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Examining engineering design students' perceptions of agency for sustainability in a problem- and project-based learning (PBL) context—a Q methodology study

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Abstract
This study explores engineering design students' perceptions of their agency for sustainability in a Danish problem- and project-based learning (PBL) context. A conceptual framework is proposed with three dimensions: personal, action, and contextual. Q methodology was adopted to investigate the subjective views of 24 first-year undergraduate students in a Sustainable Design program regarding the most important contributors in their development of agency for sustainability. The Q factor analysis identified three prevailing opinions, which emphasized: 1) The professional role of engineering designers to act for the United Nations' Sustainable Development Goals (SDGs); 2) The role of the formal curriculum in building the foundations to act for the SDGs; and 3) Collaboration within and beyond the university. These results indicate the complexity of student agency and highlight PBL's effectiveness for supporting students' learning for sustainability across all three dimensions of student agency. The results also suggest that institutions and educators should design more formal and informal sustainability-related activities with clear structures and well-defined regulations and strategies for sustainability.

Keywords Engineering design students · Q methodology · PBL · Student agency · Sustainability

Introduction

Ongoing global social change calls for an eaffirmation of the role of engineering designers as drivers of innovation and social and economic development in the quest to build a more sustainable world. Future designers in the engineering field will need to handle global challenges and problems such as climate change and its impacts across socio-economic systems and sectors (UNESCO & ICEE, 2021). In response, engineering designers will need to be

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proactive rather than reactive to such issues. They will become decision-makers and active agents to increase awareness of sustainability issues, develop knowledge in sustainability-related domains, make effective choices, take action for sustainability, and influence others and their environments for the better (Organisation for Economic Co-operation and Development (OECD), 2018; Sidiropoulos, 2022). In this regard, engineering education for sustainable development (EESD) offers a more holistic and transformational way for students to enact their agency for sustainability, and to understand contextual constraints and opportunities while developing the technologies needed to transition to a low-carbon economy and society, in which 'no one is left behind' (Hermes & Rimanoczy, 2018; Hernández-Diaz et al., 2021; Sachs et al., 2019; Sidiropoulos, 2022). While research carried out on EESD has investigated students' levels of perception, knowledge, and awareness of sustainability principles, as well as how they engage in activities to enhance sustainability (e.g. Klotz et al., 2014; Malik et al., 2019; Manolis & Manoli, 2021), it is important to develop a deeper understanding of the complexity of the relationships between these key elements and how they influence students' learning for sustainability and agentic behaviour.

Student agency has emerged as an important concept in engineering design education, referring to the quality of students' self-reflective and intentional actions, their ability to make choices and act on these choices, and their interactions with their situated environments (Klemenčič, 2017; Martin, 2004). Agency is built upon the interaction of several elements, including student-centredness, decision-making, autonomy, self-organization, self-regulation, and collaboration (Du et al., 2022). Prior studies have shown that the development of student agency and learning for sustainability is supported by pedagogical approaches such as problem-based and project-based learning (PBL) (Guerra, 2017; Guerra et al., 2022; Jollands & Parthasarathy, 2013). As a student-centred approach, PBL has been adopted to address many new demands on students to develop skills to act for sustainability (Savery, 2015; Terrón López et al., 2017). It gives students opportunities to identify, explore, and solve real-life problems, and thereby develop problem-solving skills across complex and contextualized settings (Chen et al., 2021). Students work collaboratively in teams to define learning goals (i.e., what to learn), find appropriate strategies to acquire the required knowledge (i.e., how and where to learn) and for effective communication (i.e., with whom and for whom), and reflect on what they have learned and the effectiveness of the strategies they have employed (i.e., why and what for) (Chen et al., 2021; Savery, 2015). A recent systematic review on student agency suggests that more research is needed exploring student agency in various aspects of higher education to clarify the link between agency and contextual outcomes (Stenalt & Lassesen, 2022). To address this gap, this study will contribute to the research surrounding student agency for sustainability and its link to a PBL learning context.

While student agency has been conceptualized and studied across a range of environments, it is still necessary to establish a theoretical framework of the elements contributing to student agency for sustainability, and to explore whether these elements have a hierarchy of importance (Guerra et al., 2022). Although contributions at the methodological level could provide new insights, most studies on sustainability have adopted either qualitative or quantitative approaches (e.g. Klotz et al., 2014; Malik et al., 2019; Manolis & Manoli, 2021). Q methodology (hereafter referred to as 'Q') is an approach with the potential to offer a understanding on individuals' subjective viewpoints, perceptions, or beliefs regarding a given topic (McKeown & Thomas, 2013; Watts & Stenner, 2012). Previous research has used Q to address topics such as science teachers' perceptions of the nature of technology (Yenilmez Turkoglu et al., 2022), and students' perceptions of their professional competence (Liu et al., 2015), among others. Researchers have started adopting Q to examine

agency development among engineering students in PBL contexts and indicate that a range of internal and external sources are involved (Du et al., 2022; Lyngdorf et al., 2023). However, it remains unclear how engineering design students perceive their capacity for agency within this context specifically in relation to sustainability. Q provides a useful method for capturing the complexity of student learning for sustainability and students' subjective perceptions of what is important for the development of their agency for sustainability in a PBL context. As a result, this study aims to answer the following question using Q:

> What are Sustainable Engineering Design students' views on the most important contributors to their development of agency for sustainability in a PBL environment?

A conceptual framework for understanding student agency for sustainability

Agency refers to an individual's ability to make choices freely and engage in autonomous actions (Martin, 2004). Although this concept has been explored and discussed from a variety of perspectives, the current study is inspired by socio-cognitive and subject-centred social-cultural perspectives. The former holds that individuals exert agency through their own autonomous choices and will, linking thoughts to actions and relating them to their own intentionality, self-efficacy, self-regulation, self-reflection, metacognition (Bandura, 2006), motivations (Ryan & Deci, 2000), and competence beliefs (Schunk & Zimmerman, 2006). The latter focuses on the individual's development of cognition and agentic behaviours within constantly changing social, historical, or cultural contexts (Eteläpelto et al., 2013). It centres subjects in the construction and negotiation of their agency in such contexts. Based on these two views, we define student agency as a complex and dynamic learning system consisting of three interrelated dimensions: (1) a personal sense of agency, or the extent to which students feel agentic in learning settings; (2) agentic behaviour, or how students exert their agency through active participation; and (3) students' interaction with the environment (Du et al., 2022).

In bringing together the concepts of student agency and education for sustainability, we propose a conceptual framework, adapted from that developed by Guerra et al. (2022) for understanding and organizing the elements of student agency for sustainability. This framework, shown in Table 1, has three dimensions: personal, action, and contextual.

Personal values regarding sustainability

The personal dimension reflects the epistemic, or knowledge-related, form of agency described by (Damşa et al., 2010), involving actions that aim to create awareness and shared understanding. This is the process through which students develop cognitive, affective, and motivational values relating to sustainability, including self-efficacy, awareness, interests, motivations, attitudes, and emotions. Cognitively, students may develop self-efficacy, referring to the extent to which they believe in their capacity to achieve higher goals through participation in complex learning tasks for sustainability (France et al., 2022; Mercer, 2012). It also indicates their perceptions on the development of awareness and knowledge for sustainability (Sidiropoulos, 2022), their perseverance when confronted with difficulties (Zimmerman & Cleary, 2006), and their confidence in overcoming these challenges. However, students' lack of belief in their competence, or the presence of negative beliefs,

Table 1 A conceptual framework on elements of student agency for sustainability (Adapted from Guerra et al., (2022)

Dimension(s)	Elements of student agency for sustainability
Personal	• Knowledge and awareness of sustainability and SDGs • Beliefs about sustainability • Motivation to act for sustainability • Attitudes toward sustainability initiatives • Emotional responses to sustainability
Action	• Setting goals for engaging with sustainability • Making plans for engagement/participation • Monitoring different types of engagement • Self-reflecting and evaluating choices and actions • Co-constructing, negotiating, and compromising in a collaborative environment
Contextual	• Institutional level (e.g. across programmes or one's department, faculty, or university, including policies) • Societal level (e.g. across universities and institutions, one's local community and organizations, local and regional governments, student organizations, and so on.)

may hinder their participation in learning activities (Zhao et al., 2017; Du et al., 2022). Affectively, students may hold both positive and negative attitudes and emotions when learning about sustainability and addressing relevant issues; these emotions can include responsibility, happiness, hope, anxiety, frustration, guilt, grief, and overwhelm (Manolis & Manoli, 2021; Verlie, 2019). Another influential factor is motivation, which is fluid and dynamic impacting the interplay between students' internal feelings and external contexts (Du et al., 2022). Motivated learners have the impetus, inspiration, satisfaction, and orientation to initiate actions by activating both intrinsic and extrinsic resources, identifying learning content, and determining sustainability-related problems to explore for themselves (McCormick et al., 2015; Ryan & Deci, 2000).

In a PBL setting, students' agency can be strengthened if they believe PBL is an appropriate method to support their learning for sustainability and prepare them to work on sustainability-related issues (Guerra et al., 2022). Meanwhile, PBL has been well documented to improve students' motivation and autonomy by allowing them to take responsibility for their own learning on team projects (Beagon et al., 2019; Helle et al., 2006).

Actions for sustainability

The second dimension of agency focuses on self-regulated characteristics of student agency, or students' ability to regulate their own actions and reflect on their own skills (Bandura, 2006, 2008). This highlights a process-related agency, involving projective, regulative, and relational actions, such as setting goals and making plans (projective), monitoring advancements (regulative), and redirecting critical feedback (relational) (Damşa et al., 2010). When enacting agency for sustainability, well-regulated learners are proactive in setting up goals and regulating their behaviours to achieve those goals and contribute to sustainability, making plans for engagement, monitoring their own sustainability-related decision-making processes in complex situations, and evaluating their own learning processes (Bandura, 2006, 2008; Zimmerman & Cleary, 2006).

The development of agency might further be supported or challenged by PBL's focus on how students interact, collaborate, and communicate within their project teams and beyond. As a result of this teamwork, students share and co-construct knowledge and meanings for sustainability, work on shared tasks, collectively identify learning goals and possible problems, develop effective time management strategies, explore various sources of information regarding sustainability, and negotiate and compromise with one another (Borrego et al., 2013). Relationally, the development of student agency is also fostered by positive instructor-student relations, peer support, a sense of trust and safety, effective communication, constructive reciprocal feedback, and efficient conflict resolution (Borrego et al., 2013; Hökkä et al., 2017).

Contexts for action for sustainability

The contextual dimension emphasizes students' situatedness in specific complex and interrelated systems, such as institutional, spatial, political, societal, and cultural systems, that together form their learning environments (Bandura, 2008). Bandura highlights that the individual's active role in these systems is to purposefully exert control through cognitive processes such as idea generation, creativity, and self-regulation. From this perspective, student agency for sustainability is always contextually bounded and relationally constructed, in that it is either supported or constrained by social groups, structures, norms, and values (van Wijk et al., 2019).

In this study, student agency is studied in the context of a systemic PBL environment and therefore includes broader structural and pedagogical PBL elements. As a result of the resources present in this context, reciprocal interplay is not only with peers, project teams, and instructors, but also with other institutional or societal contexts or stakeholders, such as the rules, policies, or regulations defined by programmes and institutions (Boeren, 2019), collaboration across universities and communities (Manolis & Manoli, 2021), and external help from experts (Bocong, 2015).

Methodology

Research context and participants

This study was conducted at Aalborg University in Denmark, where PBL is practiced on a systemic level for five decades, with a strong commitment from management to sustaining full-scale PBL implementation across all faculties (Askehave et al., 2015; Kolmos et al., 2013). This university used merged models to combine characteristics of "problem-based" and "project-based" in order to maximize students' learning and employability. The Aalborg University PBL model is problem-based; project-organized; collaborative; experiential; contextual; participant-directed, and exemplary (Askehave et al., 2015; Guerra et al., 2022). This means that every semester, team of students learn by identifying and formulating problems from real situations (also known as problem design) to be solved through a project (Holgaard et al., 2017). Each team is allocated one or more project supervisors (Askehave et al., 2015).

In engineering and science faculties, each semester the project module consists of 15 ECTS (European Credit Transfer System; 1 ECTS is approximately 28 h of student workload), which is the equivalent of 50% of total number of credits for one semester. The

remaining 50% are allocated to three courses of 5 ECTS each. The course modules are lecture-based, and it is where discipline specific knowledge is delivered to students. It is expected students to select and apply the theoretical knowledge to understand and solve the problems.

In addition, Aalborg University is now in the process of transforming into a mission-driven institution, where activities are organized around missions tackling SDGs. In this regard, sustainability is integrated into some activities on the campus, including research, education, cooperation, and innovation (Guerra et al., 2022). Three main strategies characterized the integration of sustainable development in engineering education: program level (e.g., programmes that sustainability is core of the program, like B.Sc. sustainable design, M.Sc. sustainable cities, B.Sc. and M.Sc. Environmental management, and sustainability, etc.); at semester level (e.g., semester project themes like sustainability lifestyles in B.Sc. Medialogy sustainability) and at module level, course, or projects (Bertel et al., 2022). Additionally, project provide the flexibility for both students and supervisors collaboratively work with sustainability but integrated it in project. PBL module is participant-directed. This means students not only define the problems, but also have the possibility topics of their own interest and that can address and learn in depth as part of the project. That said, the project provides the students with flexibility and opportunity to learn about sustainability and contextualize it in relation to their education field (Guerra & Holgaard, 2019; Guerra & Smink, 2019; Guerra et al., 2022).

After the study was granted ethical approval, 24 first-year bachelor's students from the Sustainable Design programme were recruited to participate in May 2023. This programme integrates sustainability as a core value rather than as an add-on (Valderrame Pineda & Jørgensen, 2018; Valderrame Pineda & Niero, 2020). This programme places strong emphasis on transitions to sustainability, which is understood as involving radical systemic changes and collaborative design (Clausen et al., 2020; Köhler et al., 2019). To avoid projects which favour one SDG or one indicator within one SDG without considering its trade-offs or connections with other goals, one of the teaching efforts is to follow Sachs et al. (2019)'s introduction on six transformations as modular building-blocks for achieving the SDGs in a more systematic way. For instance, when designing extensive renewable energy systems (e.g. windmill, solar cell farms, etc.), students were facilitated to consider its impact on local communities. When focusing on promotion of circularity of products (e.g. textiles) in Denmark, they were suggested to consider how the inhuman condition continues to be worsen in sweatshops which produce the primary materials and the final product. In this sense, student-centredness is emphasized with students managing their own learning progress, time, and outcomes, coordinating team learning activities, exploring multiple resources for each of the SDGs, and addressing complex problems from an interdisciplinary perspective (Askehave et al., 2015; Guerra et al., 2022). To provide experience of external collaboration, student designers are also encouraged to work with companies and communities at the regional, national, and international levels.

Research procedures

For the data collection and analysis processes in this study, we followed the six steps of Q research within educational settings as described by Lundberg et al. (2020): (1) concourse development; (2) Q set construction; (3) participants' Q sorting; (4) post-sorting activities; (5) Q factor analysis; and (6) factor interpretation.

Steps 1 and 2: concourse and Q set development

The first two steps form a preparatory stage before data collection. The term 'concourse' refers to a list of statements pertinent to the topic (Brown, 2019). In step 1, an initial set of statements was developed based on a literature review and theoretical framework, along with students' responses on qualitative surveys and interviews conducted in the course of the authors' previous work (Guerra et al., 2022). The authors' extensive research experience on PBL and education for sustainability also contributed to the statements. Through multiple sessions from March to May 2023, authors discussed, reduced, and revised these statements, resulting in a final list of 27 statements.

In Step 2, the three-dimensional framework of student agency for sustainability was used as a reference to categorize the statements as Q sets. Table 2 shows subthemes of each dimension and the corresponding statement numbers. The intrapersonal dimension of student agency comprises student knowledge of sustainability, emotional responses (e.g., anxiety, frustration, care, etc.), attitudes (including a sense of responsibility at both personal and professional levels), and motivational factors. The action dimension involves students' engagement with their immediate educational surroundings and peer groups. Thus, this dimension of agency is developed not only by working on PBL projects, negotiating and compromising within their working teams, and interacting with teachers and supervisors. The contextual dimension focuses on how student agency is supported by the larger context, such as the department, industry, municipality, student organizations, or educational institutions.

Steps 3 and 4: participants' Q sorting and post-sorting activities

The next two steps focus on data collection. We collected the data using a hard copy version of the 27 statements. In May 2023, 24 participants took part in the sorting activity, with guidance and explanation from the first author. The participants were first asked to provide demographic information, and then to rank the 27 statements on a forced-choice, quasi-normal, and symmetrical distribution grid ranging from 'the least important' (-4) to 'the most important (+4)'. This was done in response the following question: 'As a student engineer, in your opinion, which of the following statements are important in terms of your actions toward achieving the UN's Sustainable Development Goals (SDGs)?' Each participant individually sorted all of the statements according to their own views.

The Q sorting activity was followed by a post-sorting survey consisting of open-ended questions, intended to obtain the participants' explanations of their choices of the two statements that they ranked on the extremes of the grid – that is, the statements they ranked

Table 2 From concourse development to Q statements

Dimension and subdimension of student agency	Statement number	$N=27$
Personal dimension: knowledge; emotional responses; attitudes (incl. a sense of responsibility on personal and professional levels); motivation	3, 6, 9, 11, 13, 15, 17, 20, 23	9
Action dimension: setting up goals for SDGs; making plans; monitoring; self-reflecting and evaluating; co-constructing, negotiating, and compromising in a collaborative environment	1, 4, 7, 12, 18, 19, 21, 22, 24, 25, 27	11
Contextual dimension: institution and society	2, 5, 8, 10, 14, 16, 26	7

as most and least important. The survey also asked if there were additional items that the participants felt should be added to the current Q statement set.

Steps 5 and 6: Q factor analysis and factor interpretation

In Step 5, the raw data were entered into an Excel spreadsheet and imported into KADE, a Q analysis software package (Banasick, 2019). Several analytical procedures were then performed. First, a principal components analysis (PCA) scree test was conducted to determine the prospective number of factors to be extracted (Watts & Stenner, 2012). Second, centroid analysis was used as an extraction method, and a varimax rotation technique was used to clarify the relationships among the factors (Watts & Stenner, 2012). We followed the general criteria of Q analysis, with eigenvalues greater than 1.00, the related variance explained by the factor and at least two significantly loading participants in each factor (Brown, 1980; Watts & Stenner, 2012). Third, to determine participants accepted in each factor, a factor loading test was performed. According to Brown (1980) and Watts and Stenner (2012), the formula to calculate the factor loading cut-off ($p < 0.01$) is:

$$2{,}58 \times \left(1 \div \sqrt{no.\ of\ items}\right) = 2{,}58 \times \left(1 \div \sqrt{27}\right) = 0{,}4965$$

As a result, 19 of the 24 participants loaded significantly on one of the three factors, which together explained 56% of the study variance, which is higher than accepted variance in Q methodology (Kline, 2014). Five participants were removed because they either did not load significantly in any factor (participants SD4, SD7, SD20, and SD23), or loaded significantly in more than one factor (e.g. participant SD16 loaded significantly in both Factor 1 and Factor 3). The presence of participants loading in multiple factors makes the factor arrays (a weighted average of values for each statement within one single factor) less distinct (Watts & Stenner, 2012). Details of the participants' loading results for factors are shown in Table 3.

In Step 6, all factors were interpreted using a qualitative approach to create a holistic narrative of the results. Specifically, the results analysis was combined with information from across the range of factor arrays, along with intra-factor interpretation of participants' demographics and post-sorting information, in an abductive and iterative process, and cross-factor interpretation was conducted to highlight differences between factors.

Results

The statistical analysis shows three distinct factors, which represent participants' consensus on what they consider the most important contributors in student' ability to develop and enact agency in relation to the UN's Sustainable Development Goals (SDGs). These three factors will be elaborated in the following sections, in which '#' followed by a number refers to a Q item number (e.g., #1 refers to Q item 1). Each statement is referred to by its item number and rated on a scale from -4 to+4 (e.g., '#11/4' refers to statement 11 with a value of 4). The use of 'D' after the value number refers to 'distinguishing statements' ($p < 0.05$), and 'D*' represents 'significantly distinguishing statements' ($p < 0.01$), highlighting statements in which viewpoints significantly differed from those of other participants.

In the following section, results for each factor will be elaborated upon and related to the theoretical framework of student agency in PBL for sustainability. Table 4 provides

Table 3 Factor loading results for participants

Q-sort	Factor group	Factor 1	Factor 2	Factor 3
SD3	F1-1	**0,8927**	0,0862	0,0928
SD11	F1-2	**0,8069**	-0,0001	-0,1632
SD15	F1-3	**0,7803**	0,0513	0,0705
SD18	F1-4	**0,752**	0,0502	-0,0293
SD13	F1-5	**0,7368**	0,0926	0,3275
SD24	F1-6	**0,6976**	0,0017	-0,3274
SD12	F1-7	**0,6951**	0,1944	-0,1527
SD17	F1-8	**0,6884**	0,4649	0,0743
SD19	F1-10	**0,6182**	0,1319	-0,0725
SD8	F1-11	**0,616**	0,3482	-0,4559
SD9	F1-12	**0,5954**	0,1852	0,2857
SD14	F1-13	**0,5743**	0,4255	0,0117
SD21	F2-1	0,3643	**0,9134**	-0,1062
SD2	F2-2	0,0669	**0,8181**	-0,1472
SD22	F2-3	0,168	**0,6793**	0,1063
SD6	F3-1	0,0227	0,0486	**0,6168**
SD1	F3-2	0,0936	-0,4892	**0,5938**
SD5	F3-3	0,1105	-0,041	**0,5531**
SD10	F3-5	-0,2232	0,0447	**0,5093**
SD16	F1-9	0,6541	0,3009	0,6425
SD4	F1-14	0,4246	0,3444	0,0582
SD20	F1-15	0,4086	0,3066	-0,2373
SD7	F3-4	0,2692	0,2	-0,5199
SD23	F3-6	0,3236	-0,374	0,39

*'SD' followed by a number is the identifying number given to a participant (e.g., SD1, refers to participant no. 1); 'F' followed by the number 1, 2 or 3 refers to Factor number (e.g., 'F1' refers to factor 1)

an overview of the values assigned to statements for each factor, showing a list of Z-score variance values from lowest to highest, or most consensus to least consensus.

Factor 1. Emphasis on the professional role of engineering designers to act for SDGs

Twelve participants loaded significantly on Factor 1, which has an explained variance of 34%. Eleven of these participants were women, while one did not specify their gender; their ages ranged from 20 to 25. This factor emphasizes participants' anticipation of their professional responsibility as engineers to act for SDGs, with less attention to the role of policy and institutional regulations.

As shown in Fig. 1, Factor 1 participants emphasized their prospective professional practice as contributing to solving sustainability problems (#3/4D*). This view is further manifested in participants' post-sorting activities; as participant SD13 stated, '[Sustainability problems] are what I want to work with in the future, and [it is] therefore important to obtain the skills/opportunities to do so.' These participants also anticipated that professional engineers are important actors in addressing the SDGs (#13/3D) and believe that their actions in relation to the SDGs have a positive impact (#15/2D*).

Table 4 Statements sorted by level of consensus (from the most agreed with to the least agreed with)

No	Statement	D	F1	F2	F3	Z-score variance
22	Having a program that requests students to integrate SDGs in their projects	A	0	0	0	0,013
4	Having supervisors with competences related to SDGs	A	1	2	2	0,043
5	Using multiple sources of information (e.g., social media, podcast, YouTube, etc.) to know more about the SDGs	C	-2	-4	-3	0,069
7	Being provided with courses focusing on SDGs	A	2	3	0	0,109
21	Developing shared values for sustainability among project team members	A	-2	0	-2	0,149
27	Having SDGs integrated in all courses	A	0	2	0	0,177
26	Having clear institutional strategies concerning the SDGs	C	-1	0	1	0,194
12	Participating in student self-organizing activities addressing the SDGs	A	-3	-4	-1	0,215
23	Considering the SDGs in my daily life activities	P	-2	1	0	0,282
1	Using SDG as one criterion to self-reflect on the project achievements	A	-1	1	-1	0,301
3	Seeking opportunities to contribute to sustainability problem solving as part of my future career	P	4	1	1	0,341
6	Having knowledge about the SDGs	P	3	0	-1	0,436
24	Engaging to collaborative learning which supports my actions for the SDGs	A	0	-1	3	0,524
9	Being passionate about SDG-related activities	P	-1	1	-2	0,538
18	Utilizing my previous SDG related experiences in my current project	A	-1	-3	1	0,583
19	Having SDG clearly defined as part of assessment criteria for the project	A	0	4	0	0,62
14	Having opportunities to influence on educational policy making within the university	C	-4	-3	1	0,698
25	Integrating the SDGs throughout the project work	A	1	3	-2	0,728
16	Collaborating with professional communities (e.g., industry, municipality, and other stakeholders) focusing on the SDGs	C	1	-1	4	0,929
13	Seeing engineers as an important actor to help solving sustainability problems	P	3	-2	2	0,96
10	Having opportunities to collaborate with other educational institutions (e.g., universities, schools, etc.)	C	-3	-1	2	0,971
17	Being motivated to act for the SDGs	P	1	2	-3	1,055
11	Having technical competences to solve problems related to SDGs	P	4	-2	-1	1,177
15	Believing that the actions for SDGs will positively help solving sustainability problems	P	2	0	-4	1,251
2	Have my department providing co-curricular activities addressing SDGs	C	-4	-2	3	1,267

Table 4 (continued)

No	Statement	D	F1	F2	F3	Z-score variance
8	Collaborating with student organizations (e.g., Engineer without borders, BEST, SOS, etc.) focusing on the SDGs	C	0	-1	4	1,272
20	Being alerted to the sustainability problems (e.g., climate crises)	P	2	4	-4	2,151

F factor, *D* dimension, *A* action dimension, *C* contextual dimension, *P* personal dimension

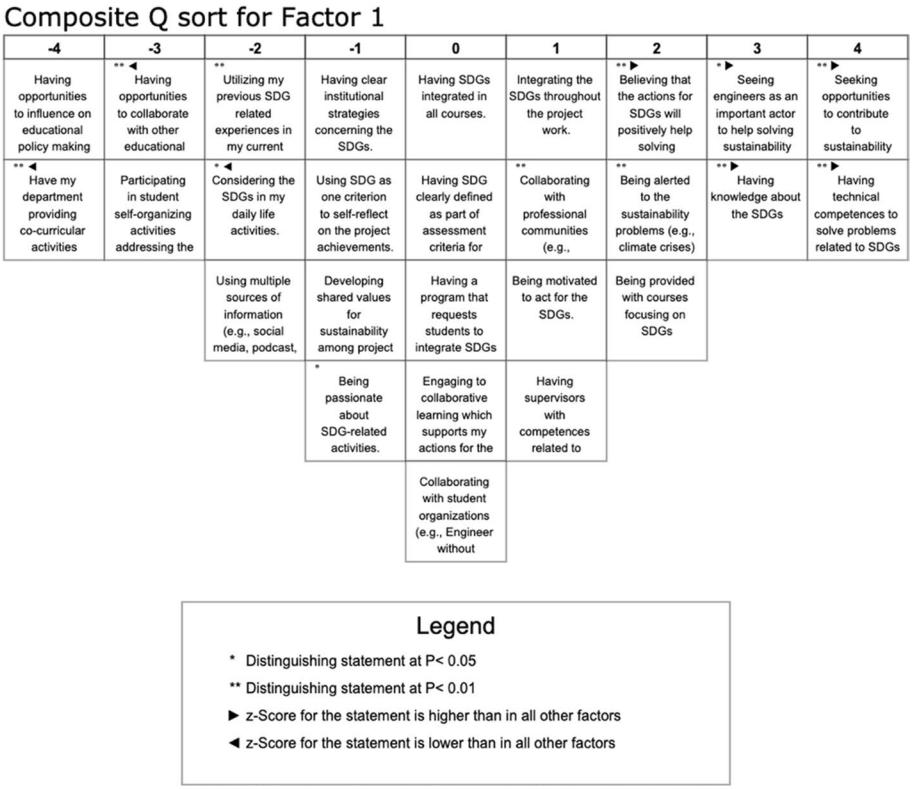

Fig. 1 Q sort for factor 1

Along with this anticipation, the participants highlighted the need for both technical competences (#11/4D*) and knowledge on SDGs (#6/3D*) to address sustainability-related issues in their future professional lives. These needs are confirmed by the reflections from participant SD15, who stated: 'If you don't have the technical competence, it is hard to make a difference.' Similarly, Participant SD12 noted: 'It is very important to know what the SDGs are if they are to be integrated into my work life.'

On the other hand, Factor 1 participants assigned low importance to institutional and societal elements in impacting their actions for SDGs. For example, participants attributed the least importance to engaging with co-curricular activities provided by their departments (#2/-4D), due to time constraints they faced in their programmes and the heavy workloads for their project work. As one participant wrote:

> I think that if the activities regarding SDGs are voluntarily, then the participation (on my behalf) would be much lower than when it is a part of the plan for each semester. Also, I do not have enough time on my hands to [participate in] after-school activities (SD 18).

These students also assigned a lower rank to the influence of educational policy-within the university (#14/-4),

> Strategies and political influence are more long-term visions, which we as students don't feel or benefit from. And now, I still find them important overall, but not for me to achieve SDG goals in my work and learning (SD4).

In addition, these students did not relate opportunities for collaboration with other educational institutions (#10/-3D*) or the integration of SDGs in their daily life activities (#23/-2D) to the development of their agency. These participants believed that it should be the universities, rather than the students, that take on the primary responsibility for policy-making and collaboration with other institutions concerning SDGs, as expressed by SD11:

> I think it is not as important to collaborate with other educational institutions. For me as a student, I don't do it now and don't think it is more important than what I do daily, though it is important for universities to share knowledge (SD11).

Factor 2. The role of the formal curriculum in building the foundations to act for SDGs

Factor 2 clusters the opinions from three female participants with an age range of 22–24, and accounts for 13% of the explained variance. These participants significantly valued the role of the curriculum in creating a foundation for students to act for SDGs. In Fig. 2, students whose responses fell within this factor emphasized the role of both the coursework and project work in enhancing their agency for sustainability, giving high importance rankings to having clear-defined SDGs as part of assessment criteria for their projects (#19/4D*), integrating SDGs into projects (#25/3) and all courses (#27/2D), being provided with courses relevant to SDGs (#7/3C), having project supervisors with competences related with SDGs (#4/2C*), and having SDG as one criterion for self-reflection on their project work (#1/1D*). As explained by SD21:

> You need to have an understanding of SDGs to incorporate [them] into the project. And by having a clear goal, it is 'easier' to achieve SDGs. (SD 21)

While they saw a high level of significance in formally-organized activities within the curriculum, these students did not value extra-curricular and self-organized activities. Aspects they ranked as least important included their participation in self-organized activities addressing SDGs (#12/-4) and their use of different information sources such as social media, podcasts, and YouTube, to learn more about SDGs (#5/-4C). One student, SD22, reflected in the post-sorting activity that these activities are time-consuming and uninteresting:

> I am not very interested in participating in self-organizing activities; I love my free time, and like to work on SDG during school time, but not much after. (SD 22)

In addition, some personal factors were ranked highly by this group, including being alert to climate change as a starting point (#20/4D*), being motivated to act for SDGs (#17/2), and being passionate about SDG-related activities (#9/1D*).

Compared to other factors, these students gave lower ranks to previous sustainability-related experiences prior to the current project (#18/-3*). This may be due to a lack of such experience; as SD21 reflected: 'I didn't have any experience with the SDGs before I started university.' (SD21).

This factor differs from Factor 1 in its lack of emphasis on technical competences (#11/-2D) and the role of engineers in the resolution of sustainability problems (#13/-2D*). As SD 22 reflected:

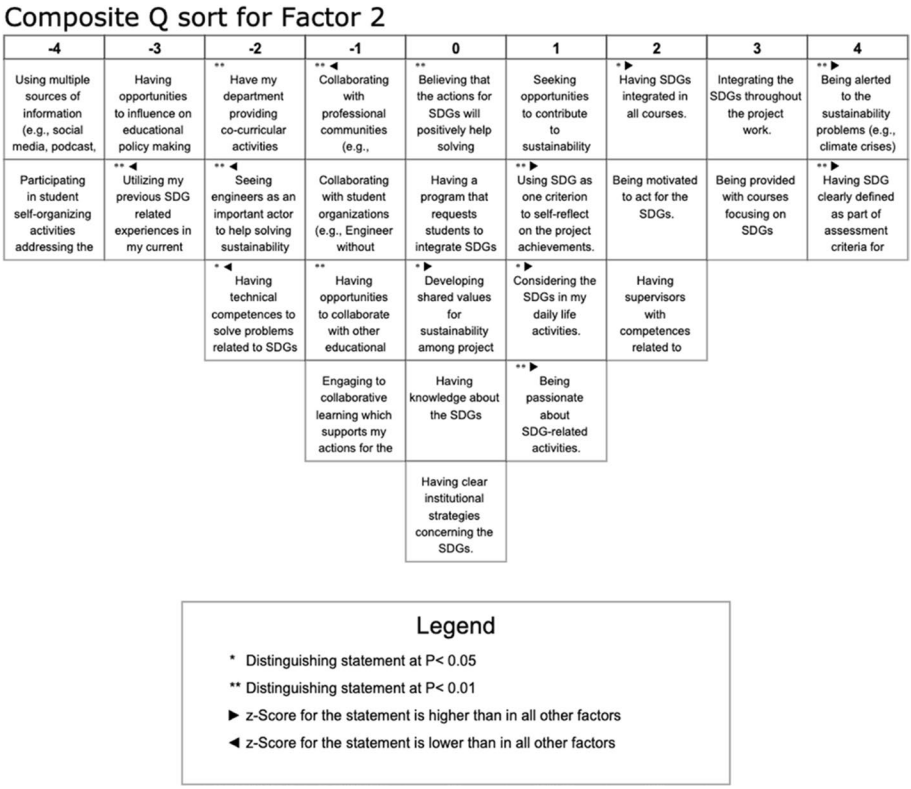

Fig. 2 Q sort for factor 2

I am not so much into the technical subjects. I like looking at people's minds, and their thoughts. (SD 22)

In addition, these participants did not consider collaborative learning to be important in supporting their actions for SDGs (#24/-1) and assigning relatively low ranks to collaboration with both student organizations (#8/-1) and professional communities that are focused on SDGs (#16/-1D).

Factor 3. Collaboration within and beyond the university

Four participants (three women and one man, aged 21–24) are significantly loaded on Factor 3, with an explained variance of 9%. Generally, participants in Factor 3 emphasize collaboration as having a powerful impact in taking action toward sustainability.

In Fig. 3 these participants prioritized collaboration with professional communities, including industry, municipality, and other stakeholders (#16/4D*) (unlike Factor 2), student organizations (e.g., Engineers without Borders, BEST, SOS) (#8/4D*) (unlike Factor 2), and other educational institutions (e.g. universities, schools, etc.) on actions for SDGs (#10/2D*). As participant SD6 wrote:

I think being able to collaborate with others is very important and a good experience. Working with people from outside the university can make the project more 'serious' and feels more real. (SD6)

These participants also believed that collaborative learning activities would enhance their engagement in SDGs (#24/3D*), unlike Factor 2.

Compared with the other two factors, along with the above statements, participants in Factor 3 value having support for the development of their agentic behaviour by other contextual elements, assigning high importance to their departments providing co-curricular activities (#2/3D*) (in contrast to Factor 1), having clear institutional strategies (#26/1D), and having opportunities to influence policymaking within the university (#14/1D*) (in contrast to Factor 2). This is reflected in one participant's statement:

I have to believe that my programme can help solve sustainability problems. And my department has to address activities so that we can work with it in all our programmes. (SD10)

Despite highlighting institutional collaboration, these students did not emphasize the significance of their personal values, such as beliefs that their actions for SDGs would positively contribute to solve sustainability problems as important (#15/-4D*) (unlike Factor

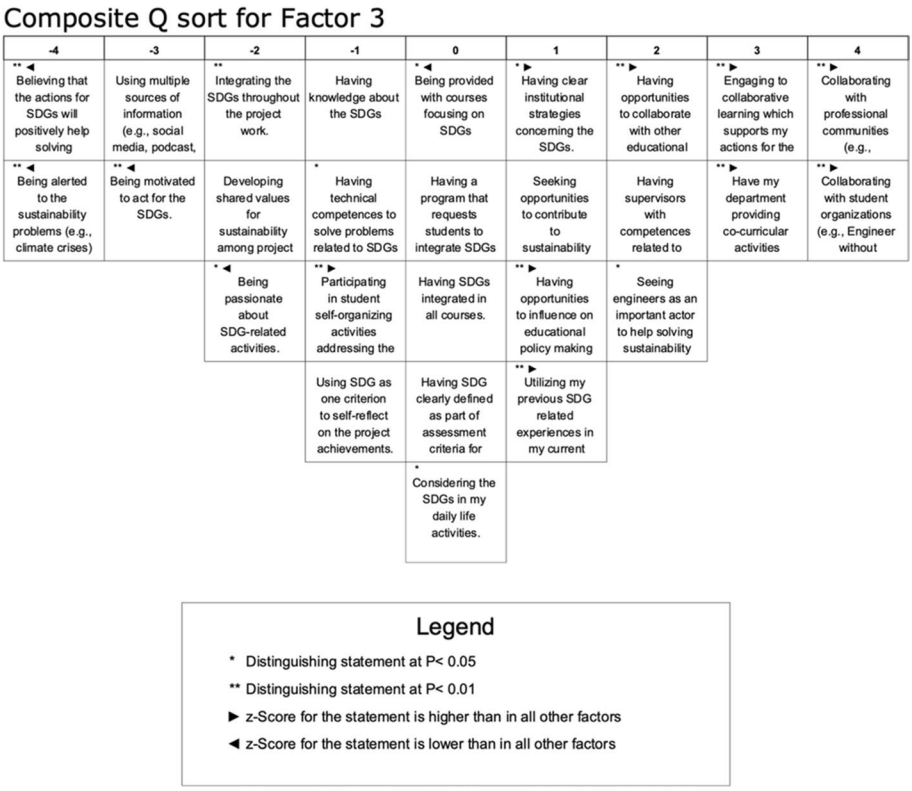

Fig. 3 Q sort for factor 3

1) and being alert to sustainability problems such as climate change (#20/-4D*) (unlike Factor 2). This is a result of insufficient information on SDGs, as SD1 explained:

> I believe that if you receive the right and enough information, you will eventually become concerned about sustainable problems and passionate about SDGs. (SD1)

Other statements that were attributed less importance in the personal dimension include being motivated to act for SDGs (#17/-3D*), being passionate toward SDG-related activities (#9/-2D), and having knowledge about SDGs (#6/-1) (unlike Factor 1). The participants believed that students should do more practical work for sustainability, as stated by SD10:

> I don't think it is enough to just know about the SDGs. We have to work with it in our projects. (SD10)

In the action dimension, lower-ranked statements were those which related to the extent to which SDGs played a role in their projects, including integrating SDGs into their project work (#25/-2D*) (unlike Factor 2), and using SDGs as one criterion for self-reflection on their project (#1/-1) (also unlike Factor 2).

Consensus

Although the results show diverse opinions, there are five statements statistically identified as having significant consensus among the participants from all three factors, as shown in Table 5. Statements 4 and 7 were ranked as particularly important, statements 5 and 21 were ranked as less important, and statement 22 was ranked as neutral.

Discussion

This Q study aimed to investigate what sustainable engineering design students consider to be most important factors in the development of their agency for sustainability in a systemic PBL environment. The results highlight three proposed dimensions of agency from the conceptual framework, i.e. personal, action, and contextual, as important in developing students' agency for sustainability. Respectively, these three emerging factors include: 1) the professional role of engineering designers to act for SDGs; 2) the role of formal curriculum to build the foundations to act for SDGs; 3) collaboration both within and beyond the university. In line with prior studies, these results provide evidence on the complexity of student agency, and Aalborg University PBL model provides opportunities for engineering design students to develop agency for sustainability across all three dimensions of our conceptual framework (Holgaard et al., 2017; Guerra et al., 2022; Sidiropoulos, 2022). Furthermore, PBL also support students' systemic thinking on addressing sustainability problems in a more holistic and multi-disciplinary manner.

The key factors are revealed by the different opinions of 24 students: participants significantly loaded in Factor 1 consider personal elements as the most important, participants loaded in Factor 2 share opinions on both personal and action dimensions of student agency, and participants loaded in Factor 3 emphasize contextual elements. At the same time, no factor clustered shared opinions around action elements as most important, despite these being related to a formal PBL curriculum. This further indicates that student agency

Table 5 Consensus statements

No	Statement	Factor 1		Factor 2		Factor 3	
		Q-SV	Z-Score	Q-SV	Z-Score	Q-SV	Z-Score
4*	Having supervisors with competences related to SDGs	1	0,376	2	0,767	2	0,852
5	Using multiple sources of information (e.g., social media, podcast, YouTube, etc.) to know more about the SDGs	-2	-0,98	-4	-1,63	-3	-1,299
7	Being provided with courses focusing on SDGs	2	0,85	3	1	0	0,24
21	Developing shared values for sustainability among project team members	-2	-0,77	0	0	-2	-0,86
22*	Having a program that requests students to integrate SDGs in their projects	0	-0,044	0	0,136	0	0,233

*Statements flagged with an asterisk are significant at $p < 0.05$

is a complex and dynamic system, which is shaped by the interrelation of personal values, institutional and social interactions with others, resources, and even boarder communities (Jiang et al., 2022; 2023; Bandura, 2008; Mercer, 2012).

Factor 1 highlights the personal dimension of agency, with half (12 out of 24) of the students regarding SDG-related knowledge, motivations, beliefs, and positive attitudes as the most important elements in action for SDGs. This aligns with the results reported by Msengi et al. (2019) and Sidiropoulos (2022), which indicated that while only a small proportion of university students knows what sustainability is, the majority acknowledged its importance. In addition, this group considers personal motivation to be an important driver of learning for sustainability. As outlined by Concina and Frate (2023), in supporting students' personal and professional growth, one goal is to foster proactive attitudes toward sustainable development and related issues.

In our study, engineering design students expressed strong beliefs and positive attitudes about their ability to solve sustainability issues, which is a prerequisite for taking action and might have a positive correlation to students' future engagement for sustainability (Hermes & Rimanoczy, 2018; Sidiropoulos, 2022; Tang, 2018). Our prior study indicated that engineering students in general treated emotion as one of the important elements in developing student agency for sustainability (Guerra et al., 2022). Upon further examination of the hierarchy of importance assigned by this group, however, their emotions (such as their passion and feelings of being alert to SDG-related issues) are not prioritised by design students in this dimension. This might be related to the fact that Aalborg University has adopted the SDGs as guiding principles at the institutional level, but is not significantly advancing in any of the goals and not studying the modest advances in some of the goals. Students might sense this contradiction, and Sustainable Design students in particular have expressed anxiety sustainability in general and toward this cognitive dissonance in the approach to SDGs. In turn, this suggests that more effort should be put toward addressing these issues, and more research is needed to develop in-depth understanding of engineering design students' feelings and emotional responses regarding sustainability, as well as the potential influence these may have on their academic and professional decision-making.

Factor 2 highlights participants' opinions regarding personal values and the action dimension. This group demonstrated their enactment of agency through PBL projects and the curriculum, rather than self-organized extra-curricular learning activities to support their actions for SDGs. In line with prior studies, they valued being aware of sustainability issues, motivation for sustainability, integration of SDGs into their courses and projects, using SDGs as a criterion to assess and self-reflect their projects, and being provided with SDG-related courses (Akeel et al., 2019; Tang, 2018; Watson et al., 2013). Previous studies have highlighted the effectiveness of courses and projects on students' learning and agency for sustainability (Manolis & Manoli, 2021; Murray et al., 2014; Tang, 2018). Although Aalborg University adopts a variety of strategies and frameworks for addressing sustainability, all students are subjected to the pressure resulting from the fact that SDGs are external to their core programmes. Participants in this group value formal courses and educational activities delivered by the institution as the main source of information for sustainability. While PBL plays a positive role in encouraging students' learning for sustainability at Aalborg University, it is certainly not sufficient motivation in its current form for students to engage in extra-curricular activities (e.g. green competitions, student organizations, academic conferences and workshops related to sustainability, local community projects that promote sustainability, etc.) or for integrating SDGs into engineering design programmes and across the entire campus.

Thus, in order to achieve a higher level of goals and actions for sustainability, the institutions and faculty must provide a more explicitly formulated and structured environment

for their students, incorporate sustainability into campus activities, and encourage students to self-explore different sources (e.g., media, news, etc.) for sustainability, while contextualising these concepts through their problem-based project work (Aginako & Guraya, 2021; Cogut et al., 2019; Sammalisto et al., 2016).

Factor 3 is significantly distinguishable from the other two factors by its focus on the contextual dimension of agency, especially in relation to collaboration within and beyond the university. A systemic PBL approach, combined with pedagogical principles with education for sustainability, can support engineering students' development of sustainability-related competences such as collaborative learning (Manolis & Manoli, 2021; Sidiropoulos, 2022). Student designers in this group prioritized both internal collaborations within their educational institutions and external collaborations with professional communities and other student organizations. However, a prior study pointed out that it is also necessary to further investigate to what extent students are actively involved in, take action relating to, and make choices based on these SDG-related collaborative activities (Aleixo et al., 2021).

Based on cross-factor analysis, we note that both Factors 1 and 2 highlighted personal values but did focus on different aspects among these. Factor 3, on the other hand, de-emphasized personal characteristics and instead underscored contextual factors, highlighting institutional and societal influences as primary drivers for development of student agency. Despite the heterogeneity among the three factors, consensus was reached regarding the importance of statements in the action dimension, especially regarding students' co-construction, negotiation, and compromise in a collaborative environment with their supervisors and peers. This confirms the important role of the university in providing a full range of resources to support students' learning for sustainability (Dagiliūtė et al., 2018). On the other hand, there was significant disagreement among the participants regarding the importance of using multiple sources of information to learn about SDGs and of having shared values for sustainability.

Concluding remarks

Guided by a proposed conceptual three-dimensional framework for student agency for sustainability, the current study examined subjective views from 24 students in a Sustainable Design B.Sc. Program regarding the development of their agency for sustainability in a systemic PBL environment. Q methodology was adopted to collect and analyse data both qualitatively and quantitatively, leading to the identification of three significant factors among the 24 participants. These three factors revealed complex interconnections between the three dimensions of student agency, namely personal, action, and contextual.

The results of this study have several practical implications. First, one group of participants indicated that they valued personal dimensions such as motivation and an understanding of sustainability. There remains a lack of clear consensus regarding the action dimension, indicating a gap between agency in terms of personal values and agentic behaviours (Cogut et al., 2019). This has been confirmed by post-sorting activities, in which students reported little actual engagement in SDG-related actions, despite recognizing the importance of the SDGs. Therefore, institutions and educators should design more structured activities, either formal or informal, that empower students to enhance their capacities in decision-making and exercising agency for sustainability. Second, it is necessary for universities to provide faculty and students with a systematic approach or framework for engaging with the SDGs and avoid cherry-picking

strategies. In other words, universities should avoid promoting interventions and projects which favour one SDG, or even one indicator within one SDG, without considering its trade-offs or how it might detract from progress in other SDGs. Third, students not only prioritized collaborations within and beyond the university, but also valued clear institutional strategies and their role on educational policy-making within the university. This suggests the educational programmes and institutions must effectively define regulations and strategies for SDGs to guide students' project work for sustainability, and to facilitate collaboration on student projects across disciplines, institutions, and communities.

It is important to note that Q methodology provides new insights when exploring subjectivity and hierarchies of importance in design education research. However, this study has some limitations that could be addressed in future studies. First, this research remains exploratory, investigating participants' retrospective self-reflections on what they perceived as important to agency development for sustainability in their early stage of university studies, and in a sustainable development-related program. Since student agency is dynamic and not static, these results should be revisited and further examined to document the long-term development of their agency.

Second, while this study presents an overview of participants' subjective opinions, five out of 24 participants' opinions were found to be individually distinct from the others and were therefore not interpreted in this study. In addition, the complexity of students' attitudes and beliefs limit the study. Their perceptions may not only relate to their own education, but also to numerous factors outside PBL context. Therefore, follow-up studies could be conducted to further explore these individuals' opinions, in the format of individual interviews or focus groups.

Third, this study recruited a relatively small sample of first-year students in a specific Bachelor's degree programme, and 21 out of 24 participants were female students. This limits the generalizability of the study's findings. While the diversity of participant backgrounds is not a core concern in this study, we recommend that future research could explore the association of participants' demographic backgrounds (e.g., gender, academic year, program, age) to the development of student agency for sustainability. More students could be recruited representing, for example, other engineering programs beyond Sustainable Design, the Master's degree level, other academic years, and/or a more gender-balanced sample.

Fourth, these data were only collected in the context of one PBL university, which may also limit the generalizability of the results. We recommended applying our Q statements in other PBL contexts, or other problem-oriented, collaborative learning environments, and comparing the results. Finally, this Q set presents only 27 statements with a four-point scale, and it is more common in Q studies to use between 30 and 40 statements (Lunberg et al., 2020). Therefore, the Q set should be expanded for future use and should adopt at least a five-point scale in order to reduce the likelihood of neutral responses.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest to declare that are relevant to the content of this article.

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