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ASSESSING COMPETENCIES FOR SUSTAINABILITY IN ENGINEERING EDUCATION – PROPOSAL OF METHOD THROUGH A PILOT STUDY

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ABSTRACT
Since 2010, the literature on Education for Sustainable Development has converged on a framework of key competencies that enable students to become relevant professional actors in the sustainability transition. We believe that the E&PDE community should build on this framework to improve the quality of pedagogical activities in design for sustainability. Our aim, through this paper, is to propose an assessment method to systematically evaluate students' competencies in relation to sustainability. We believe that this proposal will help researchers of our community by enabling teachers to have a better understanding of the level of their students in each competence. The self-assessment questionnaire we propose has been tested on 48 students, from 6 different classes. This Pilot-study enabled us to propose a ready-to-use questionnaire for colleagues of E&PDE community.

Keywords: Engineering for sustainability, key competencies, questionnaire, sustainability

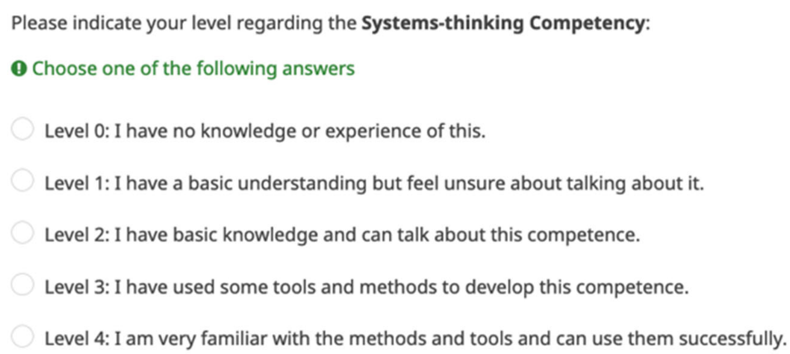
1 INTRODUCTION
Since 2010, the literature on education for sustainable development has converged on a framework of key competencies that enable students to become relevant professional actors in the sustainability transition. This framework is a "minimal set of distinct (non-overlapping) but functionally related key competencies, synthesized into an integrated perspective". Key competencies mean that the competencies are distinct from each other. The key competencies that make up a framework are systems thinking, future thinking, values thinking, strategic thinking, and interpersonal competence (collaboration). Some researchers have added intrapersonal and implementation competencies [1]. This framework has been adapted to engineering in general and can be applied to design engineering [2].
This framework can be considered as a strong basis for education for sustainability. We believe that E&PDE community do not build enough on this framework. Indeed, only 2 papers directly refer to key competencies for sustainability, in 2021 and 2023 [3], [4]. The first paper tends to understand which engineering competencies for sustainability have been developed in an engineering course; while the second paper focus on the assessment of critical thinking (1 competences added by [2]) through a specific learning activity - ideation process through design journals. Our goal, through this paper, is to propose an assessment method to systematically assess the competencies of students regarding sustainability ones. We believe that this proposal will help researcher of our community in three ways. First, it will enable teachers to have a better understanding of the level of their students in each competence. Second, it will enable teachers to reflect on their pedagogical practices to better relate their pedagogical activities with competencies for sustainability. Third, it will provide to researchers a stronger validation process to evaluate the efficiency of pedagogical activities regarding competencies for sustainability. Thus, the research question we are targeting in this paper is the following: how to systematically assess the competencies of students regarding sustainability issues? This paper describes a self-assessment method used to identify the level of students in each competency at the beginning of each semester. The method section will present the self-assessment questionnaire we have set up. The results section details the qualitative and quantitative data we gathered. The interpretation section discusses the usefulness of such evaluation for our community and proposes next steps.

2 METHOD

[5] identified eight categories of tools for assessing students' sustainability competences that can contribute to promoting sustainability transformation within an integrated framework. We decided to build the scaled self-assessment tool: “Students are asked to rate their own competency development based on a pre-determined scale” [5]. To evaluate students' competencies for sustainability, we designed a questionnaire. For each competency, the questionnaire assesses the students' proficiency level and identifies the activities that helped them develop it:

1. The eight different definitions of the competencies translated in German from [6]
2. Open text box “Can you describe a situation in which you (further) developed this competence?”
3. Self-assessment (5 levels)
4. Self-assessment (5 levels) regarding 3 or 4 methods related to the competence.

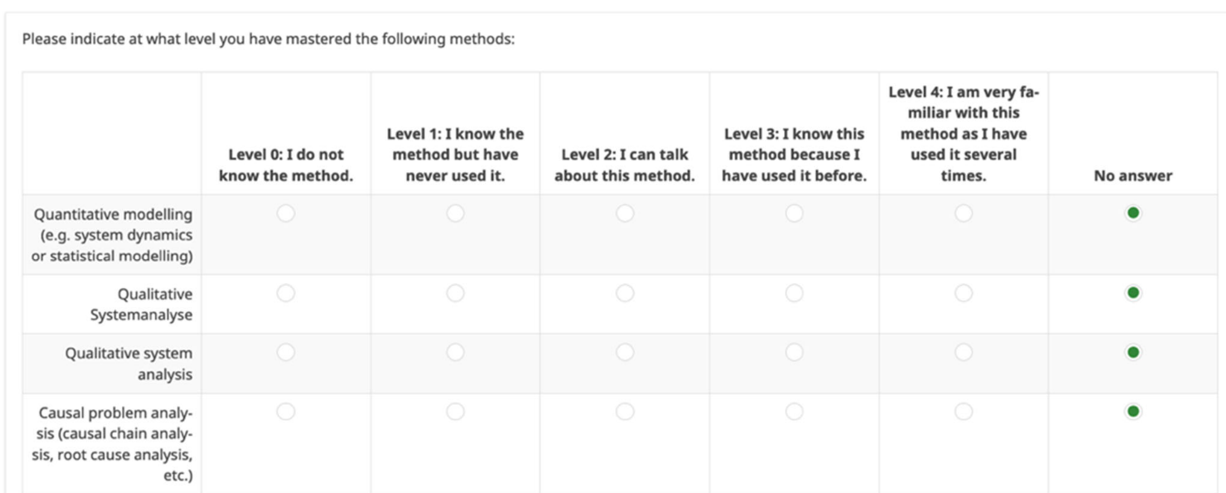
Self-assessment has some weakness, one of them being that students can “inconsistently interpret the prompt and the scale” (Cebrian et al., 2019). This is why we decided to not go for a likert-scale but to use a precise self-assessment scale that is easy to understand by students (see scale on Figure 1 and 2). Thus, the levels defined are the following: “Level 0: I do not know the method; Level 1: I know the method but have never used it; Level 2: I can talk about this method; Level 3: I know this method because I have used it before; Level 4: I am very familiar with this method as I have used it several times.”


Please indicate your level regarding the **Systems-thinking Competency**:

Choose one of the following answers

- Level 0: I have no knowledge or experience of this.
- Level 1: I have a basic understanding but feel unsure about talking about it.
- Level 2: I have basic knowledge and can talk about this competence.
- Level 3: I have used some tools and methods to develop this competence.
- Level 4: I am very familiar with the methods and tools and can use them successfully.

Figure 1. Level used for the self-assessment work in each competence


Please indicate at what level you have mastered the following methods:

	Level 0: I do not know the method.	Level 1: I know the method but have never used it.	Level 2: I can talk about this method.	Level 3: I know this method because I have used it before.	Level 4: I am very familiar with this method as I have used it several times.	No answer
Quantitative modelling (e.g. system dynamics or statistical modelling)	○	○	○	○	○	●
Qualitative Systemanalyse	○	○	○	○	○	●
Qualitative system analysis	○	○	○	○	○	●
Causal problem analysis (causal chain analysis, root cause analysis, etc.)	○	○	○	○	○	●

Figure 2. Self-assessment on different methods related to the competence (competence systemic thinking in the screenshot)

3 RESULTS

Through the questionnaire, we gathered quantitative and qualitative data. We are going to present our conclusions and then show how this type of data collection can be used for further experiments. In our sample, we had 7 bachelor student and 41 master students. Half of master students were following engineering curricula with a bit of sustainability issues whereas the other half were following a sustainable development curriculum with an emphasize in technical projects. This heterogeneity of students enabled us to test our questionnaire over different student population related to design for sustainability. We used the framework from [7] but the one from [2] could also be used to have the critical thinking competence in the results. For space reasons, we won't present intrapersonal, interpersonal and integrated problem-solving competency in the quantitative and qualitative data.

3.1 Level of students in each competency

Table 1. Level of students regarding each competency for sustainability (results gathered at the start of the semester, n=48)

Competency (definition)	Level 0	Level 1	Level 2	Level 3	Level 4
Systemic thinking (The ability to analyse complex systems of different domains in a collaborative way and to consider both local and global dimensions. The ability to consider systemic features and interactions in terms of sustainable development challenges and solution-oriented frameworks.)	21%	52%	23%	4%	0%
Future thinking (The competence to develop future scenarios based on analyses and assessments as well as to design images of (strong) sustainable development and solution-oriented framework conditions. The ability to continuously reflect critically on and adapt developed visions of the future.)	35%	35%	27%	2%	0%
Value thinking (The competence to be able to describe, apply and negotiate community sustainability-oriented values, principles and goals; based on concepts such as justice and responsibility. The ability to contextualise (historically, culturally, etc.), critically reflect, evaluate and compare individual and societal values.)	44%	38%	8%	10%	0%
Strategic-thinking (The competence to jointly develop and test (innovative) intervention, transition and transformation strategies towards sustainability (taking into account knock-on effects).)	50%	31%	15%	4%	0%
Implementation competency (The ability to solve problems relevant to sustainability and to consciously implement interventions, i.e. to take concrete action and design (ability to act). The ability to design participatory, inclusive and equitable processes of implementation and evaluation.)	35%	25%	23%	13%	2%

3.2 Relation between pedagogical activities and level of students for each competence

3.2.1 Systemic thinking

21% of students don't have any knowledge in systemic-thinking, 52% of students have a basic understanding of it but don't feel to talk about it; 23% of students can talk about the competence and only 4% know a method to develop their systemic thinking competence. The only student who put themself to level 3 (already used a method to develop systemic thinking), justified their competence by saying they designed and developed an IT system and had to integrate the wishes of the users.

In the qualitative data, we found that students developed systemic thinking through a combination of practical and theoretical activities. These activities, characterized by their intensity and duration, include completing a bachelor's thesis, conducting company audits, or engaging in software development over several months. Those activities were also recurrent, as reflected by quotes like "we talked a lot about...". This suggests that long-term, sustained pedagogical activities are more effective for cultivating systemic thinking than one-time, isolated lectures. Furthermore, students perceived systemic thinking as the ability to reconcile divergent viewpoints from different stakeholders ("Different perspectives and data shoulder thinking on a larger or different scale."), especially among those with prior corporate experience through internships or long-term employment before returning to master studies. A comprehensive understanding of systemic thinking was shared by all but two students, who explicitly stated they hadn't developed this competence before. Most students recognized instances of systemic thinking in technical contexts, such as designing mobility solutions for specific areas or creating IT and supply chain system, likely due to their prevalent technical backgrounds.

3.2.2 Future-thinking

6 students explicitly mentioned that they had not acquired this competency. Four students connected the development of future-thinking competence to personal activities, such as engaging in discussions with friends or making decisions about which classes to attend at the next semester. One student explained in the open box answers that he gained to Level 3 through visiting a lecture in the field of environmental management. Also, no one referred to the role of future-thinking in the development of critical thinking competence.

To enhance their capacity for future-oriented thinking, students engaged in case studies. For instance, some were tasked with pinpointing mobility use cases within an urban intersection, while others were assigned the challenge of identifying necessary changes for a more sustainable textile industry.

Another student underscored the integration of future-thinking skills with strategic acumen, citing the development of these skills during the formulation of their team's strategy. This student accentuated that cultivating future-thinking abilities necessitates the fostering of systemic thinking to comprehensively grasp all facets of a given problem. Through this example, we can see how competencies were interlinked.

3.2.3 Value-thinking

44% of the students said that they were unfamiliar with the value-thinking competence. Additionally, 38% of the students possess a basic understanding without the ability to discuss it, while 8% have both a basic understanding and the capability to articulate it. These findings highlight a noticeable discomfort among students regarding this competence.

6 students explicitly stated that they didn't develop value-thinking competence. For this competence, 6 students referred to stand-alone ethical classes as situations in which they developed value-thinking competence. 6 other students referred to informal activities (discussions, watching videos, debates). The case studies were less anchored into technical examples than the systemic thinking competence ones. 10% of the students demonstrate normative competence at Level 3 based on their in-depth engagement with norms and value development as social scientists and their experiences in the Life Cycle Assessment module in the Bachelor of Environmental Engineering, including a project and thesis that questioned environmental sustainability assessment systems and led to more complex thinking about sustainability. In addition, they demonstrate their normative competence through their involvement in debates on various policy issues.

3.2.4 Strategic thinking

8 students explicitly stated that they had acquired strategic thinking competence through professional experiences. Specifically, they linked this competence to activities such as internships, presenting concepts to municipalities (real-world clients in academic projects), or applying a norm in a company (norm 31000). Interestingly, one student highlighted a yoga class as a scenario in which they developed strategic thinking competence. In contrast, twelve students admitted that they were unable to identify any situation in which they had developed this particular competence.

Despite providing 10 examples in the text-box answers, these instances failed to instil confidence in students when discussing strategic thinking. Indeed, 50% of the students admitted to lacking knowledge or experience on this topic. Some students offered examples but rated themselves at level 0 or 1. For instance, a response like "Bachelor modules Innovation and Change, Innovative Value Chains" indicates a student who categorizes their knowledge or experience at "level 1," implying a lack of confidence in identifying activities that have enhanced their strategic thinking skills. There is only one student who would rate him at level 3. He refers to the fact that strategic thinking is an integral part of the work of a process engineer. However, the methodology was not used with a focus on sustainability.

3.2.5 Implementation competence

Students strongly linked this competency to real-world projects. Specifically, 13 students clearly identified their professional practice as a significant source of development for this competence. Only 2 related this competence to theoretical work, and 5 students gave examples about non-pedagogical projects (discussions, participation in a climate workshop, group work).

A breakdown of the quantitative responses reveals that 35% of the students claimed to lack any experience in implementation competence. Additionally, 25% positioned themselves with a modest level of knowledge but expressed uncertainty about discussing the topic. On the other hand, 23% of the students feel confident in discussing the competence. Furthermore, 13% have utilized a tool and method to develop implementation competence at least once, while 2% confirmed their familiarity with the tools and methods associated with this competence. Students demonstrate their implementation skills at Level 3 or 4 through their experience in implementing projects with their dual partners and within their company, leading to successful project completion and adherence to schedules. In addition, they actively participated in the planning and implementation of a funding project and gained experience in project implementation during an internship. They have also participated in a climate workshop, which demonstrates their ability to implement and design participatory, inclusive and equitable processes.

4 INTERPRETATIONS

The interpretation of the results focuses on the quality of the answers we succeeded to collect through the questionnaire. This analysis will help us determine if the questionnaire is ready for use by colleagues to evaluate their students' engineering competencies for sustainability.

4.1 Relating pedagogical activities and competencies

Students perceive real-world case studies as an effective way to acquire sustainability competencies. They feel more mature in various competencies after designing technical systems involving multiple stakeholders and considering diverse perspectives and long-term impacts. This is in line with current research [8], [9], suggesting that self-assessment results can be a good basis for a pilot-study. However, we've observed a deficiency in references related to future-thinking competence and normative thinking. It appears beneficial to delve into more extensive research on particular pedagogical activities to establish a clearer link between these activities and the relevant competencies. With this conclusion, we can identify a limit of our method, which is the direct link between pedagogical activities and competences when the competency is not clearly understood by students. Also, some links have been made between some activities and competencies (a yoga class to develop strategic thinking) and this statement would need some more justification to be taken into account. As the questionnaires were anonymous, it was not possible to get more information through individual interviews. One way of overcoming this limitation is to combine this self-assessment method with pedagogical assessments during the semester focusing on certain skills (critical review to develop critical thinking, for example). This multi-assessment approach would help to get a more objective understanding of the relations between pedagogical activities and competences. Additionally, students mentioned some pedagogical activities they remembered but not all of them. To enhance the questionnaire's effectiveness, a possible next step could be to list all the pedagogical activities first and then ask students to relate each activity to one or several competences.

The five levels of self-assessment were found to be understandable for the students. The results are somewhat easier to interpret than a Likert scale, as they allow students to indicate whether they understand the competence, can discuss it, and have experienced it. This approach provides teachers with a clearer picture of whether their pedagogical activities have enabled students to acquire a competence—understanding its meaning, experiencing it, and managing methods to improve their level.

4.2 Use of the questionnaire and quality of data collection

This survey is versatile and can be administered at different points throughout the semester, offering insights into students' progress in developing competencies. It is applicable not only at the outset but also in the middle and at the conclusion of a specific class, enabling the assessment of improvement over time. Additionally, the questionnaire serves as a valuable tool for prompting students to reflect on their overall learning experiences, not limited to a particular course but encompassing their bachelor or master program as a whole. Among the survey, approximately 1/3 of the answers were not detailed enough to know which pedagogical activities were targeted by the students. The time required to complete the questionnaire may vary, typically ranging from 10 to 25 minutes. To encourage student engagement in responding to the questionnaires, the authors incorporated "memes" into the process. Specifically, when students entered more than 20 characters in the open text box, a relevant meme associated with the competency being addressed would appear. This creative approach aimed to add a touch of humour and visual appeal, potentially enhancing the overall survey experience and motivating students to provide thoughtful responses. Unfortunately, we don't know if this strategy has an impact on students' motivation to answer the questionnaire.

Also, it is important to note that only a few students from each class completed the questionnaire (56 students out of 300 students initially targeted), so we advise the teachers to give some incentives for the students to answer the questionnaire (15 minutes during a class, not a task to be done after the class).

5 CONCLUSIONS

In this paper, we presented a questionnaire designed to assess competencies for sustainability. We tested it on students at a university of applied sciences who were enrolled in sustainability classes or curricula. Currently, the questionnaire can help other teachers understand the impact of their pedagogical activities on their students. We identified both advantages and drawbacks of our questionnaire. First, it is understandable for students, allowing them to reflect on their semester's pedagogical activities. Second, it enables teachers to gauge how students perceive the teaching activities offered. Third, it is easily reproducible across different disciplines. If researchers in the community use the same competencies and self-assessment scales, it will create a large database linking pedagogical activities with engineering competencies for sustainability.

However, there are some drawbacks: students might forget some pedagogical activities they participated in during the semester, the questionnaire takes time to complete, and some links between activities and competencies expressed by students can be difficult to understand. We recommend that teachers remind students of the activities they undertook during the semester before administering the questionnaire and allocate dedicated time during classes for completing it. This will help improve the quality of the collected data.

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