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Systems thinking among students in sustainability programs

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Abstract

This study explores how to assess systems thinking (ST) competencies among students enrolled in sustainability-related higher education programs, with a focus on both cognitive and affective dimensions. Building on recent discussions in sustainability pedagogy, we evaluate the applicability of two existing questionnaires—Davis & Stroink (2016) and Camelia & Ferris (2018)—in interdisciplinary, non-STEM settings. Data from 65 master's students at the University of Bergen, Norway, were analyzed. Results indicate that while both instruments are usable, the affective subscales demonstrate lower reliability, which constrains their validity. Findings suggest that gender and age may be associated with certain ST dimensions, while disciplinary background is not. We argue that assessing ST before or early in courses can support curriculum design and counteract instructor assumptions about student competencies. This study provides practical insights for educators and contributes to ongoing efforts to refine assessment tools in sustainability education.

Keywords: Systems Thinking; questionnaires; Scholarship of Teaching and Learning (SoTL); sustainability education

Systemdenken unter Studierenden in Nachhaltigkeitsstudiengängen

Zusammenfassung

Diese Studie untersucht, wie Systemdenken-Kompetenzen (ST) bei Studierenden in Studiengängen mit Bezug zur Nachhaltigkeit bewertet werden können, wobei der Schwerpunkt sowohl auf kognitiven als auch auf affektiven Dimensionen liegt. Aufbauend auf aktuellen Diskussionen in der Nachhaltigkeitspädagogik bewerten wir die Anwendbarkeit von zwei bestehenden Fragebögen – Davis & Stroink (2016) und Camelia & Ferris (2018) – in interdisziplinären, nicht-MINT-bezogenen Umgebungen. Es wurden Daten von 65 Masterstudierenden der University of Bergen, Norwegen, analysiert. Die Ergebnisse zeigen, dass beide Instrumente zwar verwendbar sind, die affektiven Subskalen jedoch eine geringere Zuverlässigkeit aufweisen, was ihre Validität einschränkt. Die Ergebnisse deuten darauf hin, dass Geschlecht und Alter mit bestimmten ST-Dimensionen in Verbindung stehen können, während der fachliche Hintergrund keinen Einfluss hat. Wir argumentieren, dass die Bewertung von ST vor oder zu Beginn von Kursen die Gestaltung des Lehrplans unterstützen und den

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Annahmen der Lehrenden über die Kompetenzen der Studierenden entgegenwirken kann. Diese Studie liefert praktische Erkenntnisse für Lehrende und trägt zu den laufenden Bemühungen zur Verfeinerung von Bewertungsinstrumenten in der Nachhaltigkeitsbildung bei.

Schlüsselwörter: Systemdenken; Fragebögen; Scholarship of Teaching and Learning (SoTL); Bildung für Nachhaltigkeit

1 Introduction and Background

> "The world is a complex, interconnected, finite, ecological-social-psychological-economic system. We treat it as if it were not, as if it were divisible, separable, simple, and infinite. Our persistent, intractable, global problems arise directly from this mismatch" (Meadows, 1982, p. 101).

Acquiring Meadows' insight requires learning to think in systems. Although there is a consensus that Systems Thinking (ST) is a crucial competency in sustainability-related higher education, assessing it remains a challenge. However, without reliable assessments, the effectiveness of ST-focused teaching cannot be adequately evaluated. Accordingly, establishing baseline assessments is essential for instructors who wish to understand and improve their teaching of ST. This necessitates a measurable and pragmatic definition of ST competencies. To find answers to this challenge, we created a small interdisciplinary research group interested in ST competencies. Initial conversations revealed common interest and assumptions around assessing ST competencies and around student characteristics (such as demographic and disciplinary background variables) that influence ST. In our exchanges, we found that we lacked theoretical and empirical insight and, therefore, decided to investigate students' ST competencies as a Scholarship of Teaching and Learning (SoTL, e. g., Felten, 2003) project. Our collaboration is embedded in a wider institutional initiative to strengthen sustainability education at the University of Bergen (UiB), Norway, known as the Sustainability Education Collective (Enberg & Harlap, 2021).

1.1 Approaches to sustainability education

In the face of today's grand challenges, environmental and sustainability education (and other similar concepts) are gaining in relevance in (higher) education. A core aim is to foster integrative thinking and responsible action, both individually and collectively, for the benefit of our planet, our society, and the economy (e. g., Bianchi, 2020). Within international educational discourses, two complementary approaches to sustainability education have emerged (e. g., Vare & Scott, 2007; Wals, 2011). While the *instrumental approach* aims primarily at teaching (transmissively) *about* sustainability (course content), the *emancipatory* approach focuses on enabling students to develop key sustainability competencies, such as ST or integrated problem-solving (e. g., Brundiers et al., 2021). While we recognize the relevance of teaching sustainability-related content at all educational levels, we argue that equipping students with sustainability competencies, such as the capacity to think critically, challenge dominant narratives, experiment with new ideas, and reflect on sustainability-related discrepancies, is indispensable (Brundiers et al., 2021). Our position advocates for a synthesis of both approaches. A growing body of literature supports this dual focus and has produced several competency models and frameworks (e. g., Brundiers et al., 2021; European Commission, 2022; UNESCO, 2017). In addition to competencies such as critical thinking and integrated problem-solving, ST has emerged in these and other studies as a critical skill for addressing complex sustainability challenges. The following sections will therefore explore the concept of ST and its assessment in higher-education contexts.

1.2 Conceptualizations and teaching of Systems Thinking (ST)

Systems Thinking (ST) has been conceptualized in various ways in literature (e. g., Cabrera et al., 2008; Vachliotis et al., 2014). Despite these differences, several core concepts remain consistent: ST is a school of thought that focuses on recognizing the interconnections between the parts of a system, particularly the feedback loops, and then synthesizing them into a unified view of the whole (Senge, 1990). It aims to identify patterns that emerge from the interconnections (Booth Sweeney & Sterman, 2000; Meadows, 2009). ST requires critical and interdisciplinary thinking. It considers multiple disciplinary perspectives, analyzes their strengths and weaknesses, and integrates them into a more comprehensive understanding of the issue at hand (Voulvoulis et al., 2022). ST enables the analysis of complex systems across different domains (society, environment, economy, etc.) and across different scales ranging from local to global (Wiek et al., 2011). ST entails measurable as well as non-measurable factors (Anderson & Johnson, 1997), including values, preferences, needs, perceptions, (collective) actions, decisions, power, tactics, politics, laws, and institutions, which are central to integrated problem-solving (Wiek et al., 2011).

For our study, we adopt the definition of ST provided by Wiek et al. (2011), who describe it as the "ability to collectively analyze complex systems across different domains (society, environment, economy, etc.) and across different scales (local to global), thereby considering cascading effects, inertia, feedback loops, and other systemic features related to sustainability issues and sustainability problem-solving frameworks" (Wiek et al. 2011, p. 207).

Recognizing the importance of ST, higher education institutions increasingly embed it through a range of institutional and educational measures. Specifically, ST can be found in all recent competency catalogs for sustainability in higher education (Brundiers et al., 2021). For instance, Elsawah et al. (2021) argue that combining ST concepts and methods in teaching can effectively foster ST skills in one university-level course. However, their assessment approach relies on qualitative evaluations, such as rubrics and course assignments. While insightful, such methods are not always scalable or efficient, particularly when attempting to assess students' ST abilities on a large scale or across multiple cohorts. Thus, the need remains for more efficient, reliable, and broadly applicable methods of assessing ST competencies in higher education—particularly those that serve both formative and summative purposes in curriculum design and evaluation.

1.3 Need to assess Systems Thinking as instructors

There are at least three compelling reasons why higher education instructors should evaluate systems thinking (ST) competencies. First, they need to assess ST competencies because the demand for ST *teaching* or education is unclear. As university instructors and educational developers in the field of sustainability education, we must understand how to assess ST prior to teaching because prior knowledge (both content and process-oriented) influences how the students will process ST-related learning, as previous studies in the educational sciences have repeatedly demonstrated (e. g., Hailikari et al., 2008). This is especially relevant for programs that explicitly aim to foster sustainability competencies (cf. Grohs et al., 2018; Hiller Connell et al., 2012). A similar argument has been made for sustainability competencies in general (Briens et al., 2022; Wang et al., 2022).

Second, understanding how student characteristics relate to ST development is essential for addressing instructor assumptions and implicit biases. Teachers' beliefs about student performance can strongly influence their behavior and, consequently, students' learning outcomes (e. g., Carlana, 2018). For example, if instructors presume that female students are inherently less capable in STEM-related domains, they may unintentionally disadvantage them (Carlana, 2018; Keller, 2001). Efficient assessment tools allow instructors to empirically test their assumptions about relationships between ST and background variables, such as gender, age, or disciplinary background. While previous studies have found little to no gender differences in ST (e. g., Cruz-Sandoval et al., 2023; Camelia & Ferris, 2017), some evidence suggests age might play a limited role in specific subdimensions (Camelia & Ferris, 2017).

Third, there is an urgent need for assessing ST (and similar sustainability competencies) for evaluation and development of curricula, courses, and modules in higher education. Based on the idea of program-level assessment and curriculum development (e. g., Bramwell-Lalor, 2019; Dawson & Hubball, 2014), study programs are increasingly required to demonstrate their efficacy in strengthening the competency development of their students. However, as Voulvoulis et al. (2022) note, empirical evidence for such development remains scarce. Study-program supervisors, departments, and higher-education institutions thus have a need to assess ST competency data at the outset of a program and at several points throughout the program, especially when these are centered on ST. In conclusion, there is a clear and urgent need for reliable, efficient tools to assess ST competencies in higher education. Yet, despite increasing interest, few of the existing methods are suitable for use across disciplinary boundaries and educational contexts.

1.4 Assessment of systems thinking

While several measures to assess ST have been published, few publications have offered comprehensive overviews or comparative analyses of these processes. In this section, we summarize the findings from relevant reviews, with a more detailed analysis of specific measures provided in the Results section. First, while Redman et al.'s (2021) systematic literature review of measures for assessing students' sustainability competencies does not explicitly focus on ST, it can be indicative of the wider assessment landscape. This review included publications up until 2019, and it identified eight types of measurement, grouped into three primary categories: (1) self-perception, including scaled self-assessment, reflective writing, and focus groups/interviews; (2) observation, including performance observation and regular coursework; and (3) test-based approaches, including concept mapping, scenario/case tests, and conventional tests.

Second, and more specifically for ST students, York et al. (2019) conducted a review of ST measurements in STEM education, published between 2000 and 2019. Their analysis yielded three measurements: (1) assessment rubrics for concept maps, conceptual models, and written text; (2) closed-ended measures, including text in box diagrams and two kinds of multiple-choice questionnaires; and (3) coding schemes for text responses, such as interview transcripts and written statements. According to these authors, and partially supporting the findings of Redman et al. (2021), these measure categories differ in terms of both their scalability (the multiple-choice type being the most scalable) and their resource use.

Finally, Dugan et al.'s (2022) review on measures for ST in engineering yielded distinct assessments. The authors classified the measures in four assessment types: (1) behavior-based, including assessments of student performance; (2) preference-based, including assessment of values, interest, attitude, and aptitude; (3) self-reported, including indirect assessment of learning gains; and (4) cognitive activation, including a neuroimaging assessment. In addition to these assessment types, Dugan et al. (2022) also classified the measurements by their format, yielding mapping, scenario, open-ended, oral, fill-in-the-blank, multiple choice, virtual reality, and neuroimaging formats. Interestingly, the measures were oriented towards different education levels and disciplinary backgrounds: "Sixteen of the 27 assessments targeted professionals and/or postsecondary students in engineering. Seven targeted postsecondary students not in engineering, five targeted high school students, three targeted pre-high school students, and one targeted an unspecified education level of organic chemistry students" (Dugan et al., 2022, p. 845).

These reviews indicate on a whole that existing ST assessments vary widely in format, scope, and intended audience. In education, ST measures have primarily been employed for STEM students, with fewer measures in place for students in other disciplines. The reviews also include estimates of suitability for multiple uses, such as the finding that the effort required to administer the measurement may be more relevant for use in education (Dugan et al., 2022) and that closed-ended measures, such as multiple-choice questionnaires, may be the most scalable (e. g., York et al., 2019).

Even after these extensive reviews, it still remains unclear which specific measurement tools are most suited for assessing students' ST outside of the natural sciences and engineering fields. It can therefore be concluded that there is a need for efficient and reliable measures for assessing students' general ST competencies. Additionally, there is an acute need to understand students' prior ST-related knowledge and to determine whether students' demographic characteristics, such as gender and age, are related to ST.

1.5 Research questions

Building on the previous discussion, we formulated the following research questions (RQs):

RQ 1: How applicable are existing ST instruments, originally developed in STEM contexts, for assessing cognitive and affective ST competencies in interdisciplinary sustainability programs?

RQ 2: How are students' ST competencies related to demographic characteristics, and what are the implications for teaching?

RQ 2.1: Are there gender-related differences in ST competencies?

RQ 2.2: How does age relate to ST competencies?

RQ 2.3: Do students' disciplinary backgrounds shape their ST competencies?

2 Methods

2.1 Research approach and environment

As a group of three, we conducted a collaborative Scholarship of Teaching and Learning project (SoTL, e. g., Felten, 2003; Hutchings & Huber, 2008). SoTL, broadly defined, constitutes systematic inquiry by university instructors into their own teaching practice and/or their students' learning, grounded in empirical evidence and oriented toward the iterative improvement of teaching within its specific institutional context (Felten, 2013). As such, it extends beyond personal reflection, as findings are made public and subject to peer scrutiny, lending the inquiry a cumulative, community-facing dimension. For the environment for collecting data, we chose UiB. This university offers a unique master program exclusively dedicated to system dynamics and modeling. This program provides an exceptional opportunity to investigate the competency development of students in ST. Furthermore, UiB has recently introduced an interdisciplinary master program in sustainability, deeply rooted in the principles of ST, as an integral component of sustainability education (UiB, n. d.).

2.2 Review of ST measures

To identify, evaluate, and synthesize the existing research on methods for measuring ST, we conducted an unsystematic quick literature review (Sutton et al., 2019) with two exclusion steps. We searched in the UiB library databases, including *ERIC* and *PsycInfo* as well as *Google Scholar,* with the search terms *systems thinking, instrument, assessment,* and related terms. We included English publications from the last 20 years (2005 through 2025) that presented a new or revised ST measure. We excluded publications focused solely on theory development, reuse of existing measures, overviews, and reviews.

2.3 Participants

We applied the two measures we had found to be applicable to $N = 65$ students at UiB, taught by one co-author. These students were enrolled in the Master's degree program in *System Dynamics* (in fall 2023: $n = 29$, 10 female; in fall 2024: $n = 11$, 6 female) and a course on ST in the Master's degree program in *Sustainability* (in spring 2024: $n = 25$, 17 female; in spring 2025: $n = 6$, 6 female) at UiB. They completed two different measures at the beginning of each semester (August 2023 and 2024 as well as January 2024 and January 2025) during a compulsory attendance event. Their mean age in years was $M = 29.36$ ($SD = 7.65$, Min = 20, Max = 61), and their mean work experience in years was $M = 8.91$ ($SD = 6.54$, Min = 0, Max = 30). The four groups did not differ significantly with respect to age ($p = .91$) nor work experience ($p = .69$). All students participated voluntarily and anonymously and provided informed consent where they, among others, were informed that their participation would not influence their study progress or success in the respective courses. The project was registered with the university's system for risk and compliance.

2.4 Data analysis

We analyzed the empirical data using SPSS29. The analysis included descriptive statistics, scale computations according to the original author's guidelines, internal consistency estimations, and correlation analyses. To test for differences between study programs in which the students were enrolled, we qualitatively categorized the study programs based on both their location in the university's faculties and whether the study program title contained any ecologically related terms, such as "environment" or similar.

3 Results

We first present the ST measures we have found and selected, followed by the statistical analyses regarding gender and disciplinary variations of ST, as well as the relationship between age and ST.

3.1 ST measures

Our literature review identified 15 publications that met the inclusion criteria outlined above. To evaluate each tool's suitability, we categorized each of these publications according to the following criteria in a collective effort with several revisions:

1. This measure yields quantitative results while excluding methods that produce qualitative results, e. g., qualitative interpretation of concept maps, qualitative analysis of interview data, etc.
2. This measure was designed to assess general ST while eliminating measures for discipline-specific ST aspects, e. g., engineering- or chemistry-specific ST, making it suitable for the current context. While our search process was relatively extensive, we are aware that there may have been additional measures that we did not include in the following table.
3. This measure assesses the potential economic impact on a (potentially) larger number of students in a higher-education setting.

Tabelle 1: Publications with Measurement Tools for Assessing Systems Thinking and Criteria Fulfillment

No.	Author(s) and year	Characterization	1) Quantitative results	2) Domain-general ST assessment	3) Economic use
1	Ateskan & Lane (2018); Dolansky et al. (2020), based on Moore et al. (2010)	Systems Thinking Scale (STS); 20 Likert-scale items	X	X	X
2	Cabrera et al. (2023)	Systems Thinking and Metacognition Inventory (STMI); ten dimensions (skills and confidence)	X	X	— (high costs)
3	Camelia & Ferris (2016), partially based on Frank (2010); used in Camelia & Ferris (2018) and Camelia et al. (2018)	Survey questionnaire; 30 Likert-scale items, five subscales, affective ST domain	X	X	X
4	Davis & Stroink (2016), based on Randle & Stroink (2012); used in Randle & Stroink (2018) and Thibodeau et al. (2016)	Systems Thinking Scale Revised (STSR); self-report questionnaire, 15 items; cognitive aspects of ST	X	X	X
5	Dorani et al. (2015)	Six open-ended items assessing six ST skills	—	X	X

(Fortsetzung Tabelle 1)

No.	Author(s) and year	Characterization	1) Quantitative results	2) Domain-general ST assessment	3) Economic use
6	Frank et al. (2007), used in Frank (2010) and Frank & Kordova (2015)	Capacity for Engineering Systems Thinking Inventory (CEST); 48 (40) pairs of statements, interest inventory	X	—	X
7	Grohs et al. (2018)	Scenario-based, rubric-driven tool	X	X	— (qualitative interpretation)
8	Hadgraft et al. (2008)	Survey; 42 scale items and three open-ended items; self-reported skill and course evaluation	X (partial)	—	X
9	Hiller Connell et al. (2012)	Case-study-based, rubric-driven assessment of holistic thinking and conflict resolution	X	X	— (qualitative interpretation)
10	Hung (2008)	Survey tool; ten open-ended questions; rubric-driven evaluation of system modelling exercise	X (partial)	X	— (qualitative interpretation)
11	Jaradat (2014), used in Castelle & Jaradat (2016) and Jaradat et al. (2019)	Systems Thinking Questionnaire; self-report, 39 binary items	X	X	X
12	Lavi & Dori (2019), further developed in Lavi et al. (2021)	Conceptual modeling assignments with Object-Process Methodology (OPM); Systems Thinking Assessment Rubric (STAR)	X	X	— (qualitative interpretation)
13	Sibley et al. (2007)	Box diagrams assessing systems thinking about rock, water, and carbon cycles	?	—	— (qualitative interpretation)
14	Tripto et al. (2013)	Concept map; rubric-driven analysis based on Systems Thinking Hierarchy Model (STH); biology domain	X	—	— (qualitative interpretation)
15	Vachliotis et al. (2014)	Tool with 22 System Assessment Questions (SAQ); rubric-driven analysis	X	—	— (qualitative interpretation)

Note. Criteria fulfillment is indicated by X; — indicates criterion not met or not applicable.

The table indicates multiple variations in ST measures: First, there is a range of diverse approaches to qualitative data analysis methods, from quantifying qualitative data (e. g., in rubrics) and quantitative methods (e. g., Likert scales in self-report measures [3]) to mixed-method approaches (e. g., combining open-ended questions with scales [8]). Second, the measures vary regarding their domain-specificity: While some methods are used within and for domain-specific ST (e. g., in biology [14]), others aim more towards generic ST (e. g., [1]). Third, the measures are aimed at different populations:

Some measures have been developed for students in education contexts (e. g., [13]), while others focus on people outside of these contexts (e. g., engineers [6]).

Of the remaining measures that fulfilled all criteria (see Table 1), we selected those that were based on Likert-scale items, excluding alternative variants (e. g., [11]). Three measures remained: numbers [1], [3], and [4]. Of the two *Systems Thinking Scales* ([1] and [3]), we decided on the revised version since we had doubts about the equidistance with the frequency-oriented Likert scale of 1 (cf. Redman et al., 2021, p. 123). This choice came with the additional advantage that the measures cover several aspects typically discussed in higher education: cognitive and emotive aspects.

The questionnaire developed by Davis & Stroink (2016, 15 items) has also been used by other authors and was found to be reliable (e. g., Thibodeau et al., 2016). According to its authors, it captures cognitive aspects of ST, and it is based on self-report measures. The authors define ST as a "transdisciplinary construct that has been promoted as a means of being able to better comprehend and mitigate complex social-ecological dilemmas" and that "has been argued to be essential for perceiving and understanding the behavior of complex adaptive systems" (Davis & Stroink, 2016, p. 576). This understanding resonates with our thoughts about ST that are also visible in UiB study programs taught by B. Kopainsky. In addition, these authors follow the cognitive paradigm regarding ST, describing it as "worldview, which encompasses core beliefs, values, and assumptions concerning reality and guides personal or societal philosophies and epistemologies" (Davis & Stroink, 2016, p. 576). This approach stresses the importance of both cognitive and rational aspects and includes these in a larger construct that is relevant for life in general, rather than being limited to a single course or study program students may pursue. Accordingly, the 15 items in the Davis & Stroink (2016, revised) questionnaire include aspects that can be relevant to many different life domains, ranging from personal decision-making to societal changes and earth systems.

In contrast, the revised questionnaire by Camelia & Ferris (2018) assesses a student's ability to learn ST in a particular domain. Initially developed and validated by Camelia, Ferris & Cropley (2018), it features a five-factor solution and consists of 30 items across two available versions (these versions differ with respect to the negated formulation of some of these items; in this instance, we chose to use Version 2). In several exploratory and confirmatory analyses, Camelia & Ferris (2018) found that a three-factor solution had higher construct validity. The factors are defined as *Preference or inclination towards whole of system perspective* (Scale 1), *Interest in the intended purpose or application of the system under consideration or development* (Scale 2), and *Inclination towards and participation in seeking a coherent, whole, system solution* (Scale 3). They assess both attitudinal aspects (preferences) and further motivational aspects (interest) and complement the cognitive focus assessed by Davis & Stroink (2016) with an, in our view, equally important aspect of ST competencies.

3.2 Scale reliability

In our sample, both questionnaires effectively assessed the overall reliability of the scales, where the questionnaire by Davis & Stroink (2016) reported a Cronbach's α of .72. Additionally, the three dimensions identified by Camelia & Ferris (2018) partially indicated borderline Cronbach alphas, as indicated in Table 2.

Tabelle 2: Internal Consistency for the Scales as Defined by Camelia and Ferris (2018)

Scale	Cronbach's α
Scale 1: Preference or inclination towards whole-of-system perspectives	.62
Scale 2: Interest in the intended purpose or application of the system under consideration or development	.72
Scale 3: Inclination towards and participation in seeking a coherent, whole-system solution	.63

While Scales 1 and 3 fall slightly below conventional thresholds, they are nevertheless acceptable for exploratory studies. All intercorrelations between the Davis & Stroink scale and the Camelia & Ferris subscales were significant (Spearman's $\rho > 0.39$, $p \leq .001$), indicating that while constructs overlap they remain distinct.

3.3 Gender differences

The Davis & Stroink (2016) scale showed no significant gender differences, with $F(1,66) = 0.09$, $p = .77$, $M_{\text{male}} = 5.69$, $SD_{\text{male}} = 0.65$, $M_{\text{female}} = 5.74$, and $SD_{\text{female}} = 0.65$. For the Camelia & Ferris (2016) data, we ran a repeated-measures ANOVA using the within-subjects factor Scale (3) and the between-subjects factor Gender (2). This analysis revealed a significant main effect of scales, $F(2,60) = 20.03$, $p < .001$, $\eta_p^2 = 0.38$, indicating that Scales 1 and 2 had higher values than Scale 3. The main effect Gender was not significant, $F(1,66) = 0.27$, $p = .60$. However, the interaction effect between scales and gender was significant, $F(1,66) = 7.25$, $p = .009$, $\eta_p^2 = 0.099$, which warranted further contrasts between the genders for each scale. This additional analysis yielded significant gender differences for Scale 1, Preference or inclination towards whole of system perspectives: $F(1,66) = 6.63$, $p = .01$, $\eta_p^2 = 0.091$; $M_{\text{male}} = 5.57$, $SD_{\text{male}} = 0.88$, $M_{\text{female}} = 6.07$, $SD_{\text{female}} = 0.74$. Female students had higher values for this scale than male students. For the other two scales, gender differences were not significant: $F\text{s} < 0.8$, $p\text{s} > .37$.

3.4 Relations with students' age

Correlation analysis of both scales with students' age yielded a marginally significant relationship with the Davis & Stroink (2016) scale: $r(69) = -0.21$, $p = .09$. This finding suggests that younger students tended to have higher values on their ST. In contrast, the three scales by Camelia & Ferris (2018), showed no significant relationship with age: all $r\text{s} < 0.17$, $p\text{s} > .18$.

3.5 Differences between students' disciplinary backgrounds

For testing differences between the disciplinary backgrounds, we conducted two analyses. First, we compared the student group that was enrolled in the Master's degree program in System Dynamics (assessed in August 2023 and in August 2024) with the one that took the course on ST in the Master's degree program in Sustainability (assessed in January 2024 and in January 2025). The Davis & Stroink (2016) questionnaire scale indicated no significant differences between the two groups: $F(1,62) = 1.83$, $p = .17$. The repeated-measures ANOVA with the within-subjects factor Scales (3) and the between-subjects factor master program (2) for the Camelia & Ferris (2016) data revealed a significant main effect of Scales, $F(2,66) = 21.79$, $p \leq .001$, indicating that Scales 1 and 2 had higher values than Scale 3. However, the main effect master program was not significant, $F(1,67) = 0.34$, $p = .97$, nor were the interaction effects between the factors, $F(2,67) = 1.12$, $p = .33$ (linear) and $F(2,67) = 0.34$, $p = .71$ (quadratic).

Second, we tested whether ST differed between the UiB faculties the students were enrolled in. Only the Faculty of Natural Sciences and Technology ($n = 27$) and the Faculty of Social Sciences ($n = 34$) were represented with more than two students. An ANOVA indicated no difference between the two faculties for the Davis & Stroink (2016) scale, $F(1,59) = 1.80$, $p = .18$. The repeated-measures ANOVA for the Camelia & Ferris (2016) data, with the within-subjects factor Scales (3) and the between-subjects factor Faculties (2), revealed only a significant main effect of Scales, $F(2,58) = 18.48$, $p < .001$, $\eta_p^2 = 0.39$, indicating that Scales 1 and 2 had higher values than Scale 3. The main effect Faculties was not significant, $F(1,53) = 0.39$, $p = .54$, but the linear interaction effect between the factors was marginally significant, $F(1,59) = 2.99$, $p = .09$, indicating that the students at the Faculty of Social Sciences had slightly higher values than the other students for Scale 1. To test the hypothesis that this finding is due to the fact that the Faculty of Social Sciences sample had a higher proportion of female students (48 %) than the Faculty of Natural Sciences and Technology (35 %; see the finding with gender above), we ran the same repeated-measures ANOVA again with gender as a covariate. This additional analysis yielded no significant interaction between Scales and Faculties (Fs < 1.9, ps > .18).

4 Discussion

4.1 Summary and interpretation of findings

The findings of this study offer a better understanding of ST competencies among university students enrolled in sustainability programs. First, related to our review of ST assessment methods, it is interesting that our findings do not completely match the findings by previous reviews (e. g., Dugan et al., 2022; York et al., 2019). There are some measures that our analysis includes that are not present in the other reviews (e. g., Davis & Stroink, 2016), while others were present in their findings but did not show up in our review (e. g., Degen et al., 2018). This difference could be explained by both the different study aims and methodologies (e. g., keywords) and access to publications. In our view, the divergence in findings calls for more updated efforts to systematize ST assessment, specifically in educational contexts. Nonetheless, our rapid review confirms the fragmented and varied nature of current ST measurement approaches and highlights the need for a more coherent framework, particularly in educational settings.

Second, the application of two questionnaires—Davis & Stroink (2016) and Camelia & Ferris (2018)—provided valuable insights into different dimensions of ST, including cognitive and affective components. Both measures demonstrated sufficient reliability, though some limitations were observed with the Camelia & Ferris scales, particularly regarding their internal consistency. While the Davis & Stroink (2016) questionnaire offered a more consistent measure of cognitive ST, the affective dimensions measured by Camelia & Ferris (2018) presented a more nuanced understanding of how students perceive and engage with ST from a motivational and attitudinal perspective. The intercorrelation between the scales indicates an overlap as well as specific aspects (cognitive in Davis & Stroink, 2016, affective in Camelia et al., 2018). Cognitive and affective components are related, yet each dimension adds unique value in understanding how students approach ST in sustainability education.

The third major finding concerns the (marginally significant) gender difference in one of the Camelia & Ferris (2018) scales, with female students scoring higher in their preference for whole-system perspectives. This result adds a new layer to discussions about gender and cognitive-emotional engagement in sustainability education. Previous studies, such as Cruz-Sandoval et al. (2023), did not find statistically significant gender differences, however, those studies primarily focused on cognitive aspects of ST. The current study suggests that when both cognitive and affective dimensions are considered, gender differences may emerge, particularly in how students orient themselves toward system-level thinking. This finding invites further investigation into whether these gender differences are consistent across larger samples and whether they persist in different learning contexts.

The fourth notable finding is the negative correlation between students' age and their cognitive ST abilities. Younger students demonstrated higher levels of ST on the Davis & Stroink (2016) scale, which suggests that the capacity to engage with complex systems cognitively may diminish slightly with age. This could reflect differences in exposure to ST-related curricula at different stages of students' academic careers or developmental shifts in how students approach problem-solving over time. However, the lack of age-related differences in the affective dimensions of ST suggests that motivational factors, such as interest in applying ST to real-world problems, remain stable across age groups. The finding could also be interpreted with respect to how a specialized higher education system might impact student thinking: The focus on disciplinary silo teaching regarding sustainability issues might reduce students' ST competences.

Interestingly, no significant differences were found between students based on their disciplinary backgrounds, neither between the specific study programs (Systems Dynamics vs. Sustainability) nor between UiB faculties. These findings challenge possible stereotypes about ST being more prevalent or better developed in students from some disciplines vs. others. ST seems to be distributed independently from disciplinary backgrounds, at least in this sample.

Taken together, these results provide a clearer picture of who the typical ST student is—or, more accurately, who they are not. Contrary to possible assumptions, ST competencies do not appear to be significantly shaped by students' disciplinary backgrounds, however, age and gender might play a role with ST. This reinforces the idea that ST education should be broadly accessible and applicable across a range of disciplines and demographic profiles. Moreover, it supports the argument that sustainability education needs to move beyond rigid categories of learner profiles and instead focus on the individual development of competencies across diverse student groups.

4.2 Implications for future research

The study opens several avenues for future research. The relatively small, yet diverse sample size and the self-selected nature of the participants call for larger sample sizes and a broader demographic spread that could help verify whether the trends observed here hold true in more diverse contexts. Future studies should also consider conducting factor analyses to confirm the dimensional structure of the Camelia & Ferris (2018) questionnaire, as the results from this study indicated some inconsistencies in internal reliability. In addition, the relationship between ST and other personal or contextual variables, such as students' professional backgrounds or the specific content of their prior education, remains underexplored. Given the importance of ST in addressing global sustainability challenges, it would be valuable to investigate how prior experiences and external factors influence the development of ST competencies, especially in interdisciplinary contexts. More generally, defining ST as an ability that assesses complex and relational thinking vs. assessing it through individual self-reports could create a theoretical tension, as suggested by an anonymous reviewer. Future studies could therefore explore possible measures that fulfill both the relational nature of ST, beyond an assessment in individuals, as well as its efficient and quantitative assessment suitable for instructors. To our best knowledge, there are currently no such measures available.

4.3 Implications for teaching ST and SoTL

The findings of this study offer several preliminary yet practical implications for sustainability educators, program designers, and SoTL researchers. First, our results underscore the value of pre-course assessments of systems thinking (ST). By measuring ST competencies before students begin a course or program, instructors can better understand the heterogeneity of student backgrounds and tailor teaching strategies accordingly. This practice allows educators to differentiate instruction, for example, by providing additional scaffolding for students with limited prior exposure to systems concepts, or by designing advanced challenges for those who demonstrate stronger competencies. Such early diagnostics also help counteract implicit assumptions instructors may hold about their students—for instance, that disciplinary background or gender predicts ST ability—by grounding course design in actual data rather than stereotypes.

Second, the study highlights the importance of balancing cognitive and affective dimensions of ST in teaching and curriculum development. The Davis & Stroink (2016) scale captured cognitive aspects such as recognizing feedback loops and system interconnections, while the Camelia & Ferris (2018) questionnaire emphasized affective components like preferences and motivations for whole-system perspectives. Both dimensions matter: cognitive abilities enable analytical engagement with sustainability challenges, whereas affective dispositions motivate sustained interest and commitment to systems-level solutions. Educators should therefore employ teaching approaches and methods that combine conceptual analysis with reflective and experiential activities (e. g., project-based learning, working with case studies). For example, system mapping exercises could be paired with group discussions on the values and purposes driving systemic interventions, thereby strengthening both rational and motivational aspects of ST.

Third, the results call for educators and program leaders to challenge assumptions about student profiles. Contrary to common stereotypes, ST competencies did not differ significantly by disciplinary background in our sample, suggesting that ST is not exclusive to students in the natural sciences or engineering fields. At the same time, gender and age showed nuanced associations with ST dimensions, although these effects were modest. The key implication is that educators should avoid generalizations based on demographic categories and instead adopt inclusive teaching strategies that recognize individual variability. This reinforces the need for higher education institutions to design sustainability curricula that are accessible and relevant across disciplinary and demographic boundaries.

From a SoTL perspective, the study contributes by testing and critically reflecting on the applicability of existing instruments in non-STEM higher education contexts. However, the limitations in the reliability of some subscales also illustrate the need for ongoing instrument development and validation. Future SoTL research should systematically investigate the psychometric properties of ST measures with diverse student groups and ideally employ longitudinal designs to track how ST competencies evolve over the course of an entire degree program. Moreover, cross-institutional comparisons would provide valuable insights into how institutional and cultural contexts shape ST development.

Taken together, these findings imply that effective sustainability education requires more than just delivering system-specific knowledge. It involves creating learning environments that foster both cognitive mastery and affective engagement, are sensitive to diverse learner profiles, and are guided by evidence from systematic assessment. By integrating assessment into teaching practice and curriculum design, higher education institutions can more effectively prepare students to address the complex challenges of sustainability in both their professional and civic lives.

4.4 Methodological limitations

While this study provides valuable insights, several limitations must be acknowledged. First, the rapid, unsystematic literature review employed limits the comprehensiveness of the ST measures considered. Second, the conclusions are limited by the data collection within one specific geographical, institutional, and temporal context. It remains to be seen whether the results will be the same at other institutions. Additionally, the sample size of the present study was relatively small, and the self-selection of participants raises questions about the representativeness of the findings. Future studies with larger and more diverse samples are necessary to confirm the generalizability of these results. Another limitation lies in the measures themselves: While both the Davis & Stroink (2016) and Camelia & Ferris (2018) questionnaires provided useful data, the low reliability of some scales indicates that further refinement and validation are needed. A systematic approach to measuring ST that incorporates both quantitative and qualitative tools would allow for a more holistic understanding of how students engage with ST, but it could undermine its economic viability for university lecturers.

4.5 Conclusion

Assessing students' sustainability-related competencies, such as ST, is essential to understanding how students engage with their study programs. This study demonstrated that both cognitive and affective dimensions of ST can be effectively measured using existing tools, although further validation is needed. To track the development of student ST over time and across different academic settings, we are currently planning further longitudinal studies using the same measures and students, as well as some new student cohorts. We invite all colleagues in these programs and beyond to assess ST and other sustainability-related competencies of university students before they begin courses so that they can tailor their teaching and programs to the students' prior knowledge.

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