexibility for participants to create new problems, solutions, or connections as needed, encouraging innovation and adaptability.

At the beginning of the game, each participant receives a set of mixed dual pieces and problem pieces to work with. Every participant is given one solution piece to write down their biggest current problem, which will serve as their mystery piece. The game begins with a randomly chosen participant placing one piece on the puzzle board to present the first problem (labeled blue). This kickstarts the discussion and sets the context. After a problem is presented, every participant chooses one of their solution pieces (labeled red) they believe can solve the problem on the board. If they don't have a fitting piece, they can use a problem piece to create a new solution. Participants take turns explaining their chosen solutions, fostering dialogue and allowing for diverse perspectives. Following the explanations, participants vote on whether the proposed solution fits the problem presented. The majority vote determines whether the piece is placed on the board. If the votes are tied, participants can discuss whether to place both pieces on the board at the same time. Participants connect raised parts for piece with solution with recessed parts for piece with problem, creating a visual representation of their reasoning. At any time during the game, players can introduce new elements using blank pieces, ensuring that the discussion remains dynamic and relevant.

Teachers' role as facilitator

Teachers will act as facilitators in the game, supporting open communication and guiding students through the process. The game can be introduced mid-semester for inspiration and serve as an enjoyable break from routine activities. Throughout the game, teachers circulate among teams, observing discussions to identify when support may be needed and offering feedback on collaboration and group dynamics. Based on their observations, they can suggest additional strategies or resources for managing ambiguity that students might apply in future projects. Research supports this role, as sharing personal experiences with ambiguity can help students relate and build confidence (Stephens & Lazarus, 2024). If a participant struggles to articulate a challenge, the teacher can prompt with guiding questions, encouraging deeper reflection. In cases where the game reaches a standstill, teachers can introduce new problems to spark discussion and keep the game moving forward. After the game, teachers can lead a debriefing session, facilitating reflection by asking participants to consider what they learned from each round of discussion. This could involve questions about their thought processes, the effectiveness of their solutions, and how they navigated ambiguity. By encouraging participants to share their insights and the strategies they found helpful, learning is reinforced and helps to solidify the skills they develop during the game.

The learning objective would be:

- Equip students with strategies to navigate ambiguity, enhancing their confidence and resilience in problem-solving under uncertain conditions.
- Foster an interactive and enjoyable learning environment that encourages open communication, teamwork, and active participation.
- Encourage students to reflect on their problem-solving experiences, enabling them to recognize and analyze their approaches to handling ambiguity, ultimately deepening their understanding of ambiguity in complex scenarios.

Piece-by-piece Game

Introduction: This game is designed to encourage participants to navigate ambiguity by identifying problems and collaboratively finding solutions through discussion, reasoning, and teamwork. By combining individual insights, participants not only solve each other's problems but also gain new perspectives on their own challenges.

Game Element

Puzzle Board: A central area where puzzle pieces will be placed as the game progresses.

Puzzle Pieces:

- Dual Pieces: These pieces contain both a prewritten problem (labelled blue) and a prewritten solution (labelled red).
- Problem Pieces: These pieces have only a prewritten problem related to ambiguity. Participants can fill in the missing solution during the game and then use the piece like any other.
- Solution Pieces: These pieces offer only a prewritten solution for navigating ambiguity. At the start of the game, each participant receives one solution piece and writes down their biggest current problem or a problem they need advice on. This transforms this solution piece into a "mystery piece," which will be explained in the game setup.
- Blank Pieces: Empty pieces that participants can use at any point during the game to create new problems, solutions, or connections as needed.

Game Setup

- Each participant receives a set of mixed dual pieces and problem pieces.
- Each participant also receives one solution piece, which they will use to write down the biggest problem they face in their current project or problem-solving in general. This becomes their mystery piece.
  - The mystery piece can be played like any other piece, at any time during the game.
  - The owner of the mystery piece gets 2 votes when deciding which piece to place next, giving them extra influence over the game's direction when their problem is involved.
- The pile of blank pieces is placed next to the board for use later.
- The game begins with a randomly chosen participant placing one piece on the puzzle board.
- Each puzzle piece has raised parts representing solutions and recessed parts representing problems. During the game, participants use raised parts for piece with solution to connect recessed parts for piece with problem. If there are more than one raised or recessed part, participants can decide themselves how to connect.

Voting system

- For each turn, participants present their reasoning for their selected piece. After each explanation, all players vote on whether the piece fits into the puzzle.
- Each participant normally has 1 vote.
- The owner of the mystery piece receives 2 votes when a solution is proposed that connects to their mystery piece.

How to play

1. Starting the Game: The game begins with a randomly chosen participant placing one piece on the puzzle board to present the first problem (labeled blue).
2. Selecting a Solution: Each participant chooses one of their pieces with a solution (labeled red) that they believe can solve the problem on the board. If no piece fits well, participants can use a problem piece to write down their own solution.
3. Explaining Solutions: Participants take turns explaining why they think their chosen piece provides a solution to the problem on the board.
4. Voting: After everyone has explained their reasoning, the team votes. When the majority agrees, the piece is placed on the board.
5. Connecting Pieces: Participants connect pieces by using the raised parts on the solution piece to fit into the recessed parts on the problem piece. If there are multiple raised or recessed parts, participants decide how to connect them.
6. Using Blank Pieces: At any point, players can use blank pieces to introduce new problems, solutions, or connections to keep the game moving forward.
7. Winning the Game: The game ends when all puzzle pieces, especially mystery pieces, have been placed and their problems solved.

Figure 7: Piece-by-piece game rule for players.

8

Validation

This chapter describes the validation process of the Piece-by-Piece game, which is a pilot test session conducted at the Faculty of Applied Sciences. Participants from the CDI master's program engaged with the game, providing feedback and evaluations. The chapter will outline the setup for validation, the execution of the game test session, and the feedback from participants.

8.1 Validation Set up

A pilot test was organized on campus with students to observe how they interact with the game. The primary purpose is to gather evaluations on the game design, validating the game, and collecting feedback from students for further improvements and refinements.

There are several well-established measures for assessing tolerance of ambiguity, including Budner's 16-item scale (1962), AT-20 (MacDonald, 1970), MAT-50 (Norton, 1975), and the Multiple Stimulus Types Ambiguity Tolerance Scale-II (MSTAT-II) (McLain, 2009). However, these scales typically conceptualize TOA as a stable trait that reflects an individual's general attraction to or aversion to perceived ambiguity. Therefore, only relevant statements were selected and adjusted. For example, one statement from the MSTAT-II reads, *"I avoid situations that are too complicated for me to easily understand."*

In this study, the focus is on TOA within problem-solving scenarios. To better align the evaluation with this context, additional questionnaires related to problem-solving and decision-making were reviewed. These include the Decision Self-Efficacy Scale (O'Connor, 1995), which measures confidence in decision-making (e.g., *"figure out the choice that best suits me"*), and the Problem Solving Confidence Questionnaire (PSCQ) (Gok, 2012), with statements such as *"I am sure that I am able to solve even a difficult problem."*

To ensure the statements are directly relevant to this project, custom statements were crafted based on findings from this study and the objectives of the game design, including statements *"I am aware of ambiguity in complex problems and its role in the problem-solving process." "I know how to take action when faced with challenges caused by ambiguity."*

Eventually, a curated list of tolerance of ambiguity statements was compiled by selecting and modifying statements from studies, while also incorporating statements directly relevant to this project. The full list is shown in figure 8.

The evaluation utilized a horizontal line scale, allowing respondents to indicate their level of agreement, ranging from "not true at all" on the left to "completely true" on the right. This

format allows for more accurate capturing of attitudes and sentiments, as well as slight changes in perception. Participants will complete this evaluation both before and after playing the game, allowing for a pre- and post-intervention assessment of their tolerance of ambiguity.

The post-intervention evaluation of the Piece by Piece game centered on several key areas, primarily focused on the game's ability to meet its design objectives. The first aspect involved the participant's assessment of the overall design direction, specifically the game's emphasis on open communication "*I find it valuable to discuss difficulties and challenges with others.*" Another critical measure was determining whether the game inspired participants to generate ideas for navigating ambiguity, captured by the statement, "*This game inspired me to think more deeply about how to handle ambiguity.*" Lastly, the potential long-term impact of the game was assessed using the statement, "*This game can be applied multiple times in different classes and situations.*"

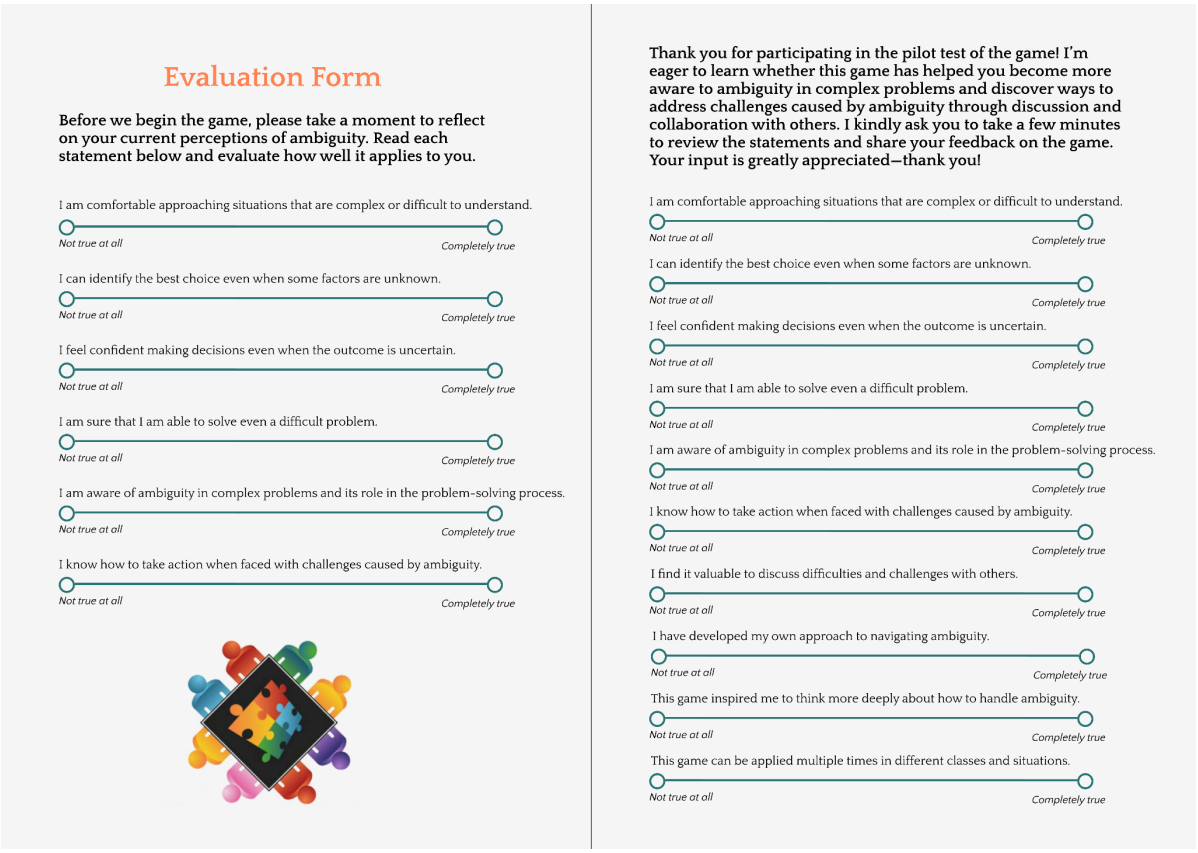

Figure 8. Evaluation form for the test session

8.2 Game test session

Invitations to the event were distributed among CDI students, as well as in TU Delft student group chats online to attract potential interested students. Ultimately, 2 individuals attended, both were CDI Master's graduating students. All participants signed inform consent form for participating in the pilot session. The event took place in Applied Sciences Faculty in the TU Delft campus and lasted for 45 minutes (30 minutes for the game and 15 minutes for filling evaluation form and reading rules). Before it started, essential materials such as game setting and evaluation forms were prepared and organised on the table. The event began with everyone signed informed consent form and reading the game rule. The game rule can be found in Appendix E. Then the game started. Since the players were not working on any same project at this moment, the test started generally by each player have their own project in their mind, and play the game in genreal.

Firstly, players wrote down their biggest problem on the solution piece they got and then this piece became their mystery piece. A random piece placed on the board to start. And the game started smoothly. One problem emerged when one player misunderstood the rule for mystery piece that they thought they need to think of a problem that can be solved by the solution on that piece. When they put their mystery piece on the table for discussion, they expressed they met the challenge several weeks ago, and they figured out the challenge can be solved by the solution. It is nice to hear that the participant has already go through the challenge, but also it reminds me to make the rule for mystery piece clearer. Another problem for the game is that the rule allows players to put more than one piece on the board at the same time if they believe both solutions work for the problem, however, the shape of some pieces don't allow them to be followed by multiple solutions or pieces.

One finding found during the playing process was that players not only coming up solutions for the pop-up problems every turn, but also pay attention to the blankness between pieces and wanted to fill it. They first found it hard to have a piece in-between two pieces as there were more requirements to meet, but with the use of blank pieces, it gave more freedom. Also, players pay attenion to solved pieces and think of alternative solutions for the problem. These were not explicitly stated in the rule, but it was the essence of the game that the players would decide how the shape went.

As a facilitator of the game, I stepped in and guided for three times. The first time is to explain the rule, and help with the setup of the game. After putting a random piece on the table, I am an observer. And the second time is to remind players to play mystery pieces sooner so that their pieces can be adviced. And the third time is to remind the time as the game has started for 30 minutes and lead to the discussion for the player who hasn't play their mystery piece. And when the player expressed their problem on the mystery piece, I noticed that the other player seemed to have the same problem as well or they can't think of any solutions for the problem, I tried to give my opinion by playing a piece to explain my solution to solve the challenge.

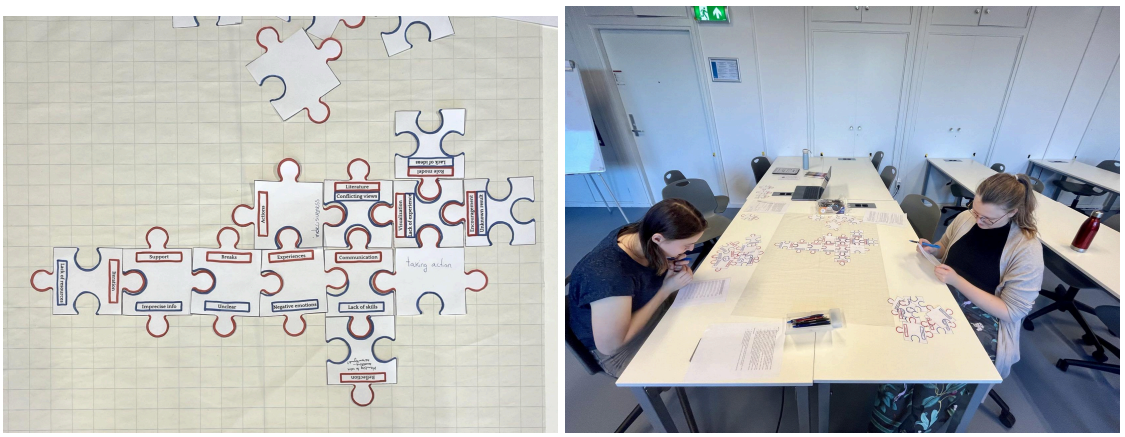

Figure 9. Participants are playing the game.

8.3 Feedback from participants

Both participants showed a positive attitude toward the game. One participant mentioned that they initially viewed it as a game to win by finding the best solution. However, as the game progressed, they moved away from the idea of "winning" and instead enjoyed exchanging perspectives through conversation.

Both participants completed the evaluation form, with each form assigned an anonymous code. The full evaluation form can be found in Appendix x. Before the event, they completed a list of statements measuring their tolerance of ambiguity. Each participant rated themselves at 50% or higher on the TOA scale, reflecting a relatively high initial level of TOA. It is understandable because the two participants have finished courses in CDI programme, which have an extreme focus on dealing with complex problems. This may also explain why there was no significant difference in TOA levels after the game, though most if not all statements showed slight increases, although there was a decrease of approximately 20% in the statement of "I am sure that I am able to solve even a difficult problem"from one participant. While regarding confidence level, the other participants showed a 10% to 20% increase. Both two participants experienced a 10% to 20% increase regarding comfortable level and actions to take.

Regarding the game effect, both participants rated it highly on all four assessment statements. In the statement of discussing difficulties and challenges, both participants rated above 80%, with one participant rated as nearly "completely true". In the statement "I have developed my own approach to navigate ambiguity", both participants rated around 75%. Regarding the inspringness of the game, both participants rated around 80%, and same rating for statements about the game's long-term viability.

9

Discussion

In the final chapter, the discussion will reflect on the overall research process, evaluating the impact of the design and addressing any limitations identified throughout the study.

9.1 Discussion

This project was initiated within the context of Delft University of Technology, a research university in the Netherlands, with the objective of exploring how Tolerance of Ambiguity can be developed as a skill with the support of teachers in a problem-based learning environment.

In the first phase of the project, the focus was on understanding how teachers perceive and address tolerance of ambiguity development and challenges they have faced. This phase combined a survey, designed as a synthesis of existing literature, with interviews that provided deeper insights into the unique context of TU Delft. Hillen's (2017) framework for categorizing responses to ambiguity—grouped into cognitive, behavioral, and emotional responses—served as a foundation for understanding the phenomenon. Although the framework is useful for explaining the phenomenon, it is not comprehensive in an educational setting. Some aspects can be influenced by external factors, such as teachers' support, while other aspects may be less affected. Certain responses, such as acknowledgment and confidence, are highly valued by teachers. As a result, teachers tend to focus on helping students respond in ways that align with these expectations. This includes recognizing that ambiguity is inherent in problem-solving, understanding that learning to navigate ambiguity is part of the learning process, and developing confidence in dealing with ambiguity.

Strategies identified from both the literature and interviews were either general to PBL or specifically targeted TOA development. The findings revealed that although developing TOA may not always be an explicit learning objective in PBL, it is inherently part of the learning process. Furthermore, given the nature of PBL, students can develop this skill through active participation and gaining experience. Therefore, the strategies aim to make this inherent development more meaningful and intentional for students.

Key strategies preferred by teachers included:

1. **Challenging Students' Preconceptions**: Encouraging students to think beyond their initial assumptions and approach problems from new perspectives.
2. **Making Methods Explicit**: Helping students articulate and reflect on their problem-solving methods to identify areas for improvement.

Both strategies involve asking intentional questions that nudge students toward critical thinking and ownership of their solutions. These approaches align with teachers' expectations of students. Since real engineering problems often contain open-ended questions with no single correct answer, students need to be aware of the possibility of multiple solutions and develop flexibility. Additionally, making students more conscious of their reasoning and better equipped to justify their choices, even in uncertain contexts, can enhance their confidence in decision-making. Furthermore, interview participants highlighted the usefulness of scaffolding—helping students become gradually familiar with ambiguity without introducing unnecessary or undesirable ambiguity—and creating a safe, supportive environment that allows students to fail and learn from their mistakes. This environment can be fostered through classroom decoration, verbal encouragement, and informal talks.

When supporting students, teachers also meet challenges. The main challenges identified were adapting strategies to unique students and student groups. Interview participants noted that "teacher blindness" and the inability to empathize with students' struggles could undermine a safe and supportive environment. Tailored guidance requires familiarity with students' characteristics and progress, which teachers primarily assess through observation and task completion time. However, time spent on tasks can be misleading, highlighting the need for effective communication between teachers and students.

The findings informed the development of the Piece by Piece Game, an educational tool designed to foster open communication and equip students with methods to navigate ambiguity. The game was later validated with students by comparing their TOA ratings before and after gameplay. The evaluation revealed a notable increase in TOA levels among participants, suggesting the game effectively empowered participants' TOA. Additionally, since it used participants' existing examples and experiences for discussion, the results support the importance of reflection as suggested in the experiential learning.

The results demonstrated that participants valued the engaging discussions and found the game inspiring for deeper thinking, with one participant saying: *"I really like it as a challenge; even though you might not find the exact right solution, it helps you think about tackling difficult problems and how you would approach them, which I think is really nice."* Regarding the long-term viability, one participant noted, *"When I was filling in the questionnaire, I felt that next time I'll think back to this game."* They also expressed that it was generally enjoyable to play, commenting: "*It doesn't become a discussion about who's right; you just listen to each other and share your point of view."* They speculated that, if the game were played among a project team, it might foster more debate, with *"one person arguing against another."* However, one participant also mentioned that *"the game is quite ambiguous itself in a way"* since there are no strict rules and it leaves room for personalization. One participant said, *"When I was working towards finishing the game, I kind of kept winning the game out of my mind."*

Apart from the feedback on the game's final outcomes, there were additional discussions about the game itself. Since the game was played by only two people in the test session, one participant mentioned that *"there were a lot of cards in the beginning. I think it's better if each person has a little fewer cards, so you can also get to the blank cards more quickly."* Furthermore, to explore the potential of generalizing the game to be played in a wider range of circumstances, the reusability was revisited. As mystery cards played an important

role in giving participants a targeted experience, the thesis supervisor suggested that *"the game can set placing their mystery cards as the goal."* One participant also mentioned that *"it can also be really well applied to younger students, if they can handle the abstractness. But I feel like, sometimes, if children are in a problem and then go to their mom and dad, like 'I have a problem,' the game can be used to teach them skills on how to deal with uncertainty."* Another participant added that the words could be changed to a simpler and more understandable manner for children.

9.2 Limitation

This project faced several limitations that may have impacted the findings and generalizability of the results.

In the problem exploration phase, the sample size for both the survey and interview with educators was relatively small, limiting the generalizability of the findings. Moreover, the use of voluntary response sampling may have introduced bias, as it often attracts participants with stronger opinions on the topic. Despite this, the research was fortunate to receive some survey responses reflecting a reluctance to incorporate transdisciplinary skills into courses, providing valuable perspectives from a less commonly expressed angle. However, a lack of interest among potential participants made it difficult to identify and interview educators who shared this viewpoint, limiting the opportunity to gain deeper insights into their reasoning. Additionally, the study focused solely on educators' perspectives, while students' perspectives were drawn from existing literature, my own experience as a student, and informal observations of fellow students. Though some students were consulted informally to provide insights and feedback during the design iterations of the game, their involvement was limited and did not constitute formal data collection.

Regarding the validation of the finalized game, the pilot was limited by a small sample size consisting of only two participants, both from the Communication Design for Innovation program. Given that this program involves active engagement with complex, real-world problems, both participants demonstrated relatively high TOA levels before the game. This made it challenging to assess whether the game intervention led to a significant increase in TOA, as any observed changes in TOA levels were minimal. Feedback indicated that the game encouraged reflection on ambiguity, but its immediate impact on well-developed TOA was limited, especially for students already skilled in navigating ambiguity.

To enhance future iterations, the game could be tested with participants from a broader range of academic backgrounds to assess its impact on students with varying levels of TOA experience. Additionally, gathering feedback from experts in education could provide valuable perspectives on the game's effectiveness, offering insights beyond those of participants alone.

10

Conclusion

10.1 Conclusion

This project aimed to explore how educators can support students' development of tolerance of ambiguity since ambiguity is an implicit element rooted in complex problems . Enhancing TOA can equip students with the adaptability needed for effective problem-solving, a skill increasingly valuable across disciplines. University graduates require a skillset that includes both hard skills and such transdisciplinary skills for success in diverse work environments. The literature review highlighted that problem-based learning courses are particularly effective for fostering TOA as they involve real-world cases that encourage experiential learning. Consequently, this project examined the perspectives of TU Delft educators experienced in PBL to understand their expectations, strategies, and challenges related to fostering TOA in students.

Insights from this research indicate that TU Delft teachers expect students to engage actively with ambiguity by taking concrete actions, cultivating self-awareness, and developing confidence. To foster these outcomes, teachers employ strategies such as questioning techniques, promoting exploration, and gradually increasing ambiguity in problem scenarios. Challenges identified include the need for tailored guidance and the ability to empathize with students' varying levels of comfort with ambiguity. Open communication emerged as essential for understanding and addressing students' needs. Through disclosure, teachers can identify specific struggles faced by students and offer guidance tailored to each student's learning stage. Open communication can also help within team settings, allowing students to express uncertainties, receive peer support, and gain diverse perspectives on problem-solving.

Based on these insights, a game is designed aimed at actively involving students in navigating ambiguity through open communication, collaboration, reasoning, and reflection. The game's design was informed by literature related to TOA development, insights from surveys and interviews, and theories on experiential learning, self-determination, and self-efficacy. Together, these elements shaped a learning experience that encourages students to approach ambiguity with greater awareness and confidence.

A pilot evaluation of the game for validation showed a slight increase in TOA among participants, though the change was subtle. While this does not directly confirm the game's effect on TOA, feedback from participants was positive, particularly regarding its ability to foster open communication and provide a supportive environment for exchanging ideas.

Participants noted that the game was engaging and provided a relaxed break from regular coursework, making it an appealing addition to the learning environment.

Through iterative design, I crafted a game that actively involves students in navigating ambiguity by requiring open communication, collaborative problem-solving, reasoning, and reflection. The game's design aligned with insights gained from literature on TOA, findings from surveys and interviews with TU Delft educators, and theories on experiential learning, self-determination, and self-efficacy, each of which provided valuable perspectives on how students can learn to approach uncertain scenarios with greater confidence and resilience.

By validating the game with students, the evaluation results demonstrated a slight increase in tolerance of ambiguity level among participants who experienced the intervention. Though the increase is not a direct indicator if the game has direct effect on TOA improvement, the game gained positive feedback regarding fostering open communication and setting supportive environments for exchanging perspectives and learn from others. Additionally, since it is a game, the fun element of the game hope to easily get students engaged and relax as a break. Participants found the game inspiring and thought-provoking, noting that it allowed them to practice problem-solving without the pressure of finding a perfect solution, with potential long-term benefits as a reference point for future ambiguous situations. These responses suggest that the game effectively engages players while fostering a senses of awareness to ambiguity and a growth mindset. Additionally, the pilot session demonstrated the game's adaptability, showing that it can be used effectively in general settings outside the classroom, even though it was initially designed as an in-class activity for team-based projects.

This study serves as an exploratory investigation at TU Delft aimed at increasing educators' awareness of developing transdisciplinary skills, such as tolerance of ambiguity. The findings indicate that, although the term "tolerance of ambiguity" may not be familiar to most educators, its importance is widely recognized. The teaching strategies compiled from literature and included in the survey are intended to provide educators with insights into the various approaches they can use to support skill development in the classroom. I was encouraged to discover that some teachers are already interested in this topic and felt inspired by the study. However, I also recognize that some educators believe universities should primarily focus on disciplinary knowledge. This study does not intend to suggest that higher education should shift its emphasis solely toward transdisciplinary skills. Instead, it highlights the importance of developing these skills among university graduates. Future research could further explore how to reduce the effort required from teachers in supporting transdisciplinary skills and what higher education institutions can do to facilitate this development.

The tool is initially designed for teachers to use in problem-based courses, providing a setting time period for students to discuss problems and challenges they are facing, and getting ideas from fellow students and guidance from teachers, and teachers can be familiar with students' learning stages, thus providing targeted guidance. Besides, the tool can also be used in workshops to develop decision-making and adaptability skills where people can reflect on problems and challenges they faced before. The game is also envisioned to be played out of class setting, and played by people who meet a life problem since ambiguity also exists in one's life. However, the cards may need adjustifaction to be used in more generalizes situations.

10.2 Reflection

Looking back, I am happy to have finished the project. To be honest, the things I have done, along with the knowledge, theories, and design process, are not unfamiliar to me. I have encountered most of them in previous CDI courses. I feel like I am using what I have learned to solve a real problem with more autonomy, applying the old and familiar methods. However, it was an individual task, unlike before when I had teammates to discuss and rely on. This time, if I needed help, I had to take the initiative to ask people if we could have a discussion.

I was interested in this topic because I feel that I lack the ability to tolerate ambiguity. The term "tolerance of ambiguity" and the thesis process itself felt ambiguous to me. When I started to learn more about the definition of tolerance of ambiguity, I found that the term itself is full of ambiguity. There are different definitions, and it's quite different from what I expected as a skill. Over time, scholars have changed views and found that it is not a stable trait, but a state that can vary in different contexts. While I believe it is more like a skill that can be improved with influence or time.

The process of finishing the thesis was also unclear to me. I didn't envision what I have now. The first step after the literature review was to collect data. While I wanted to do quantitative research and analyze the data based on fields of research or different faculties, the fact that I didn't get enough responses required me to find another way. I assume this added more ambiguity to the process. I didn't expect the end product to be an educational tool at first. The adoption of design-based research in the middle of the research also caused some limitations, such as not including all relevant stakeholders at the start. But on the other hand, I'm happy that I responded flexibly and timely to this unexpected challenge and adjusted my research method accordingly.

For me, ambiguity mostly arises when I feel like I don't know what to do next or when there are too many options, or they may actually be the same thing. Both of these situations leave me feeling stuck. One thing that inspired me during the process was an interviewee's comment: *"Every step you take matters. Even if you don't find it useful now, maybe it will turn out to be useful in leading you to the result."* I found myself adopting a methodology or mindset to navigate ambiguity: "*走一步看一步*" (take it one step at a time), which guides me to do whatever I can and then see what I get. No matter what I do, I move a bit closer to the end.

Reference

Anderson, Terry & Shattuck, Julie. (2012). Design-Based Research. Educational Researcher. 41. 16-25. 10.3102/0013189X11428813.

Awati, K., & Nikolova, N. (2022). From ambiguity to action: integrating collective sensemaking and rational decision making in management pedagogy and practice. *Management Decision*, 60(11), 3127-3146.

Babenko, O., & Lee, A. (2022). Ambiguity and uncertainty tolerance and psychological needs of medical students: A cross-sectional survey. *Clinical Teacher*, *19*(6). https://doi.org/10.1111/tct.13523

Bandura, A. (1994). Self-efficacy. In V. S. Ramachaudran (Ed.), *Encyclopedia of human behavior* (Vol. 4, pp. 71-81). New York: Academic Press. (Reprinted in H. Friedman [Ed.], *Encyclopedia of mental health*. San Diego: Academic Press, 1998).

Bandura, A., & Wessels, S. (1997). *Self-efficacy* (pp. 4-6). Cambridge: Cambridge University Press.

Banning, K. C. (2003). The effect of the case method on tolerance for ambiguity. *Journal of Management Education, 27*(5), 556-567.

Bartle, E. (2015). Experiential learning: an overview. *Institute for teaching and learning innovation. Australia: The University of Queensland.*

Bohm, N. L., Klaassen, R., Van Bueren, E., & Den Brok, P. (2023). Between Flexibility And Relativism: How Students Deal With Uncertainty In Sustainability Challenges. European Society for Engineering Education (SEFI). DOI: 10.21427/PCG5-D760

Botke, J. A. (2021). *Understanding the Transfer-to-Work of Soft Skills Training: Examining Transfer Stages, the Role of Work Factors and Self-Efficacy.* [PhD-Thesis - Research and graduation internal, Vrije Universiteit Amsterdam]. s.n.

Bozic, M., Certic, J. D., Vukelic, M., & Cizmic, S. (2018). New instructional approach for fostering generic and professional competences: case study of the project and problem based learning engineering practice course. Int. J. *Eng. Educ*, 34, 1581-1591.

Cernega, A., Nicolescu, D. N., Meleșcanu Imre, M., Ripszky Totan, A., Arsene, A. L., Șerban, R. S., Perpelea, A. C., Nedea, M. I., & Pițuru, S. M. (2024). Volatility, Uncertainty, Complexity, and Ambiguity (VUCA) in Healthcare. *Healthcare*, *12*(7), 773. https://doi.org/10.3390/HEALTHCARE12070773

Choo, S.S.Y. (2012). Scaffolding in Problem-based Learning. In: O'Grady, G., Yew, E., Goh, K., Schmidt, H. (eds) One-Day, One-Problem. Springer, Singapore. https://doi.org/10.1007/978-981-4021-75-3_8

De Graaf, E., & Kolmos, A. (2003). Characteristics of problem-based learning. *International journal of engineering education,* 19(5), 657-662.

Design Council. (2023). *The Double Diamond*. Retrieved May 15, 2024, from https://www.designcouncil.org.uk/our-resources/the-double-diamond/

Dishon, G., & Gilead, T. (2020). ADAPTABILITY AND ITS DISCONTENTS: 21ST-CENTURY SKILLS AND THE PREPARATION FOR AN UNPREDICTABLE FUTURE. *British Journal of Educational Studies, 69(4)*, 393–413. https://doi.org/10.1080/00071005.2020.1829545

Douglas, E. P., Agdas, S., Lee, C., Koro-Ljungberg, M., & Therriault, D. J. (2015, October). Ambiguity during engineering problem solving. In 2015 *IEEE Frontiers in Education Conference (FIE)* (pp. 1-4). IEEE.

Douglas, E. P., Therriault, D. J., Berry, M. B., & Waisome, J. A. M. (2022). Comparing Engineering Students' and Professionals' Conceptions of Ambiguity. *Proceedings - Frontiers in Education Conference, FIE, 2022-October*. https://doi.org/10.1109/FIE56618.2022.9962415

Dubikovsky, S. (2017). Ambiguity and Uncertainty of Engineering Projects and Defining Goals in Engineering Capstone Courses. *2017 27th EAEEIE Annual Conference, EAEEIE 2017*. https://doi.org/10.1109/EAEEIE.2017.8768604

Durrheim, K., & Foster, D. (1997). Tolerance of ambiguity as a content specific construct. *Personality and individual differences, 22*(5), 741-750.

Ehlers, U. D. (2020). *Future skills: The future of learning and higher education*. BoD–Books on Demand.

Ehlers, Ulf. -D., Kellermann, Sarah A. (2019): Future Skills - The Future of Learning and Higher education. Results of the International Future Skills Delphi Survey. Karlsruhe

Endres, M. L., Camp, R., & Milner, M. (2015). Is ambiguity tolerance malleable? Experimental evidence with potential implications for future research. *Frontiers in Psychology*, *6*. https://doi.org/10.3389/FPSYG.2015.00619

Endres, M. L., Chowdhury, S., & Milner, M. (2009). Ambiguity tolerance and accurate assessment of self-efficacy in a complex decision task. *Journal of Management and Organization*, 15(1), 31-46. Retrieved from https://www.proquest.com/scholarly-journals/ambiguity-tolerance-accurate-assessment-self/docview/233253783/se-2

Feng, X., Wang, X., Huo, Y., & Luo, Y. (2024). Inquiry in uncertainty-nursing students' learning experience in challenge-based learning: A qualitative study. *Nurse Education Today*, *135*, 106093. https://doi.org/10.1016/J.NEDT.2024.106093

Fenten, J., Bohm, N. L., & van den Berg, B. (2021). Higher Education and Wicked Problems Students Engaging with Complexity and Uncertainty in Sustainability Transitions. *The Barcelona Conference on Education*. https://papers.iafor.org/submission61236/

Furnham, A., & Ribchester, T. (1995). Tolerance of ambiguity: A review of the concept, its measurement and applications. *Current psychology, 14*, 179-199.

Futurefit skills. Future Fit Academy. (2022, November 3). https://www.futurefitacademy.com/futurefit-skills/

Gadusova, Z., Pavlikova, M., & Havettova, R. Intervention in teaching reading in a foreign language: development of divergent thinking and ambiguity tolerance.

Gallagher, S. E., & Savage, T. (2023). Challenge-based learning in higher education: an exploratory literature review. *Teaching in Higher Education*, *28*(6), 1135–1157. https://doi.org/10.1080/13562517.2020.1863354

Goh, K. (2014). What Good Teachers Do to Promote Effective Student Learning in a Problem-Based Learning Environment. *Australian Journal of Educational & Developmental Psychology*, 14, 159-166.

Gok, T. (2012). Development of problem solving confidence questionnaire: Study of validation and reliability. *Lat. Am. J. Phys. Educ. Vol*, 6(1), 21.

Grenier, S., Barrette, A. M., & Ladouceur, R. (2005). Intolerance of Uncertainty and Intolerance of Ambiguity: Similarities and differences. *Personality and Individual Differences*, *39*(3), 593–600. https://doi.org/10.1016/J.PAID.2005.02.014

Hadar, L. L., Ergas, O., Alpert, B., and Ariav, T. (2020). Rethinking teacher education in a VUCA world: student teachers' social-emotional competencies during the Covid-19 crisis. *Eur. J. Teach. Educ*. 43, 573–586. doi: 10.1080/02619768.2020.1807513

Hillen, M. A., Gutheil, C. M., Strout, T. D., Smets, E. M. A., & Han, P. K. J. (2017). Tolerance of uncertainty: Conceptual analysis, integrative model, and implications for healthcare. *Social Science & Medicine*, *180*, 62–75. https://doi.org/10.1016/J.SOCSCIMED.2017.03.024

Klementyeva, M. V., & Ivanova, V. I. (2021). *Correlation Between Biographical Reflection And Tolerance Of Ambiguity*. 143–151. https://doi.org/10.15405/EPSBS.2021.12.02.18

Klementyeva, M. V., & Ivanova, V. I. (2021). Correlation Between Biographical Reflection And Tolerance Of Ambiguity. In E. Bakshutova, V. Dobrova, & Y. Lopukhova (Eds.), Humanity in the Era of Uncertainty, vol 119. European Proceedings of Social and Behavioural Sciences (pp. 143-151). European Publisher. https://doi.org/10.15405/epsbs.2021.12.02.18

Kolb, B. (1984). Functions of the frontal cortex of the rat: a comparative review. *Brain research reviews, 8*(1), 65-98.

Lakhana, A. (2012). *Running head: TOLERANCE OF AMBIGUITY IN EDUCATIONAL TECHNOLOGY Tolerance of Ambiguity in Educational Technology: A Review of Two Social Science Concepts*.

Lazarus, M. D., Gouda-Vossos, A., Ziebell, A., & Brand, G. (2023). Fostering uncertainty tolerance in anatomy education: Lessons learned from how humanities, arts and social science (HASS) educators develop learners' uncertainty tolerance. *Anatomical Sciences Education*, *16*(1), 128–147. https://doi.org/10.1002/ASE.2174

Lehman, J. D. , George, M. , Buchanan, P. , & Rush, M. (2006). Preparing Teachers to Use Problem-centered, Inquiry-based Science: Lessons from a Four-Year Professional

Development Project. *Interdisciplinary Journal of Problem-Based Learning*, 1(1). Available at: https://doi.org/10.7771/1541-5015.1007

Mac Donald Jr, A. P. (1970). Revised scale for ambiguity tolerance: Reliability and validity. *Psychological reports, 26*(3), 791-798.

McCune, V., Tauritz, R., Boyd, S., Cross, A., Higgins, P., & Scoles, J. (2023). Teaching wicked problems in higher education: ways of thinking and practising. *Teaching in Higher Education*, *28*(7), 1518–1533. https://doi.org/10.1080/13562517.2021.1911986

McLain, D. L. (2009). Evidence of the properties of an ambiguity tolerance measure: The multiple stimulus types ambiguity tolerance scale–II (MSTAT–II). *Psychological reports, 105*(3), 975-988.

McLain, D. L., Kefallonitis, E., & Armani, K. (2015). Ambiguity tolerance in organizations: Definitional clarification and perspectives on future research. *Frontiers in Psychology*, *6*(MAR), 122037. https://doi.org/10.3389/FPSYG.2015.00344/BIBTEX

Merenluoto, K., & Lehtinen, E. (2004). Number concept and conceptual change: Towards a systemic model of the processes of change. *Learning and Instruction, 14*(5), 519-534.

Nel, P. W., Keville, S., Ford, D., McCarney, R., Jeffrey, S., Adams, S., & Uprichard, S. (2008). Close encounters of the uncertain kind: reflections on doing problem-based learning (PBL) for the first time. *Reflective Practice*, *9*(2), 197–206. https://doi.org/10.1080/14623940802005582

Norton, R. W. (1975). Measurement of ambiguity tolerance. *Journal of personality assessment, 39*(6), 607-619.

O'Connor AM. User Manual - Decision Self-Efficacy Scale [document on the Internet]. Ottawa: Ottawa Hospital Research Institute; ©1995 [modified 2002; cited 2024-10-20]. 4 p. Available from https://decisionaid.ohri.ca/docs/develop/user_manuals/UM_decision_selfefficacy.pdf

P. Blumenfeld, E. Soloway, R. Marx, J. Krajcik, M. Guzdial and A. Palincsar, Motivating Project-Based Learning: Sustaining the Doing, Supporting the Learning, Educational Psychologist, 26(3 & 4), 1991, pp. 369–398.

Peschl, H., Deng, C., & Larson, N. (2021). Entrepreneurial thinking: A signature pedagogy for an uncertain 21st century. *The International Journal of Management Education*, *19*(1), 100427. https://doi.org/10.1016/J.IJME.2020.100427

Rittel, H. W., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy sciences, 4*(2), 155-169.

Rowan, C. J., McCourt, C., Bick, D., & Beake, S. (2007). Problem based learning in midwifery–the teachers perspective. *Nurse Education Today, 27*(2), 131-138.

Runco, M. A. (2023). Personality and Motivation. *Creativity*, 37–79. https://doi.org/10.1016/B978-0-08-102617-5.00008-4

Ryan, R. M. (2017). *Self-determination theory: Basic psychological needs in motivation, development, and wellness*. Guilford Press.

Saarikoski, L., & Rybushkina, S. (2019). Developing tolerance for ambiguity and uncertainty by interdisciplinary intensive courses.

Salikhova, N. R., Lynch, M. F., & Salikhova, A. B. (2019). *The Associations Between Tolerance for Ambiguity and Internal and External Motivation in the Scholarly Activities of Doctoral Students*. *14*. https://orcid.org/0000-0002-5319-3235

Savery, J. R. (2006). Overview of Problem-based Learning: Definitions and Distinctions. *Interdisciplinary Journal of Problem-Based Learning, 1*(1). Available at: https://doi.org/10.7771/1541-5015.1002

Schick, A., Hobson, P. R., & Ibisch, P. L. (2017). Conservation and sustainable development in a VUCA world: the need for a systemic and ecosystem-based approach. *Ecosystem Health and Sustainability, 3*(4), e01267.

Schrader, S., Riggs, W. M., & Smith, R. P. (1993). Choice over uncertainty and ambiguity in technical problem solving. *Journal of Engineering and Technology Management*, *10*(1–2), 73–99. https://doi.org/10.1016/0923-4748(93)90059-R

Stanley Budner, N. Y. (1962). Intolerance of ambiguity as a personality variable 1. *Journal of personality*, 30(1), 29-50.

Stephens, G. C., & Lazarus, M. D. (2024). Twelve tips for developing healthcare learners' uncertainty tolerance. *Medical Teacher*. https://doi.org/10.1080/0142159X.2024.2307500

Suzawa, G. S. (2013). The learning teacher: Role of ambiguity in education. *Journal of Pedagogy*, *4*(2), 220–236. https://doi.org/10.2478/JPED-2013-0012

Taajamaa, V., Kirjavainen, S., Repokari, L., Sjöman, H., Utriainen, T., & Salakoski, T. (2013, December). Dancing with Ambiguity Design thinking in interdisciplinary engineering education. In 2013 *IEEE Tsinghua International Design Management Symposium* (pp. 353-360). IEEE.

Tynan, M. (2020). Multidimensional tolerance of ambiguity: Construct validity, academic success, and workplace outcomes.

van de Pol, J., Volman, M. & Beishuizen, J. Scaffolding in Teacher–Student Interaction: A Decade of Research. *Educ Psychol Rev* **22**, 271–296 (2010). https://doi.org/10.1007/s10648-010-9127-6

Yu, M., Wang, H., & Xia, G. (2022). The Review on the Role of Ambiguity of Tolerance and Resilience on Students' Engagement. *Frontiers in Psychology*, *12*, 828894. https://doi.org/10.3389/FPSYG.2021.828894/BIBTEX

Zimmerman, B. J., Bandura, A., & Martinez-Pons, M. (1992). Self-motivation for academic attainment: The role of self-efficacy beliefs and personal goal setting. *American educational research journal, 29(3), 663-676.*

A

Informed Consent

The first question in the survey

You are being invited to participate in a research study titled *Supporting Tolerance of Ambiguity Development in Problem-Based Learning Environments at TU Delft*. This study is being conducted by Yiwei Tao from TU Delft under the supervision of Éva Kalmár as part of the requirements for the Communication Design for Innovation program.

The purpose of this research study is to investigate effective teaching strategies to support students' tolerance of ambiguity development in problem-based learning environments. Participation will take approximately 20 minutes to complete. You will be asked to answer multiple-choice questions and open questions about your understanding of tolerance of ambiguity, your previous experience teaching this skill, and your perspective on challenges faced at TU Delft.

As with any online activity, the risk of a data breach is always possible. To the best of our ability, your answers in this study will remain confidential. We will minimize any risks by not collecting your IP addresses. Personal identifiable information (e.g., faculty, email address) and associated research data (e.g., your views) will be collected (optional) but will not be shared beyond the study team. The information collected will be confidential and stored in a secure location accessible only to the study team. Your responses and views may be quoted anonymously in the report, but no individual participant will be identified in the resulting report. The study team will adhere to all relevant data protection laws and regulations.

If you have questions or concerns about this study, please contact the corresponding researcher at Y.Tao-6@student.tudelft.nl or the responsible researcher at E.Kalmar-1@tudelft.nl.

Your participation in this study is entirely voluntary, and you can withdraw at any time. You are free to omit any questions. By clicking "Yes," you agree to the above-mentioned conditions; by clicking "No," you will exit the survey.

Participants need to sign this before the interview starts

Research Title:
Supporting Tolerance of Ambiguity Development in Problem-Based Learning Environments at TU Delft

Researcher:
Yiwei Tao, Communication Design for Innovation program, TU Delft
Supervised by Éva Kalmár, TU Delft

Purpose of the Study:
You are being invited to participate in a research study designed to explore effective teaching strategies that support students in developing tolerance of ambiguity within problem-based learning (PBL) environments. This study is part of the requirements for the Communication Design for Innovation program at TU Delft.

Participation Details:
The interview will last approximately 45 minutes. During this time, you will be asked to share your experiences and insights related to tolerance of ambiguity in teaching, particularly within PBL courses. This will include discussions on how you have observed students managing ambiguity, the challenges they face, and the strategies you use to support them.

Confidentiality:
Your participation in this study is voluntary, and your responses will remain confidential to the fullest extent possible. No identifying information will be included in any publications or presentations resulting from this research. All data, including interview recordings, will be securely stored and accessible only to the research team. If quotes from the interview are used, they will be anonymized to ensure your identity is not disclosed.

Risks:
As with any research, there are minimal risks involved, including the potential for a data breach. However, we are taking all necessary precautions to protect your data. Personal identifiable information, such as your faculty affiliation or email address, will not be shared beyond the study team.

Voluntary Participation:
Your participation is entirely voluntary. You have the right to withdraw from the study at any time without any consequences. You may also choose to skip any questions that you do not wish to answer.

Contact Information:
If you have any questions or concerns about this study, please feel free to contact the following:

- **Primary Researcher:** Yiwei Tao, Y.Tao-6@student.tudelft.nl
- **Supervising Researcher:** Éva Kalmár, E.Kalmar-1@tudelft.nl

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Consent:

By signing below, you acknowledge that you have read and understood the information provided above, and you agree to participate in this interview under the conditions stated.

Participant's Name:
Please print your name here

Participant's Signature:
Please sign here

Date:
Please enter the date here

B

Survey Questions

Q1. Informed Consent

Q2. Which faculty do you belong to? (Mandatory)

Q3. In which field do you do your research?

Q4. How many problem-based learning (PBL) courses have you been involved in?

* In this survey, PBL refers to courses that simulate real-world, ill-structured problems and allow for free inquiry. Additionally, PBL has the following characteristics:

- Constructive: PBL is a student-centred approach where learners construct their own knowledge, guided by the teacher.
- Collaborative: PBL encourages students to co-construct knowledge and share ideas.
- Self-directed: PBL promotes self-directed learning skills among students, such as planning, reflection, evaluating understanding, and managing information and resources.

Q5. We are looking for participants with experience teaching courses with a specific focus. If you are not familiar with these, thank you for your time so far. Have you been involved in project-based learning courses, challenge-based learning courses, team-based learning courses, inquiry-based learning courses, or capstone courses?

[Logic: If participants chose “none” in Q4]

Q6. Are you familiar with the concept of Tolerance of Ambiguity (TOA)?

*TOA has multiple definitions. In this survey, it specifically refers to the extent to which individuals are comfortable with ambiguous situations and their ability to operate effectively in an uncertain environment by considering a range of solutions or options.

Q7. Please indicate your level of agreement with the following statements (strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, strongly agree):

- I believe tolerance of ambiguity is important to develop at the university level.
- I believe tolerance of ambiguity is important in my discipline.
- I agree that the PBL approach can help increase students’ tolerance of ambiguity.
- I don’t see the need to improve tolerance of ambiguity in PBL courses.
- I agree that the PBL approach will help students to deal with ambiguous situations better.
- I don’t think that TOA development should be integrated into PBL courses.

Q8. If you recognize the importance of supporting students' Tolerance of Ambiguity, what are your primary goals? Please select all the verbs that describe your aim.

- Address ambiguity
- Confront ambiguity
- Cope with ambiguity
- Deal with ambiguity
- Embrace ambiguity
- Manage ambiguity
- Reduce ambiguity
- I do not want to support TOA in my class

Q9. Please drag to rank the following sources of ambiguity based on where you believe they most commonly originate in problem-based learning within your discipline.

- unclear or changing scope
- conflicting information
- imprecise information
- missing information
- unknown result
- applying different criteria in finding the solution
- unknown path to a solution
- multiple possible solution
- conflicting perspectives amongst the people involved

Q10. Which aspects do you believe students should exhibit when facing ambiguity? Please select all that apply.

- Acknowledgement: Learners' awareness and recognition that ambiguity is an implicit part of the course.
- Approach: Learners adopt proactive strategies to engage with ambiguous situations.
- Attraction: Learners experience joy and fulfillment from overcoming challenges associated with ambiguity.
- Calm: Learners exhibit openness and acceptance, showing a composed response to ambiguity.
- Confidence: Learners feel empowered and have confidence in navigating ambiguous circumstances.
- Courage: Learners do not fear being held accountable for the limits of their knowledge.
- Curiosity: Learners cultivate a sense of curiosity and excitement when faced with ambiguity.
- Decision Making: Learners make informed decisions even when faced with ambiguous information.
- Disclosure: Learners openly share their uncertainties and seek feedback.
- Faith: Learners' self-assurance in their ability to manage when presented with ambiguous stimuli.
- Information Seeking: Learners actively seek out additional information to reduce ambiguity.

- Opportunity: Learners' openness to exploring and responding to ambiguous situations through the pedagogy.

Q11. Which aspects of Tolerance of Ambiguity do you believe are important for educators to support in problem-based courses? Please select all that apply.

Q12. To what extent have you supported learners in developing the following aspects of Tolerance of Ambiguity in your previous problem-based courses? (never, rarely, sometimes, often, very often)

Q13. How likely are you to include the following aspects of Tolerance of Ambiguity in your future problem-based courses? (extremely unlikely, somewhat unlikely, neutral, somewhat likely, extremely likely)

Q14. Could you please specify why you believe these aspects are important?

Q15. Could you please specify why you believe these aspects are not important?

Q16. How often have you utilized the following strategies to support the development of learners' Tolerance of Ambiguity in problem-based courses?

- Purposefully designing ill-structured, open-ended, real-life, and challenging problems that involve ambiguity.
- Highlighting the development of tolerance of ambiguity a part of the learning goals.
- Introducing ambiguity progressively, depending on the learning stages.
- Motivating learners to be explicit about the methods they use.
- Setting dedicated time for PBL group teams to discuss uncertainty and ambiguity.
- Letting learners visualize the ambiguity they face.
- Challenging students' preconceptions by encouraging exploration of possibilities outside their current frame of reference.
- Suggesting exercises that help to narrow down learners' ideas.
- Motivating learners to quickly choose a direction.
- Giving compliments.
- Incorporating ambiguity management tools (e.g., self-reflection, strategies for managing risk and accepting error).
- Sharing personal experiences of ambiguity similar to those faced by learners and explaining how they were managed.

Q17. How effective do you think the following strategies are in developing learners' Tolerance of Ambiguity? (not effective at all, slightly effective, moderately effective, very effective, extremely effective)

Q18. Which strategies do you think you will adopt in your future teaching practices? Please select all that apply.

Q19. Can you describe any specific strategies you have found effective in developing learners' Tolerance of Ambiguity in Problem-based courses?

Q20. What challenges have you encountered in trying to support learners' development of Tolerance of Ambiguity?

- I am unclear about my role in PBL courses.
- I am not confident in helping learners manage the anxieties of ambiguity.
- I need to adjust my strategies to facilitate each unique PBL group.
- I find it hard to align my actions with the unique learning contexts of each PBL scenario.
- I am unsure how much to intervene or how much guidance to provide learners.
- I find it challenging to create an environment where perspectives are effectively shared, and team members collaborate and discuss issues.
- I encounter resistance from students when trying to encourage flexible methods for presenting their findings.
- I am worried about the emotional and/or mental load of the process for the learners.
- I feel anxious about dealing with ambiguity.
- I am concerned about the lack of resources and support for implementing effective PBL strategies.

Q21. What other challenges have you faced in supporting learners' Tolerance of Ambiguity in Problem-based courses?

Q22. What additional support or resources would help you better support learners' Tolerance of Ambiguity development in Problem-based courses?

Q23. Are there any other comments or insights you would like to share regarding Tolerance of Ambiguity and Problem-based Learning at TU Delft?

Q24. Would you like to receive updates on the research? Please leave your email address here.

Q25. There might be further research on this topic. Would you like to be involved?

C

Interview Protocol

Part 1 Opening

Introduce myself with name and education
Purpose of interview

- Ask about their understandings / insights
    - of where does ambiguity comes from
    - of how students respond to ambiguity (Cognitive, Emotional, Behavioural)
- Ask about their experiences in teaching
    - of identifying students struggle
    - of helping students to deal/work with ambiguity
- Ask about challenges they have faced
    - Opportunities that institutions could help

Sign the consent form
Can I record the interview?
Are there other things you want us to know before we start the interview?

Part 2 Understanding and experience with PBL and TOA

Experience with problem-based courses

- What type of course was it? - mixed faculties? real case provided by company? team collaboration?
- My scope is PBL, but what advantages or disadvantages do you think to support TOA in PBL? Or if not PBL, what type of class would you like to support TOA?

Understanding of Tolerance of Ambiguity

- Have you heard of this skill / term before?
- How do you understand this term?
- How do you perceive ambiguity in the problems you design for your problem-based courses? (or Where does ambiguity come from in your discipline?
- Do you think there are differences between your perception of ambiguity and your students' perception of ambiguity?
- Can you provide examples of how this ambiguity manifests and how students typically respond to it?
- Have you noticed that some students struggle with intolerance of ambiguity in your courses? What do you think contributes to their difficulties with handling ambiguity?

Part 3 Teaching strategies

The strategies may vary according to stages (based on double-diamond)

- Task: Design the course problem / select the case for the course
- Diverging & Converging
- Feedback, hints, explanation, instruction, questions you asked

Methods used

- After you find students struggling with ambiguity, what methods have you tried to help them?
- What specific strategies have you used in different stages?
    - What strategies are effective?
    - What strategies are not effective?
- How do you balance guiding students and allowing them to navigate ambiguity on their own?

Assessment

- Do you believe your teaching strategies help students become better at tolerating ambiguity?
- Have you seen any differences in how students deal with or feel about ambiguous situations throughout a course or over several years of teaching?
- To what extent you will be satisfied as a teacher about students' ability to work with ambiguity?
- What will be the grading standards? (It might be a question from me as a student)
    - Result or process matter?
    - Students' strategies (to deal with ambiguity) or attitude (facing ambiguity) matter?

Part 4 Challenges

- What challenges have you faced in teaching students to deal with ambiguity?
- What kind of support or training do you receive from the faculty or university to regarding teaching TOA? Do you think the resources are enough? Or what other support do you want to receive?
- How have your approaches (to TOA) evolved over time?

Part 5 Ending

- Are there things I didn't ask but you want to mention?
- Do you have any questions for me?
- Thank you for your participation

D

Codebook

Code Group	Code	Count	Used in Document
Ambiguity Source	Complexity	3	No1.docx, No4.docx, No5.docx
Ambiguity Source	Different perspectives	4	No2docx, No4.docx
Ambiguity Source	Missing information	6	No1.docx, No3.docx, No6.docx
Ambiguity Source	Multiple possible solution	6	No1.docx, No2.docx, No3.docx, No5.docx, No6.docx
Ambiguity Source	Undefined scope	3	No5.docx, No6.docx
Ambiguity Source	Unknown path to a solution	2	No1.docx, No6.docx
Ambiguity Source	Unknown results	3	No1.docx, No4.docx, No6.docx
Demographic	Bachelor level	3	No2.docx, No3.docx, No5.docx
Demographic	Master level	4	No1.docx, No2.docx, No4.docx, No6.docx
Demographic	Multidiscipline	2	No2.docx
Demographic	PhD level	1	No1.docx
General	Design (iterative process)	6	No2.docx
General	Exploring the context	2	No2.docx
General	Faculty-wise	4	No3.docx, No6.docx
General	Future	2	No1.docx, No3.docx
General	Measurement of TOA improvement	3	No1.docx, No2.docx
General	Rubric	9	No2.docx, No3.docx, No5.docx, No6.docx
Student Needs	Be aware of unknowns	3	No3.docx, No5.docx
Student Needs	Interest	2	No4.docx, No6.docx
Student Needs	Ownership	9	No2.docx, No3.docx, No4.docx, No5.docx, No6.docx
Student Needs	Team element	6	No1.docx, No2.docx, No3.docx, No4.docx, No5.docx
Student Problems	Grade pressure	2	No6.docx

Student Problems	Ignore feedback	1	No5.docx
Student Problems	Lack diverging	4	No1.docx, No4.docx
Student Problems	Lack of experience	8	No1.docx, No3.docx, No4.docx, No6.docx
Student Problems	Make decision	8	No1.docx, No2.docx, No3.docx, No4.docx, No5.docx
Student Problems	Oversimplify	2	No1.docx
Student Problems	Peer pressure	1	No6.docx
Student Problems	perceived solution	6	No4.docx, No5.docx, No6.docx
Student Problems	result than process	6	No4.docx, No5.docx, No6.docx
Student Problems	Time management	4	No4.docx, No6.docx
Student Responses	Behavioural Response	16	No1.docx, No3.docx, No4.docx, No5.docx, No6.docx
Student Responses	Cognitive Response	5	No4.docx, No5.docx, No6.docx
Student Responses	Emotional Response	13	No1.docx, No3.docx, No4.docx, No5.docx, No6.docx
Teacher challenge	Empathize	6	No2.docx, No3.docx, No4.docx, No6.docx
Teacher challenge	Expectations	7	No2.docx, No3.docx, No4.docx, No5.docx
Teacher challenge	Freedom	2	No1.docx, No6.docx
Teacher challenge	Guide individual student	12	No1.docx, No2.docx, No3.docx, No5.docx, No6.docx
Teacher challenge	Ineffective methods	8	No1.docx, No6.docx
Teacher challenge	Lack of support	3	No3.docx, No5.docx
Teacher challenge	Need to get trained	2	No3.docx
Teacher challenge	process than result	7	No3.docx, No4.docx, No5.docx
Teacher challenge	Resource-constrained	6	No3.docx, No5.docx, No6.docx
Teacher challenge	Sharing experience	2	No3.docx, No6.docx
Teacher challenge	Student resistance	1	No5.docx
Teacher challenge	Teacher Blindness	6	No2.docx, No3.docx
Teacher challenge	Time pressure	1	No1.docx
Teacher Challenges	Classroom size	5	No1.docx, No5.docx
Teacher Challenges	Disciplinary differences	2	No2.docx
Teaching Strategies	Asking intentional questions	12	No3.docx, No5.docx, No6.docx
Teaching Strategies	Atmosphere	6	No1.docx, No3.docx, No5.docx
Teaching Strategies	Break	1	No3.docx

Teaching Strategies	Compliments	3	No3.docx, No4.docx, No5.docx
Teaching Strategies	find essence	1	No4.docx
Teaching Strategies	formative feedback	1	No5.docx
Teaching Strategies	Learning objective	4	No1.docx, No3.docx, No4.docx
Teaching Strategies	Meeting regularly	11	No1.docx, No2.docx, No3.docx, No4.docx, No5.docx, No6.docx
Teaching Strategies	Non-examinative	2	No3.docx, No5.docx
Teaching Strategies	Non-interference	3	No1.docx, No4.docx
Teaching Strategies	Problem design	8	No1.docx, No2.docx, No3.docx, No5.docx
Teaching Strategies	Scaffolding	12	No1.docx, No2.docx, No3.docx, No5.docx, No6.docx
Teaching Strategies	Setting boundary	2	No1.docx
Teaching Strategies	Student need knowledge	2	No4.docx
Teaching Strategies	Summative feedback	1	No1.docx
Teaching Strategies	Teaching Assistant	1	No3.docx
Teaching Strategies	No term	1	No6.docx
Teaching Strategies	trial and fail	6	No2.docx, No3.docx, No5.docx
Teaching Strategies	Visualizing the result	4	No3.docx, No6.docx
Way to identify	Asking	2	No1.docx
Way to identify	Observation	5	No1.docx, No2.docx, No5.docx, No6.docx
Way to identify	Reflection	7	No3.docx, No4.docx, No5.docx
Way to identify	Time	9	No1.docx, No2.docx, No3.docx, No4.docx, No6.docx

E

User manual [Piece by piece]

This user manual will be used together with the game. In this manual, you will find

- Why use this game in class (for teachers)
- What preparations to be done
- how to play this game

Introduction: This game is designed to encourage participants to navigate ambiguity by identifying problems and collaboratively finding solutions through discussion, reasoning, and teamwork. By combining individual insights, participants not only solve each other's problems but also gain new perspectives on their own challenges.

In a classroom setting, teams work together on one shared puzzle board, while the teacher observes, occasionally providing guidance or introducing new problems and solutions if the game reaches a standstill. The game promotes critical thinking, collaboration, and creative problem-solving.

Setup:

Puzzle Board: A central area where puzzle pieces will be placed as the game progresses.

Puzzle Pieces:

- **Dual Pieces**: These pieces contain both a prewritten problem (labelled blue) and a prewritten solution (labelled red).
- **Problem Pieces**: These pieces have only a prewritten problem related to ambiguity. Participants can fill in the missing solution during the game and then use the piece like any other.
- **Solution Pieces**: These pieces offer only a prewritten solution for navigating ambiguity. At the start of the game, each participant receives one solution piece and writes down their biggest current problem or a problem they need advice on. This transforms this solution piece into a "**mystery piece**," which will be explained in the game setup.
- **Blank Pieces**: Empty pieces that participants can use at any point during the game to create new problems, solutions, or connections as needed.

Game Setup:

- Each participant receives a set of mixed dual pieces and problem pieces.

- Each participant also receives one solution piece, which they will use to write down the biggest problem they face in their current project or problem-solving in general. This becomes their mystery piece.
    - The mystery piece can be played like any other piece, at any time during the game.
    - The owner of the mystery piece gets 2 votes when deciding which piece to place next, giving them extra influence over the game's direction when their problem is involved.
- The pile of blank pieces is placed next to the board for use later.
- The game begins with a randomly chosen participant placing one piece on the puzzle board.
- Each puzzle piece has raised parts representing solutions and recessed parts representing problems. During the game, participants use raised parts for piece with solution to connect recessed parts for piece with problem. If there are more than one raised or recessed part, participants can decide themselves how to connect.

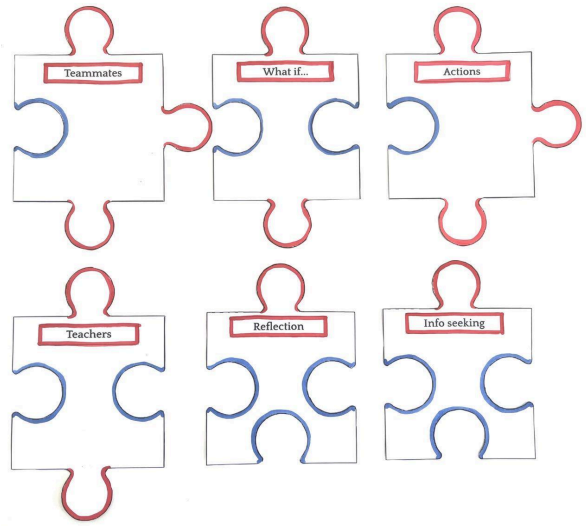
How to Play:

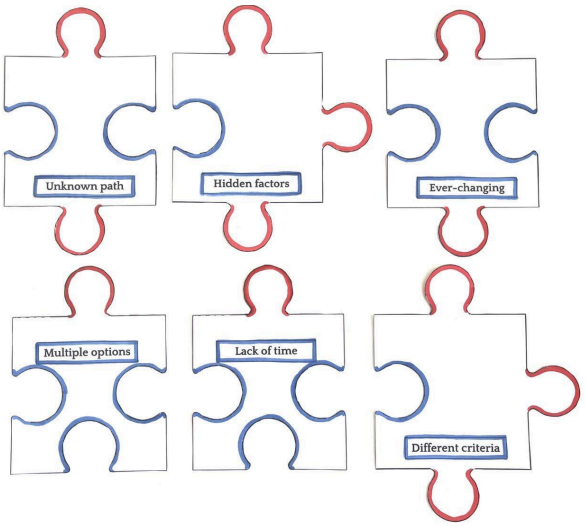
1. **Starting the Game**: The game begins with a randomly chosen participant placing one piece on the puzzle board to present the first problem (labeled blue).
2. **Selecting a Solution**: Each participant chooses one of their pieces with a solution (labeled red) that they believe can solve the problem on the board. If no piece fits well, participants can use a problem piece to write down their own solution.
3. **Explaining Solutions**: Participants take turns explaining why they think their chosen piece provides a solution to the problem on the board.
4. **Voting**: After everyone has explained their reasoning, the team votes. When the majority agrees, the piece is placed on the board.
5. **Connecting Pieces**: Participants connect pieces by using the raised parts on the solution piece to fit into the recessed parts on the problem piece. If there are multiple raised or recessed parts, participants decide how to connect them.
6. **Using Blank Pieces**: At any point, players can use blank pieces to introduce new problems, solutions, or connections to keep the game moving forward.
7. **Winning the Game**: The game ends when all puzzle pieces, especially mystery pieces, have been placed and their problems solved.

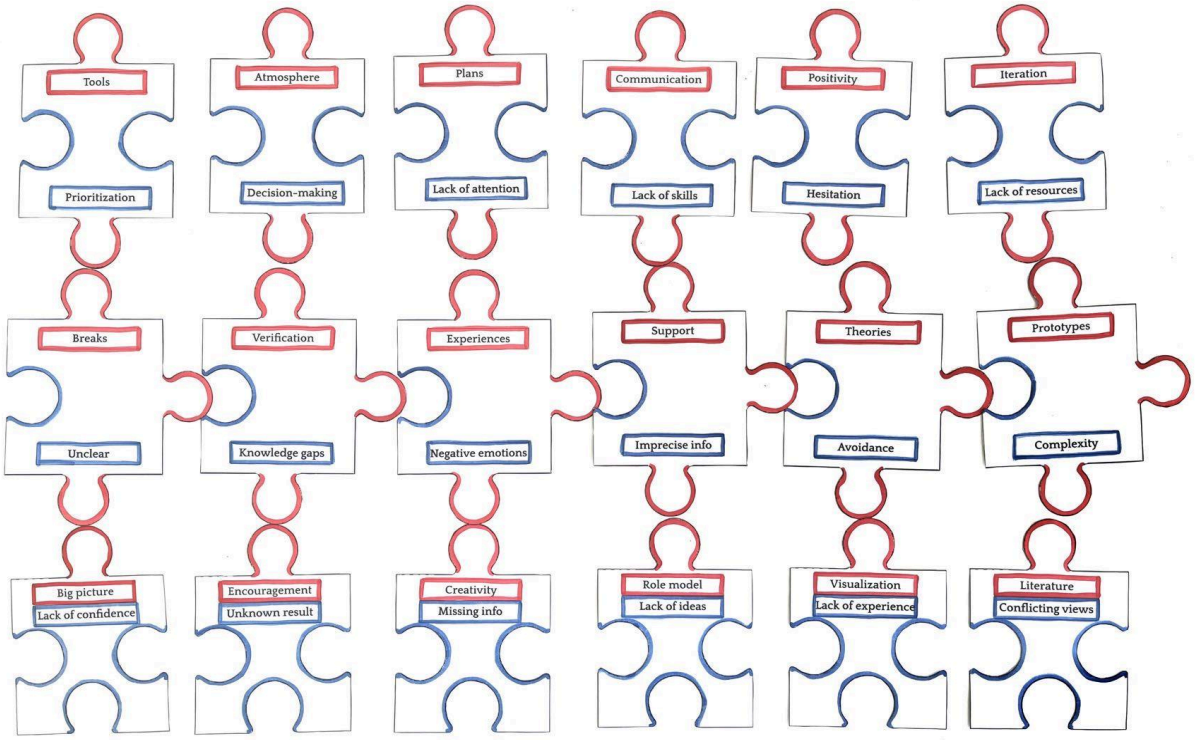
Voting System:

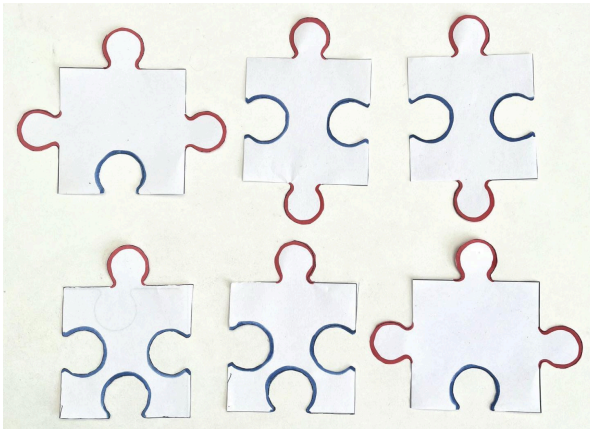
- For each turn, participants present their reasoning for their selected piece. After each explanation, all players vote on whether the piece fits into the puzzle.
- Each participant normally has 1 vote.
- The owner of the mystery piece receives 2 votes when a solution is proposed that connects to their mystery piece.

Game cards:


Teammates
What if...
Actions
Teachers
Reflection
Info seeking


Unknown path
Hidden factors
Ever-changing
Multiple options
Lack of time
Different criteria


Tools
Prioritization
Atmosphere
Decision-making
Plans
Lack of attention
Communication
Lack of skills
Positivity
Hesitation
Iteration
Lack of resources
Breaks
Unclear
Verification
Knowledge gaps
Experiences
Negative emotions
Support
Imprecise info
Theories
Avoidance
Prototypes
Complexity
Big picture
Lack of confidence
Encouragement
Unknown result
Creativity
Missing info
Role model
Lack of ideas
Visualization
Lack of experience
Literature
Conflicting views



F

Evaluation Form

Evaluation Form

Before we begin the game, please take a moment to reflect on your current perceptions of ambiguity. Read each statement below and evaluate how well it applies to you.

I am comfortable approaching situations that are complex or difficult to understand.

Not true at all — *Completely true*

I can identify the best choice even when some factors are unknown.

Not true at all — *Completely true*

I feel confident making decisions even when the outcome is uncertain.

Not true at all — *Completely true*

I am sure that I am able to solve even a difficult problem.

Not true at all — *Completely true*

I am aware of ambiguity in complex problems and its role in the problem-solving process.

Not true at all — *Completely true*

I know how to take action when faced with challenges caused by ambiguity.

Not true at all — *Completely true*

Thank you for participating in the pilot test of the game! I'm eager to learn whether this game has helped you become more aware to ambiguity in complex problems and discover ways to address challenges caused by ambiguity through discussion and collaboration with others. I kindly ask you to take a few minutes to review the statements and share your feedback on the game. Your input is greatly appreciated—thank you!

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Not true at all — *Completely true*

I know how to take action when faced with challenges caused by ambiguity.

Not true at all — *Completely true*

I find it valuable to discuss difficulties and challenges with others.

Not true at all — *Completely true*

I have developed my own approach to navigating ambiguity.

Not true at all — *Completely true*

This game inspired me to think more deeply about how to handle ambiguity.

Not true at all — *Completely true*

This game can be applied multiple times in different classes and situations.

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