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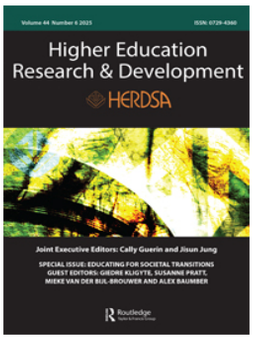

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Adaptive guidance for uncertainty: how teachers use scaffolding in transdisciplinary courses

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ABSTRACT

Increasingly, sustainability challenges in transdisciplinary courses are used to confront students with different dimensions of uncertainty, such as unpredictability, lack of knowledge, or ambiguity. However, little is known about how teachers adapt their teaching to scaffold students through such uncertainty. This design-based study investigates the adaptive guidance (scaffolding) employed by teachers to guide students through problem-solving in uncertainty. Using a sixteen-week challenge-based learning (CBL) course called the 'Living Lab' as a case study, we monitored how teachers developed scaffolding based on a workshop they received before the course began. Through qualitative questionnaires and focus groups conducted every four weeks, teachers reflected on their teaching practices and coaching strategies. The study identifies teaching problems faced by teachers in transdisciplinary courses, including theoretical grounding, tensions with the commissioner, and assignment clarity. Teachers most frequently used scaffolding for frustration control, marking critical features, and direction maintenance. Additionally, teachers lacked diagnostic strategies to assess student progress on personal learning objectives. This research contributes to a deeper understanding of the role of teachers as coaches in transdisciplinary courses. Practical implications include informing and inspiring teachers to enhance their scaffolding practices on diagnostics, theoretical grounding, and personal learning in CBL courses.

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1. Introduction

Transdisciplinary education changes the role of the teacher. Traditionally, higher education is teacher-centered and teachers are positioned as the primary source of knowledge in the learning environment. In transdisciplinary education, knowledge is dispersed, and students need to collect information from all kinds of people, not just their teachers (Fam et al., 2018). In this new role, teachers become coaches who assist

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in the process of collecting and weighing information and making decisions (van den Beemt et al., 2020). Additionally, the teachers coach team dynamics and advise on the relationship with 'commissioners'. A commissioner is an extra-academic actor that works outside of the university and introduces the challenge to the students (O'Sullivan et al., 2025). Ultimately, teachers help students deal with the uncertainty of working on complex real-world problems, such as the transition to a sustainable society (Steiner & Posch, 2006). Societal transitions are inherently open-ended and uncertain (Frantzeskaki et al., 2012) and higher education is challenged with the task to prepare students to navigate that uncertainty.

Previous research has shown that constructivist learning, such as challenge-based learning (CBL) or education in living labs, concrete guidance from teachers is crucial (Kirschner et al., 2006). Without it, students will drift off from the learning objectives or get stuck in the complexity of the problems they work on. Additionally, in constructivist learning approaches engagement with the content can vary throughout a course and requires teachers to adapt their guidance over time (Rotgans & Schmidt, 2011). Especially in transdisciplinary education, where knowledge is dispersed amongst stakeholders and where students have different epistemological backgrounds, teachers are urged to look for adaptive approaches to teaching (Kirschner & Hendrick, 2020).

Scaffolding is a teaching model that aims to tune into the level of the student and then provide tailored support to grow to the next level of problem-solving (van de Pol et al., 2010). Scaffolding requires a back-and-forth process between teacher and student, where the teacher holds the idea of where the student wants to go and the student explores how to get there autonomously. As scaffolding is an adaptive form of teaching, teachers could use it specifically for teaching the complex competencies that transdisciplinary education deals with (Brundiers et al., 2020).

However, in transdisciplinary education scaffolding research is limited (Lönngren et al., 2017) and often focuses on tools rather than the experiences of the teacher (Markauskaite & Goodyear, 2014). Moreover, real-life challenges are complex, require complex competencies for problem-solving, and therefore, might be scaffolded in a particular way (Acosta-Gonzaga & Ramirez-Arellano, 2022; Birdman et al., 2022). Specifically, dealing with uncertainty is a part of problem-solving in societal transitions that is difficult to provide support for (Wijnia et al., 2011). Although in previous research we found that within transdisciplinary courses students encounter uncertainty (Bohm et al., 2025) and find ways to deal with it (Bohm, Klaassen, et al., 2024b), we know little about how teachers adapt their teaching to scaffold students through uncertainty.

Therefore, in this educational design research (EDR), we investigate what scaffolding strategies teachers use during a transdisciplinary course. We aim to answer the research question: **What scaffolding strategies do teachers use over time to guide students toward problem-solving in uncertainty?**

The design research is done within the 'Living Lab' course that is part of a two-year transdisciplinary master program in the Netherlands. This 16-week course teaches students how to deal with a complex sustainability challenge. We introduced the ten teachers involved in the course to scaffolding as a design intervention before the start of the course. Then, we evaluated through a questionnaire and focus groups at three different moments in the course how teachers adapted scaffolding to their teaching practice.

2. Theoretical background

2.1. What is scaffolding?

'Scaffolding' is a metaphor to describe how to teach problem-solving. Wood et al. (1976) came up with the term while studying how 3–5 year-olds learn to build a tower of wooden blocks. Problem-solving, such as building a block tower, is a complex skill with a hierarchical structure (Kirschner & Hendrick, 2020). Children need to master lower-order skills before they can move on to more difficult skills (van Merriënboer & Kirschner, 2007). 'Building' a complex skill needs to be guided by an expert, often a teacher or parent. The expert provides temporary support, 'scaffolds', where the child is not yet able to complete a task on their own. The support can take different forms, from a teacher demonstrating a certain task to asking specific questions. Overall, scaffolding happens in interaction. Soon after its introduction, scaffolding was transferred from parent–child interaction to student–teacher interaction (Cazden, 1979).

Scaffolding originates from research with a constructivist perspective on learning (van de Pol et al., 2010). Constructivist theory approaches students as unique individuals with a personal construction of knowledge. Following this perspective, learning means that students add to the construction of knowledge they already have or they adapt the construction to fit new understanding (Illeris, 2018). Therefore, scaffolding is more than helping students complete a task; it means helping them construct a new piece of cognitive, metacognitive, or affective understanding (Lönngren et al., 2017).

2.2. The main characteristics of scaffolding

In their review of scaffolding research, van de Pol et al. (2010) found three main characteristics of scaffolding: contingency, fading support, and transfer of responsibility. *Contingency* refers to the tailored support the teacher provides with scaffolding. The difficulty of contingency is finding out what the level of the student is (diagnostic strategies) and connecting to it (scaffolding strategies) (van de Pol, 2012). To find out what the level of the student is, teachers use diagnostic strategies. Contingent teaching takes a constant back and forth between the teacher and a (group of) student(s) to adapt the support to the actual learning process. To do so a teacher holds two mental models at once: their own mental model of the problem and the mental model of the student (Kirschner & Hendrick, 2020).

The two other characteristics of scaffolding are different sides of the same coin. *Fading support* means that the teacher gradually deconstructs the scaffolds they have built. While fading, the student should take control of what they have learned, leading to a *transfer of responsibility* from teacher to student.

Scaffolding strategies consist of intentions (what is scaffolded) and means (how is scaffolding taking place). In their original article, Wood et al. (1976) defined the six intentions of scaffolding that most researchers have been using since (Table 1). In addition, Tharp and Gallimore (1988) distinguish six scaffolding means: feeding back, giving hints, instructing, explaining, modeling, and questioning. In this research, we look for the specific means to describe how teachers guide students' problem-solving in complex sustainability challenges based on predefined scaffolding intentions.

Table 1. Scaffolding intentions according to Wood et al. (1976) and (Kirschner et al., 2022).

Intentions of scaffolding	Description
Recruitment	The teacher must somehow elicit the problem solver's interest in the task and the kinds of skills needed to complete it.
Reduction in degrees of freedom	This essentially refers to the teacher simplifying the task to a much smaller number of possibilities so that the student is not overwhelmed.
Direction maintenance	Keeping the student interested and focused on the task in hand is a vital part of scaffolding, especially when (s)he would experience success on a simpler part of the overall task.
Marking critical features	The teacher should mark out or emphasize key milestones in the development of the task. The key thing here is to make visible discrepancies between where the student is at the moment and where they need to go next.
Frustration control	Having empathy concerning the possible frustration of the student is a vital aspect of scaffolding and requires skill as there is a danger that if the teacher makes it too easy, the student can develop too much dependency on the teacher.
Demonstrating	It is not enough to simply model solutions to a task, the effective teacher will perform an 'idealization' of the task to be performed.

2.3. Scaffolding for uncertainty

Scaffolding was already a well-researched field a decade ago and the pedagogical approach remains a widely used concept in educational research (Lönngren et al., 2017; Stone, 1998; van de Pol et al., 2010). In previous research (Bohm et al., 2025), we found that different kinds of uncertainty play a role in the complex challenges that students work on in transdisciplinary education: unpredictability, knowledge incompleteness, and knowledge frame multiplicity. Specifically, the metacognitive skills (learning about the process of learning) help students to deal with 'not-knowing,' the uncertainty in societal transitions (Peng et al., 2022). Students might feel overwhelmed when confronted with those uncertainties (Lönngren & Svanström, 2015) and the open course structure learning should be well guided (Kirschner et al., 2006). Therefore, in this research we investigate which scaffolding teachers develop to guide students through different dimensions of uncertainty in sustainability challenges.

3. Methods

3.1. EDR in the living lab course

We approached this EDR research in a series of three design cycles (McKenney & Reeves, 2012). The design cycles took place in a 16-week course called the 'Living Lab', part of the MSc Metropolitan Analysis, Design and Engineering (MSc MADE). The MSc MADE is a joint degree of two universities (the University of Wageningen and the University of Technology Delft) that focuses on urban sustainability. The Living Lab course is a capstone course in the final year of the program, where students work in teams of 4–5 students on a complex sustainability challenge together with a commissioner. During the course, student teams receive guidance from the commissioner and access to the context and stakeholders involved in the challenge. Additionally, they are coached by a teacher employed at university. This teacher is responsible for monitoring and assessing the learning process. The aim of this research is to capture the scaffolding teachers use during the coaching sessions with students.

Each design cycle consisted of three generic design phases. Gravemeijer and Cobb (2013) describe them as: (a) preparing for the experiment, (b) experimenting in the

classroom, and (c) conducting retrospective analysis. Before the start of the course, the first author gave a workshop on scaffolding strategies to the teachers[1] and set goals with teachers to experiment with the scaffolding strategies in the coaching sessions (Figure 1). During the course, we revisited the teachers three times to collect their use of scaffolding strategies in guiding the students. The first moment of data collection was when students were 'building' their Living Lab projects; the second moment when they were in the middle of 'doing' the co-creation and experiments in the projects; and the third moment was when students were 'reflecting' and evaluating the impact of the projects.

All teachers in the course provided written consent for data collection in this study. We obtained approval for our study from the Human Research Ethics Committee at TU Delft, under reference number 3501.

3.2. Data collection: questionnaire and focus groups

We monitored the three design cycles with two methods. First, we used a self-completion questionnaire (Bryman, 2016) with a combination of open-ended and closed questions to collect the perspectives of teachers. This questionnaire was designed to (1) estimate the learning progress of the student team, (2) reflect on how they experimented with scaffolding in their teaching, and (3) set goals for the next coaching session. Parts 1 and 2 of the

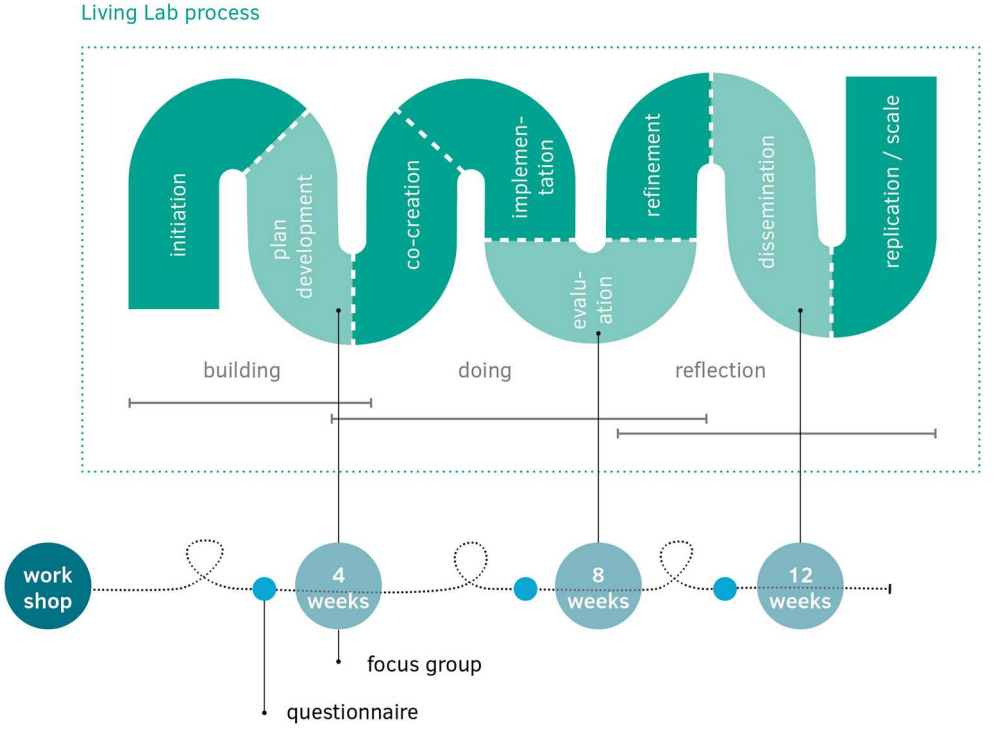

Figure 1. Illustration of Living Lab course process including the monitoring moments as part of the research (illustration by author).

questionnaire aimed to conduct the retrospective analysis of the design cycle (e.g., Which of the scaffolding strategies did you use during the coaching sessions?) and part 3 aimed to prepare for the next cycle (e.g., Which learning objective is most important to you in the upcoming coach sessions?). The questionnaire was designed in Qualtrics software and the questionnaire questions are open access available (Bohm, Klaassen, et al., 2024a).

The second method we used was observation during the coach check-ins of the course focused on the discussion of the teachers. These check-ins were a regular part of the course, where the ten teachers discussed challenges and prepared the next steps in the course with the course coordinator. Like the teachers, the course coordinator is employed at the university and coordinates the overall organization of the course. In this research, the 1 h coach check-ins served as a focus group (Bryman, 2016). The first author observed the teachers during their discussions in the first 45 min of the check-in and then moderated a discussion on the use of scaffolding in the next 15 min.

3.3. Data analysis: coding uncertainties and scaffolding strategies

The results are based on a triangulation of the data collected in the questionnaire and focus groups. We analyzed the data in two steps based on the analytical framework in Figure 2.

First, we coded the qualitative answers on the questionnaires to find the teaching problems and scaffolding in the course. To code the teaching problems, we used a codebook based on uncertainty, which was developed and tested in two previous studies (Bohm, Klaassen, et al., 2024b; Bohm et al., 2025). The codebook distinguished uncertainty in three dimensions based on Brugnach et al. (2008): the unpredictability of real-world scenarios (unpredictability), unfamiliar aspects of problems (knowledge incompleteness), and

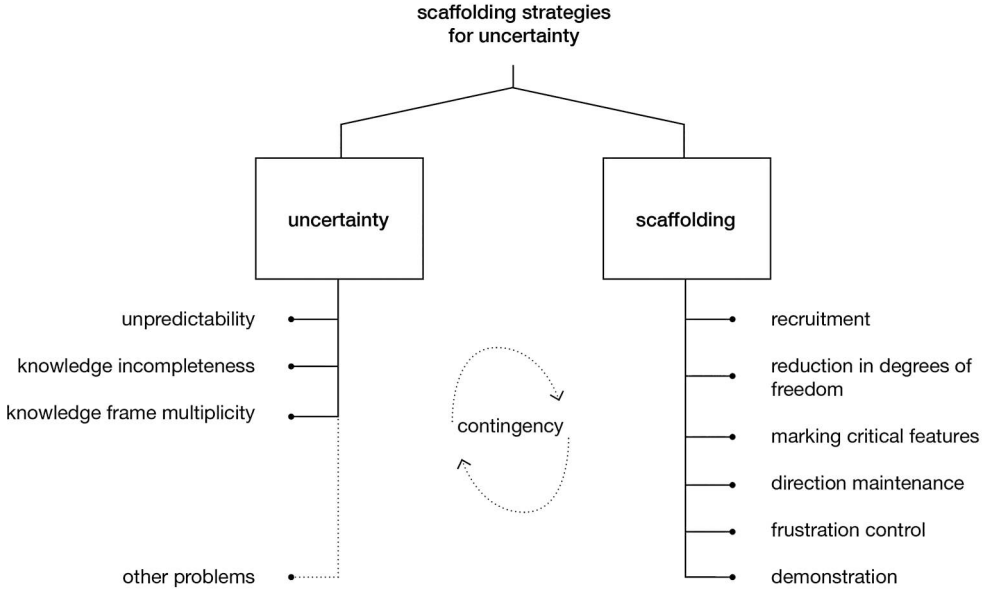

Figure 2. Analytical framework for analyzing scaffolding strategies for uncertainty (illustration by author).

conflicting viewpoints among the people involved (knowledge frame multiplicity). In this study, the teachers reported 25 problems throughout the course. 13 of these problems were coded with the a priori codes for uncertainty and 12 were given emergent codes in the category 'other problems'. We used the category 'open problems' when teachers described a problem that was not specifically related to Brugnach et al. (2008)'s uncertainty model, but that they did describe a scaffolding strategy for.

Second, to code the scaffolding strategies used by teachers to deal with the perceived uncertainties, we used the six scaffolding intentions as code groups: recruitment, reduction in degrees of freedom, marking critical features, direction maintenance, frustration control, and demonstration. Within those groups, all codes were emergent. The first author was responsible for the coding and discussed the results with the other authors to calibrate the codes and the code groups. Both codebooks are available open access (Bohm, Klaassen, et al., 2024a).

Additionally, to deepen our understanding of contingency, we observed and discussed the results of the questionnaire answers in focus groups with the teachers (Table 2). During the focus group, the first author presented the answers of the teachers on the questionnaire questions Q1.1, Q2.3, Q3.1, and Q3.2 for the teachers to reflect on how they used scaffolding and how they plan to use it in the next cycle. In section 4.3, we present the main themes in this discussion to clarify and contextualize the responses of the questionnaire at specific moments in time.

4. Results

We present the results in three parts. First, an overview outlines the uncertainties (and other problems) perceived by teachers when guiding students. Second, we present the corresponding scaffolding strategies teachers employed to deal with these uncertainties. Third, Section 4.3 details the results for three different monitoring moments (after 4, 8, and 12 weeks) in the course to clarify how scaffolding was used contingently.

4.1. Uncertainties (and other problems) perceived by teachers

Although an important part of what the teachers were scaffolding was related to uncertainty (57), teachers also had to pay attention to other problems that the students encountered (25). In the category of 'other problems', teachers most often described their own struggle of finding the right diagnostic strategy to find out what the level of the students was. Overall, the most common uncertainty that teachers encountered was 'knowledge incompleteness' (26), specifically related to theoretical grounding (Figure 3).

Table 2. Questionnaire questions further discussed in focus groups with teachers.

Questionnaire number	Question
Q1.1	How would you currently assess the performance of the student team on the learning objectives?
Q2.3	Which of the scaffolding strategies did you use during the coaching sessions?
Q3.1	Which learning objective is most important to you in the upcoming coach sessions?
Q3.2	Which scaffolding strategy would you focus on for this learning objective?

4.1.1 Theoretical grounding

The most frequently mentioned problem was 'theoretical grounding'. Teachers mentioned that students struggled with creating a theoretical framework for several reasons; they found it unnecessary, did not know how to go about it, or felt scared by the academic parts of the project. In the same way, one teacher wrote the living lab format of the course was a challenge, because they, the teachers, did not understand it completely:

> I am always a bit struggling with the format 'living lab' […] I still find it pretty broad, and I don't feel I 'master' this format. So that makes me feel a bit insecure and improvising about how to support them best.

4.1.2 Unclarity of assignment

Additionally, teachers saw that the assignment was unclear to the students (6 times) or that there was unclarity about their role (5 times). In all those cases, students struggled to make decisions on the direction of the research project. On the other hand, teachers also struggled with their own knowledge being incomplete about what the students were doing. In those cases, we coded this as a lack of 'diagnostic strategies' (6 times), because teachers sought ways to diagnose what the problems were that students were struggling with.

4.1.3 Tensions with the commissioner

Furthermore, uncertainty also frequently arose from knowledge frame multiplicity, such as tensions with the commissioner, mentioned 9 times in the questionnaires. Such conflicts arose when the commissioner was absent or unwilling to share necessary information or data with the students. Additionally, one teacher noted that the commissioner's ideas constrained the students' freedom within the project:

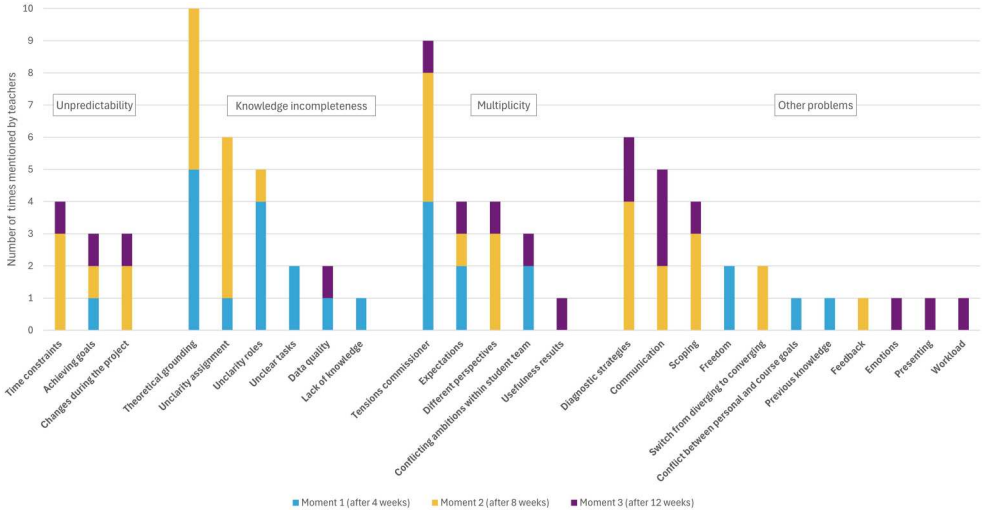

Figure 3. Bar graph showing all the coded problems per category and how often they were mentioned by the teachers.

> They are working with a well-defined deliverable (instead of a well-defined challenge), which limits their research freedom. I often do not work like this, because I believe students should be able to follow their own interests/passion when exploring a new topic.

4.2. Scaffolding uncertainties

To respond to the uncertainties, the teachers developed scaffolding to guide students in their problem-solving. In this section, we present the most prominent scaffolding strategies for each group of uncertainties. Table 2 shows how often teachers connected specific uncertainties to specific scaffolding intentions (Table 3).

4.2.1 Marking critical features to scaffold knowledge incompleteness

First, theoretical grounding was mentioned as the most common uncertainty across the student teams. Teachers made use of 'marking critical features' scaffolds to guide students, for instance, asking questions about theory and providing feedback. Additionally, they helped students to scope their projects by brainstorming and discussing the consequences of certain research methods, as is illustrated in this quote:

> The students struggle to find suitable outcomes to present their research. They had several ideas in mind but they didn't seem to be aligned with what they wanted to achieve. So I provided different examples of outcomes relating them to specific examples while explaining the reasoning/thinking process behind it.

4.2.2 Frustration control to scaffold knowledge frame multiplicity

To scaffold knowledge frame multiplicity and knowledge incompleteness, teachers predominantly used scaffolding for 'frustration control'. For example, when teachers dealt with tensions that arose from the commissioner (knowledge frame multiplicity), they emphasized to students that it is normal that not everything is clear and that it is a learning process for all of them. Other forms of frustration control would be to offer support, for instance, by joining the students in a meeting with the commissioner.

4.2.3 Direction maintenance and reduction in degrees of freedom to scaffold unpredictability

Lastly, teachers scaffolded unpredictability mainly by 'reduction in degrees of freedom'. They helped students by offering an overview of the directions they could choose and later on assisted in 'direction maintenance'. One teacher describes that process:

> Students felt a bit uncertain about to what extent the commissioner's organization should be incorporated into research questions. I told them that they could go a couple of different directions and that the introduction part should be adjusted in a way that aligns with the direction they would like to go.

4.3. Contingency in scaffolding uncertainty

To gain a better understanding of fading support and transfer of responsibility from teachers to students (contingency), this section describes which scaffolds were important at different moments in the course. Overall, frustration control was the only scaffolding

Table 3. Connections between codes for uncertainty that the teachers perceived with the students and codes for the scaffolding they described to deal with this.

		Scaffolding Recruitment	Reduction in dgrees of freedom	Direction maintenance	Marking critical features	Frustration control	Demonstrating
Uncertainty	**Unpredictability**	0	3	2	2	1	2
	Knowledge incompleteness	2	4	3	6	5	3
	Knowledge frame multiplicity	0	3	3	3	5	3
	Other problems	2	1	4	2	2	2

strategy that faded during the course and that might have led to a transfer of responsibility to students (Figure 4). In the early stages of the course (after four weeks), teachers said frustration control was crucial to mediating the tensions with the commissioner and the unclarity of the assignment and their roles. In the middle of the course (after eight weeks), teachers said that the students struggled with the theoretical grounding of the living lab projects. Teachers disagreed on the quality and applicability of common living lab frameworks, but also on how students should make use of living labs and other theoretical backgrounds in their studies. At the end of the course (after twelve weeks), teachers focused on maintaining the students' direction they chose earlier in the project and prepared them for the final assessment. Additionally, teachers were more concerned with measuring the progress on the personal learning objectives of the students at this stage.

4.3.1 Design cycle 1 (after 4 weeks)

During the first focus group, teachers discussed three main topics. First, they discussed co-creation, because this was what students were most concerned with in their meetings with the teachers. However, the teachers would like students to get interested in co-creation later in the course as at this stage their focus should be on plan development. One teacher mentioned:

> There is a small gap between what students feel most excited about (practical activities such as organizing co-creation and co-design sessions) and what I am used to communicating with students (academic stuff such as literature review, data collection, and methodology, etc.)

Although this quotation shows that at this stage teachers were already sensing tensions between practical and academic activities in the course, they did not talk about this during the focus group.

Second, teachers planned conversations with the students individually to discuss their personal development goals in the course. These conversations have helped the teachers

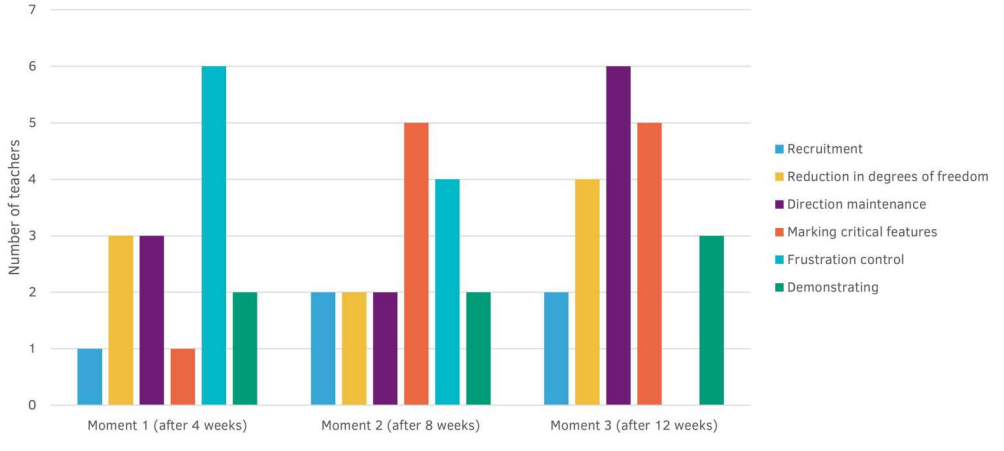

Figure 4. Bar graph of questionnaire results showing how often scaffolding strategies were reported after each design cycle.

to gain a better understanding of the passions and interests of individual students in their group. Making sure that students can pursue a direction that they are passionate about, is important to the teachers to avoid frustration. Figure 4 shows that frustration control is the most prominent scaffolding strategy in this part of the course. One of them describes this in the questionnaire:

> In terms of frustration control, I provided multiple suggestions that would allow them to pursue a direction they are passionate about while preventing tensions with the commissioner.

Third, several teachers encounter challenges in monitoring their students' activities. While the questionnaire did not reveal any problems with diagnostic strategies, some teachers noted during the focus group discussions that students were not actively seeking their guidance. Consequently, some teachers find themselves uninformed about their students' progress and unable to offer appropriate guidance.

4.3.2 Design cycle 2 (after 8 weeks)

After eight weeks, all teachers in the focus group agreed that relating theory to practice was the most difficult aspect of the Living Lab course for students. The teachers perceived this issue in different ways. Initially, some teachers mentioned that living lab theory is not very helpful to the students when they are developing a tool or a product. The theory does not help them to make decisions. Moreover, some teachers say they do not understand the theory themselves. During the focus group, a teacher says:

> Does the theory really help anybody?

Although the teachers' discussion on theoretical grounding is extensive, in the questionnaires they did not describe scaffolding strategies to solve this issue as extensively. In the questionnaire, teachers mentioned 'reduction in degrees or freedom' (simplifying how to write down theory in the report) and 'marking critical features' (by giving feedback on and asking questions about the theory) as main strategies.

Next to discussing theory, the teachers talked about taking time to reflect with the students. Particularly after co-creation sessions, the teachers wanted students to maintain their direction and they helped them to bring the project aims back into focus.

4.3.3 Design cycle 3 (after 12 weeks)

In the final focus group, the teachers' shared understanding was that the student teams were doing well and that not much scaffolding needed to be done. The questionnaire results in Figure 4 show that teachers used scaffolding for direction maintenance. For example, this teacher described direction maintenance as keeping things simple for the students:

> Students want to make a website as a delivery. I saw that there is an idea to make something complex. I suggested that a simple, clickable presentation would be enough, considering the time left and other deliveries to be produced.

Additionally, the personal learning objectives concerned the teachers. During the focus group, most of the discussion was about the assessment. More specifically, the teachers wondered how to go about the assessment of the personal learning objectives.

Although, many teachers paid attention to the students' ambitions, passions, and personal learning objectives during the course, how to measure learning on those objectives seemed difficult to them.

5. Discussion

This study used a sixteen-week CBL course called the 'Living Lab' to investigate how teachers use scaffolding to guide students toward problem-solving in uncertainty. In summary, the most prominent uncertainties observed by teachers were theoretical grounding, tensions with the commissioner, and unclarity of the assignment. These problems were contingently scaffolded through frustration control, marking critical features, and direction maintenance. Additionally, teachers struggled to find out what happened with the student team and they reported a lack of diagnostic strategies to gather that information.

This section discusses the challenges of teachers when educating in uncertainty, which scaffolding strategies might be important to consider for transdisciplinary education, and what scaffolding strategies might still be missing from current teaching practice. Furthermore, we touch upon the limitations and suggestions for future reach that arise from this study.

5.1. Challenges of uncertainty in transdisciplinary education

The results of this study suggest that the issue of theoretical grounding needs further attention. As the teachers in this case did not agree on which way to make use of theory within the transdisciplinary projects of the students, it is difficult to teach students how to do this. Popa et al. (2015) propose that transdisciplinary research needs a combination of conventional and transformative approaches, yet this might confuse students. Similarly, teachers with experience in this area are difficult to find, because the approaches to transdisciplinarity in the university are still quite uncommon (Friman et al., 2021).

Furthermore, the tensions with the commissioner, unclarity of roles and the assignment challenge teachers' adaptivity as they need to decide how much support they would like to offer and to what extent they believe that struggle and failure are a productive part of the learning process (Kapur, 2014). Teachers can provide structure (Wijnia et al., 2011), but this might lead to a loss of the uncertainty that students should learn to structure themselves (Savin-Baden, 2014). Savin-Baden (2014) argues that a lack of agreement on the pedagogical ideas in such learning configurations does not improve the quality of education.

5.2. Scaffolding strategies for cognitive, metacognitive, and affective learning objectives

The main scaffolding strategies teachers used to scaffold students in the Living Lab course were intended to mark critical features, maintain the direction of learning within the project, and manage frustrations. These three scaffolding strategies each support students in different types of learning activities (van de Pol et al., 2010). First, marking critical

features, such as giving compliments or checking if feedback is well understood, supports students' cognitive activities. The rubric-based study of Lönngren et al. (2017) is in line with this finding. Additionally, this study concludes that cognitive processes are not sufficient for complex problem-solving. Learning how to deal with complex problems also requires affect and metacognitive activities (Molenaar et al., 2014).

In our study, the second main scaffolding strategy, direction maintenance, might support students' metacognitive activities. Metacognition refers to the awareness and regulation of the process of thinking (van de Pol et al., 2010). Social assistance from teachers, for instance through direction maintenance, is important to support students in dealing with uncertainty (Bohm, Klaassen, et al., 2024b). Through direction maintenance, such as discussing the effects of choosing certain methods or visualizing connections between the results, teachers provide insight in students' thinking process and might enlarge their regulation abilities.

The third scaffolding strategy, frustration control, supports students' affect. It was the only scaffolding intention that faded out during the course. Students can be overwhelmed with uncertainty at the start of the course (Lönngren et al., 2017), but as they decide upon a specific direction to approach the challenge and their assignment is clarified, also the frustrations decrease and teachers start using other scaffolding strategies that focus more on the cognitive and metacognitive learning activities. How to provide effective scaffolding for affect is scarcely studied through an empirical lens (Zheng et al., 2023) and difficult to research (van de Pol et al., 2010). At the time of writing, several engineering education researchers explore pathways to research emotions in sustainability education (Lönngren et al., 2023).

Our study implies that emotion is an important factor when learning to deal with uncertainty. Especially at the start of the course, when assignments and roles are unclear and different perspectives can be overwhelming, teachers need tools to scaffold frustration control. This scaffolding should aim for students to, in time, be able to address their emotions and support others in their team when faced with climate anxiety and uncertainty in societal transitions.

5.3. A lack of diagnostic strategies for team dynamics and personal development

Furthermore, teachers encountered difficulties in understanding student team dynamics and the personal development of individual students in the group, which hindered the contingency of their teaching. The teachers lacked diagnostic strategies to assess the situation. Although diagnostic strategies are essential for teachers to be able to provide scaffolding, research in this direction is limited (van de Pol et al., 2010). Hardy et al. (2022) found that even if teachers made use of the appropriate diagnostic strategies, they rarely acted adaptively. This adds to the general idea that scaffolding is an advanced teaching practice and requires the professionalization of teachers (Kirschner et al., 2022).

In this educational design research, teachers were able to evaluate their behavior and through reflection professionalize their teaching as part of the research. We recommend other researchers and teachers to collaboratively work on educational research this way and at the same time advance teaching practice. Especially in challenge-based learning, where students are frequently asked to set their own learning goals and teachers need

to guide those personal objectives adaptively (van Ravenswaaij et al., 2022), scaffolding offers a concrete approach to start professionalizing such guidance.

5.4. Limitations and suggestions for future research

At the same time, the EDR approach to research does present some limitations. Scaffolding is always difficult to measure but most studies are based on observations during classroom interaction (van de Pol et al., 2010). In this study, we based our findings on the experiences of teachers and their reflections on those experiences. Although this approach allows for a deeper understanding of the teacher perspective, direct observations of the interactions by a researcher might provide a deeper understanding of what happens in the learning environment. Future research in the context of transdisciplinary education would benefit from observations, as well as a further examination of teaching for the uncertainty in sustainable transitions. Specifically, the perspective of the student on some of the issues found in this study would be relevant for future reach, as these might not necessarily correspond with what teachers experience (den Brok et al., 2006).

6. Conclusion

In transdisciplinary education, how to teach complex competencies, such as dealing with uncertainty, challenges teachers. In this design-based study, we investigated the scaffolding teachers used to guide students when problem-solving in uncertainty by answering the question: What scaffolding strategies do teachers use over time to guide students toward problem-solving in uncertainty?

We found that through frustration control, marking critical features, and maintaining students' direction teachers scaffold students through uncertainty. This study suggests scaffolding strategies are time-bound and possibly need to be linked to pivotal moments in the learning process. Further research on scaffolding might explore some of the issues we found more extensively, such as which diagnostic strategies could be used in an early stage, and how to scaffold theoretical understanding and personal learning objectives in a transdisciplinary environment.

In teaching practice, this study might inform and inspire teachers to identify, reflect, and improve their scaffolding. Ultimately, we aspire for this study to contribute to the growth of teachers as adept coaches for transdisciplinary approaches that are crucial to societal transitions.

Note

1. At the kick-off workshop, seven of the ten teachers were present. The three teachers that were missing were sent a recording of the workshop.

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