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ORIGINAL ARTICLE

Current practice of assessing students' sustainability competencies: a review of tools

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Abstract

While there is growing agreement on the competencies sustainability professionals should possess as well as the pedagogies to develop them, the practice of assessing students' sustainability competencies is still in its infancy. Despite growing interest among researchers, there has not yet been a systematic review of how students' sustainability competencies are currently assessed. This review article responds to this need by examining what tools are currently used for assessing students' sustainability competencies to inform future practice. A systematic literature review was conducted for publications through the end of 2019, resulting in 75 relevant studies that detail the use of an assessment tool. We analyzed the described tools regarding their main features, strengths and weaknesses, as well as potential improvements. Based on this analysis, we first propose a typology of eight assessment tools, which fall into three meta-types: self-perceiving, observation, and test-based approaches, providing specific examples of practice for all tools. We then articulate strengths and weaknesses as well as potential improvements for each tool (type). This study structures the field of sustainability competency assessment, provides a criteria-based overview of the currently used tools, and highlights promising future developments. For the practice, it provides guidance to sustainability (science) instructors, researchers, and program directors who are interested in using competencies assessment tools in more informed ways.

Keywords Sustainability competencies · Assessment · Evaluation · Tools · Methods · Learning outcomes

Introduction

The world is in urgent need of competent professionals to contribute to societal transformations towards sustainability (Gordon et al. 2019), and educational institutions ought to prepare students for these roles (Barth 2016; Franco et al. 2019). In response to this challenge, there has been a proliferation of sustainability science programs (O'Byrne et al. 2015), which increasingly define the learning objectives for their students in terms of sustainability competencies (Salovaara et al. 2020). Competencies are "complex combination[s] of knowledge, skills, understanding, values, attitudes and desire which lead to effective, embodied human action in the world" (Crick 2008). There is increasing agreement on the set of key competencies in sustainability (Redman et al. 2020), namely, systems-thinking, futures-thinking, values-thinking, strategic-thinking, and interpersonal competencies (Wiek et al. 2011)). Similarly, scholars and educators have started to converge on effective and efficient pedagogies to develop these competencies (Brundiers et al. 2010; Frisk and Larson 2011; Barth and Michelsen 2013).

Yet, the practice of assessing students' sustainability competencies is still in its infancy (Waltner et al. 2019). A broad range of assessment tools are currently in use for both research and instructional purposes (Cebrián Bernat et al. 2019). However, these tools are rarely selected with clear and informed intention, largely due to a lack of guidance in the literature (Besong and Holland 2015). Despite a

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growing body of research describing innovative pedagogies (Hallinger and Chatpinyakoop 2019), there is a shortage of empirical evidence of whether and in what ways these pedagogies are successful in developing students' sustainability competencies (Osagie et al. 2016; Mindt and Rieckmann 2017; Garrecht et al. 2018). Meanwhile, course instructors, curriculum designers, and program directors lack the means to effectively assess whether or not they are successfully educating sustainability professionals through their courses and programs, which is a core purpose of assessment (Kuh et al. 2014). This is a significant gap when it comes to constructive alignment (Biggs 1996) and putting all critical components of sustainability (science) education in place (Fig. 1). As this figure illustrates, reliable and valid tools for assessing competencies, which is the focus of this article, fulfill an important function in supporting structured teaching efforts and student learning for sustainability.

Education science researchers have called out traditional methods of assessment as inadequate for measuring multidimensional and performance-oriented competencies (Frey and Hartig 2009). Traditional assessments are already challenging for experts to create and apply properly (Reckase 2017) and adequate assessment of competencies even more so (Leutner et al. 2017). Nonetheless, much exploratory work on assessing competencies has begun (Hartig et al. 2007), though a review found that progress on competency assessment was limited, particularly in the non-cognitive dimensions (Zlatkin-Troitschanskaia et al. 2015). For sustainability competencies in particular, Barth (2009) provided a conceptual framing, and sporadic if increasing efforts to develop tools has been undertaken by individual instructors and researchers around the world (Cebrián Bernat et al. 2019). This growing body of research has yet to be brought together in a systematic review which compares the existing tools and provides guidance to instructors, researchers, and program directors.

This review article examines what tools are currently used for assessing students' sustainability competencies, as documented in the literature through the end of 2019. We conducted an in-depth analysis of a comprehensive sample of peer-reviewed publication ($N = 75$) and distilled a typology of assessment tools for sustainability competencies. We also evaluate strengths and weaknesses of these tools and offer avenues for improvements. The article provides guidance to instructors, researchers, and program directors who are interested in using competencies assessment tools in more informed ways.

Research design

To review literature on assessing students' sustainability competencies thus far, we systematically collected publications from SCOPUS, Web of Science, ERIC, and Google Scholar, published in English through 2019 resulting in a first pool of 3908 publications. Following Moher et al.'s (2009) and Fink's (2014) systematic review approaches, we then iteratively excluded publications by first reviewing the titles, then abstracts and finally the full text. This yielded 75 publications focused on sustainability competencies assessments (see appendix for a full description of procedures). For this sample, Fig. 2 shows the steady growth of publications on sustainability competencies assessments over the last 10 years. However, they still only represents less than 7% of the sustainability (science) education research field as reviewed in 2017 (Grosseck et al. 2019). The publications come from 35 outlets, yet, research took place almost exclusively in OECD countries (93%) and at higher education

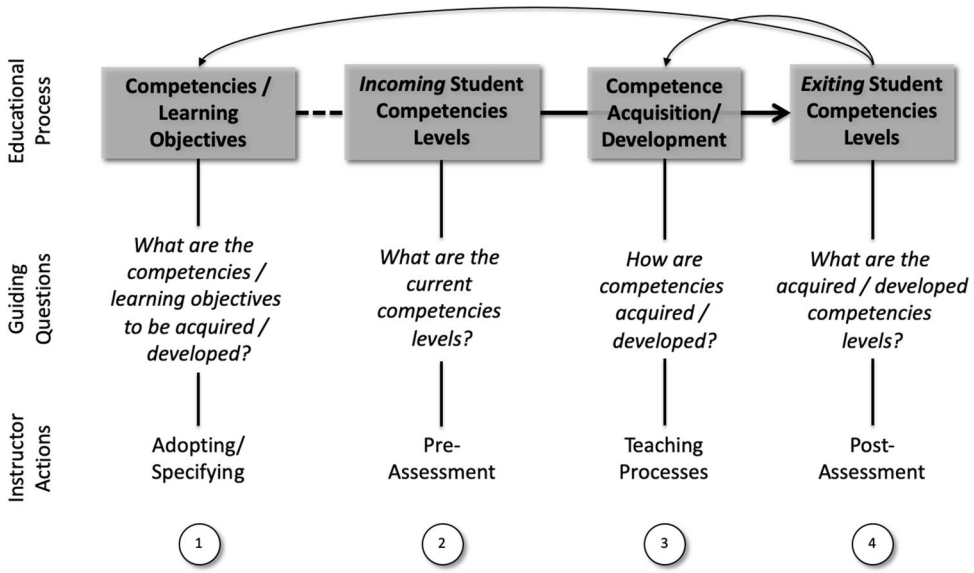

Fig. 1 Framework which indicates the crucial role assessment plays in supporting student learning

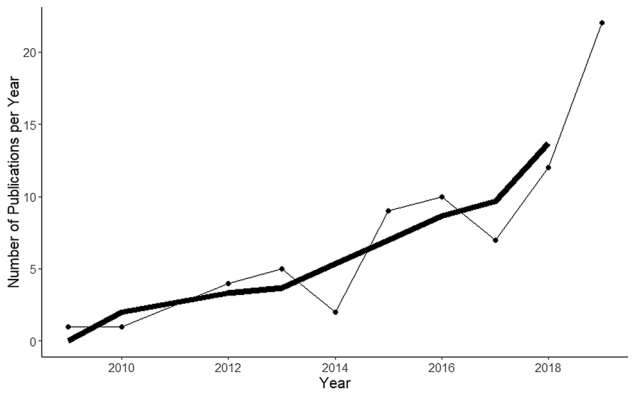

Fig. 2 Publications on sustainability competencies assessments per year in final sample (solid line is rolling 3-year average)

institutions (87%). Sustainability/environmental degree programs, teacher training, general education, and business/management education were the most frequent foci areas of the studies. Research on assessment in sustainability (science) education appears to likely be in its emergent growth phase, trailing the pattern of research growth in sustainability science by about 15 years (Fang et al. 2018).

In reviewing the sampled literature, we identified 121 total tools in use (many of the 75 reviewed studies used more than one tool), which we classified into eight distinct types of tools currently being used to assess students' sustainability competencies. To be clustered into a type, a tool has to have a record of several applications (with documentation). We disregarded terminological differences in cases, where authors used different names for the same tool. We first generalized the descriptions to cover all specific tools under each type and then standardized the descriptions to make the tools comparable (Table 1). We then analyzed each tool (type) independently and in contrast to each other using a set of common attributes (Table 2). We finally appraised strengths and weaknesses of each tool (type), as well as explored potential improvements (Table 3). This appraisal was informed by insights on competencies assessments gleaned from the broader educational literature.

Typology of tools for competencies assessment

Instructors use a wide variety of tools for assessing students' sustainability competencies (121 in total were identified from this sample). They can nonetheless be clustered into eight major tools (types) (Table 1), currently in use. Some of these types are quite broad (e.g., reflective writing), while others are narrower, but also more refined (e.g., concept mapping). Many studies used more than one tool ($n = 31$) with scaled self-assessment being disproportionately represented among these (80%) when compared to the overall sample (56%). Generally, there were only few cases, where a single tool was developed over multiple publications. The exception to that was the scenario/case test type, where four tools were iteratively developed over 14 publications.

We first present examples of each tool (Table 2). These examples were chosen based on three criteria: (1) representativeness of tool, (2) clarity of description in publication (a frequent deficiency), and (3) if they used the competency framework articulated by Wiek et al. (2011). We chose to purposefully select examples which use the same key competencies, so that comparability between tools is enhanced. In our sample, the Wiek et al. (2011) framework was the only one used across enough studies to make this possible, besides it being highly influential on the broader field of sustainability (science) education as noted in other reviews (Grosseck et al. 2019). However, it is not possible to conduct a comprehensive meta-analysis of assessment results due to the diversity of what is being assessed, i.e., the specific sustainability competencies targeted.

The examples are drawn from a single source for each tool. They are described by two sets of characteristics: one for the tool itself and one for its application. The table can

Table 1 Currently used tools for assessing students' sustainability competencies (with frequency)

Tool	Brief description	*N*
Scaled self-assessment	Students are asked to rate their own competency development based on a pre-determined scale	42
Reflective writing	Students respond in writing to prompts reflecting on their competency development	17
Scenario/case test	Students are presented with a case and asked to respond to specific competency-requiring prompts	16
Focus group/interview	Students respond to prompts verbally reflecting on their competency development	15
Performance observation	Students are evaluated for competency while carrying out course activities in or out of the classroom (e.g., professional setting)	11
Concept mapping	Students are given a prompt and asked to create a two-dimensional image with nodes and connections (specific to systems-thinking competence)	7
Conventional test	Students take a test which may include multiple choices or short answers which are linked to competencies	7
Regular course work	Students complete regular course work which is analyzed for evidence of competencies	6

Table 2 Examples of each assessment tool with description and application

Tool	Example tool used				Example tool application					Source
	Competencies	Assessment data	Testing time	Analysis	Location	Program	Part	Timespan	N^a	
Scaled self-assess-ment	Framework from Wiek et al. (Wiek et al. 2011)	Students are asked to rate their agreement with three statements for each competence (e.g., for normative competence: "I feel confident and competent to: Articulate a vision of a just and sustainable society"), on a 4-point Likert scale	Pre and Post	Mann–Whitney *U* test for statistical comparison of change	Dalhousie University, Canada	RBC Sustainability Leadership Certificate (SLC) for under-graduate students (4 years)	Whole program	Single Cohort	32	Savage et al. (2015)
Reflective Writing	Five responsible leadership competencies (Maak and Pless 2006)	Students are asked to write one personal reflection and one comparing sustainability initiatives	Post	Uses a coding scheme that operationalizes competencies; counts how many competencies appeared in each student's work; and sums up results to compare between courses	Duquesne University, USA	MBA program (1 year, 3 semesters)	Mandatory study abroad experiences	3 years (10 experiences)	62	Sroufe et al. (2015)
Focus group/ interview	Framework from Wiek et al. (Wiek et al. 2011)	Students are asked to trace their competency development based on a course timeline (provided) and pictures (photovoice) in a focus group (75 min)	Post	Uses students' direct and indirect statements (recorded and transcribed), codes them, and extracts evidence of competencies	Arizona State University, USA and Leuphana University of Lüneburg, Germany	Dual-degree Master program in Global Sustainability Science (2 years)	3 semester mandatory project course	1 course	12	Konrad et al. (2020)

Table 2 (continued)

Tool	Example tool used				Example tool application					Source
	Competencies	Assessment data	Testing time	Analysis	Location	Program	Part	Timespan	N^a	
Perfor-mance obser-vation	Professional skills from various sources (Fallows and Steven 2000)	Community "cli-ents" are asked to provide feed-back on student performance by rating their agreement with seven state-ments (e.g., "Students were well-prepared") as well as providing opened-ended feedback	Post	Calculates and compares agreement percentages for each statement. Open responses were analyzed unsystemati-cally	University of Saskatche-wan, Canada	Professional Master program of Sustainable Environmental Management (1 year)	Mandatory first course "Field Skills in Envi-ronment and Sustainability	1 year	13	Kricsfalusy et al. (2018)
Regular course work	Eight program competencies (Habron 2012)	Students submit evidence that demonstrated competence as a graduation requirement	Post	Evaluates based on a five criteria rubric. Counts evidence of competencies at levels (1–8) and sources of evidence. Explanations and reflec-tions are also analyzed	Michigan State University, USA	Minor in Sustainability (4 years)	Graduation requirement of program	3 years	13	Habron (2015)
Concept map-ping	Systems thinking of the frame-work from Wiek et al. (Wiek et al. 2011)	Students are asked to create a concept (sys-tem) map for a sustainability issue (20 min)	Pre and Post	Uses a rubric to guide counts of nodes, con-nections, and levels of hier-archy as well as evaluating content knowl-edge. T-test for statistical comparison of change	Arizona State University, USA	Bachelor program in Elementary Education (4 years)	Mandatory 1 semester introductory sustainability course	2 years	234	Foley et al. (2017)

Table 2 (continued)

Tool	Example tool used				Example tool application					Source
	Competencies	Assessment data	Testing time	Analysis	Location	Program	Part	Timespan	N^a	
Scenario/case test	Framework from Wiek et al. (Wiek et al. 2011)	Students are asked to read a case study and responded to six questions covering specific competencies (case study presents a sustainability challenge, a solution, and stakeholders involved)	Pre and Post	Uses a rubric to score the responses on a scale of 0–5	Arizona State University, USA	Bachelor program in Sustainability (4 years)	Introductory Sustainability Course	1 semester	103	Remington-Doucette et al. (2013)
Conven-tional test	Six environmental competencies from various sources (Roth 1992)	Students are asked to answer 15 closed scale questions and respond to one open question for which they analyze causes and consequences based on example descriptions	Post	Clusters students into three knowledge levels for comparison and T-test for statistical comparison between universities	University of Girona and University of Balearic Islands, Spain	Bachelor program in Primary Education (4 years)	Students in the last (fourth) "course" of their degree	Once	274	Álvarez-García et al. (2015)

[a]*N* is the number of students assessed in the example application

Table 3 Appraisal of the assessment tools organized by cluster

Tool	Current practice	Strengths	Weaknesses	Potential improvements
Cluster 1: self-perceiving-based assessment procedures				
Scaled self-assessment	Students are asked individually to rate their agreement to pre-defined competencies statements on an 4- to 9-point Likert scale Before and after the course Quantitative data analysis	Easy to administer, analyze, and scale (Cebrián Bernat et al. 2019) Integrated with other survey-based data collection (Kanbar 2012) Produces quantitative data to which statistical analysis and modeling can be applied (Faham et al. 2017) Is an effective tool for formative assessment (Andrade 2019) and practice improves student self-awareness (Galt et al. 2013)	Results are based on the unknowable way in which each student (inconsistently) interprets the prompt and the scale or understands the competency (Cebrián et al. 2019) Distance between items on scales cannot assumed to be linear (Bishop and Herron 2015) Students are unlikely to have ability to rate their own capacity in an activity they have never practiced (Holdsworth et al. 2018) Poor record of alignment with more objective tools (Baggen et al. 2017)	Use or build on existing scales (Brandt et al. 2019) Focus on aspects which are addressed in the learning unit (Khaled et al. 2014) Make as concrete as possible with sufficient number of statements per competence (Khaled et al. 2014) Take proper caution and interpret results as "what students regard themselves" (Migliorini and Lieblein 2016) Statistically test constructs with appropriate samples (Lans et al. 2014) Build psychometric models which robustly link competencies to tool (Cabral and Lochan Dhar 2019)
Reflective Writing	Students keep a journal during the course or write essays at specific instances Students are asked individually (through specific questions) to reflect on their development of specific competencies Before, during, or after the course Qualitative data analysis	Easy to administer or be included as a course assignment (Sroufe et al. 2015) Supportive of student competence development as reflection as important for learning (Clevenger and Ozbek 2013) and as a sustainability-relevant competence (Migliorini and Lieblein 2016) Can provide input for revising course activities for next offering (Galt et al. 2013) Adds depth to scaled self-assessment (Savage et al. 2015)	Interpreting open reflection can be very challenging and subject to contestation Time consuming to analyze Students may not understand the competency they are being asked to reflect on (Halberstadt et al. 2019) Assessment may be impacted by incentives to engage (e.g., grades) (Gordon and Thomas 2018) Students are unreliable evaluators of their competence (Clevenger and Ozbek 2013)	Train students in reflection, specifically on their learning and competencies (Gardiner and Rieckmann 2015) Develop a reliable coding book via qualitative content analysis (Sroufe et al. 2015) Tailor reflection assignment to the instructional goals (Migliorini and Lieblein 2016) Integrate with other forms of assessment (Clevenger and Ozbek 2013)
Focus group/interview	Interviews with individual students or focus groups of 6–8 students Students are asked (through specific questions) to reflect on and discuss the learning activities and their development of specific competencies During or after the course Qualitative data analysis	Enables linking of learning outcomes (developed competencies) to teaching and learning activities (Brandt et al. 2019) Discussion with facilitator or peers may prompt further reflection/insights (Konrad et al. 2020) Unexpected avenues can be explored	Interpreting student statements for evidence of competence is challenging and subject to contestation Time consuming to analyze Responses may be influenced by social factors with peers (focus groups) or with facilitator (Konrad et al. 2020)	Appoint as facilitator someone who was not an instructor in the course (Birdman, Lang, Redman, 2020) Clearly explain the competencies whose development the students are reflecting on Utilize photovoice or other methods to improve recall of learning experiences (Konrad et al. 2020)

Table 3 (continued)

Tool	Current practice	Strengths	Weaknesses	Potential improvements
Cluster 2: Observation-based assessment procedures				
Perfor-mance Observation	Students perform a task as part of a course which presents the opportunity to demonstrate competencies Instructor or (stakeholder) expert assesses students' competencies (against a set of pre-defined criteria) During the course Quantitative and/or qualitative analysis	Students' performance can be evaluated by an expert (Kricsfalusy et al. 2018) Actual performance of competence can be evaluated (Charatsari and Lioutas 2019) May capture unexpected occurrences (Božić 2016) Does not add additional burden on students	Classroom settings may not provide appropriate opportunities Stakeholders may not understand competencies Challenging to scale beyond a few students at a time Subjectivity of assessment may be contested	Create a rubric which is tailored to both the activity under observation and competencies (Charatsari and Lioutas 2019) Utilize non-participatory observers or stakeholders more extensively (several times during a course) Use multiple evaluators to assure inter-rater reliability
Regular Course Work	Students complete coursework that offers opportunity to demonstrate competencies Instructor searchers for evidence of competence During the course Quantitative and/or qualitative analysis	Can add as a data source ex-post Does not add any burden on students (Habron 2015) If competencies are a learning objective, assignments should already be design to assess against them (Fuertes-Camacho et al. 2019)	Assignments are rarely well suited for assessing competencies (Albareda Tiana and Alférez Villarreal 2016) Significant work needed to customize rubrics and do assessments (Fuertes-Camacho et al. 2019) Subjectivity of assessment may be contested	Create a rubric which is tailored to both the assignment and competencies (Habron 2015) Use multiple evaluators to assure inter-rater reliability (Fuertes-Camacho et al. 2019) Align assignments required in the course to the competencies
Cluster 3: test-based assessment procedures				
Concept Mapping	Students draw a concept (system) map based on a prompt within a time limit (15–20 min) Analysis is done using a rubric to rate characteristics of the maps Before and after the course Quantitative and/or qualitative analysis	There is an extensive literature from other fields (Foley et al. 2017) Aligns well with demonstrating systems thinking competence (Ateskan and Lane 2017) Results can be quantified for statistical analysis Assessment can be done in little time with no training (Benninghaus et al. 2019)	Limited utility for competencies besides systems-thinking competence (Foley et al. 2017) Significant work needed to create rubrics and analyze maps Measures are primarily limited to complexity and content Quantity is assessed versus quality (Benninghaus et al. 2019)	Base rubric on competencies Use multiple evaluators to assure inter-rater reliability (Mehren et al. 2018) Give a more specific prompt based on the course (Foley et al. 2017) Have experts generate "reference maps" which can be used to asses quality (Benninghaus et al. 2019)
Scenario/case test	Students are asked to read a case description and respond to a series of questions Cases are written to be as real as possible with a length of 1–3 paragraphs Questions can be either open-ended or multiple choice Rubric to evaluate open responses on a scale (e.g., 0–5) Before and After the course; One-off Quantitative and/or qualitative analysis	Students demonstrate competence in a real situation (Sandri et al. 2018) The cases can be designed based on the types of challenges that competencies are supposed to help with (Eggert and Bögeholz 2009) Rigorous work to craft and then to improve tools has been done by some research groups (Bögeholz et al. 2014) Results can be quantified for statistical analysis (Holdsworth et al. 2019a) Provides context which reduces ambiguity (Holdsworth et al. 2018)	Only a limited and hypothetical representation of reality (Holdsworth et al. 2018) Trade-offs in types of responses, lengths of cases presented etc Burden on students/class time to get sincere effort Significant time is required to analyze open responses and develop quality criteria for responses (Baggen et al. 2017) Evaluates primarily conceptual aspects of competencies (Böhm et al. 2016)	Develop psychometric models to link competencies to questions (Holdsworth et al. 2019b) Anonymize actual cases to make as real as possible (Connell et al. 2012; Ploum et al. 2018) Improve alignment between the cases, questions and competencies to be measured (Remington-Doucette and Musgrove 2015) Include as part of course to ensure full and sincere student participation Apply published rubrics in additional cases (Remington-Doucette and Musgrove 2015)

Table 3 (continued)

Tool	Current practice	Strengths	Weaknesses	Potential improvements
Conventional test	Students are asked to take a test with many potential question formats Similar to traditional, knowledge-based tests Rubric to evaluate open responses Before, during and/or after the course Quantitative and/or qualitative analysis	Scalable (Sandri et al. 2018) Instructors and students are comfortable with this tool Results can be quantified for statistical analysis (Alvarez-García et al. 2018)	Competencies do not lend themselves well to traditional tests (Sandri et al. 2018) Lack of psychometric models linking the test questions to actual competencies (Sandri et al. 2018) Rigor (including pilot testing, etc.) is needed for proper development (Waltner et al. 2019) Significant burden on students/class time to get sincere effort (Sandri et al. 2018)	Develop psychometric models to link competencies to questions (Holdsworth et al. 2019b) Rigorously test and develop test questions which are reliable and valid (Waltner et al. 2019) Include as part of course to ensure full and sincere student participation

be read horizontally to give an overview of each example or vertically to enable comparison between tools for each characteristic. The different tools were each fairly widely applied (as represented by the captured characteristics). The scope of applications described in Table 2 well represents those within the overall sample. For each tool, there was also quite a variety of application settings.

Having identified eight distinct assessment tools (types), each of the studies (full list in the "Appendix") was reviewed again, particularly with respect to the research methods used, and an analysis for each tool conducted. The first result of this analysis was that the eight tools can be further clustered into three meta-types: self-perceiving-based assessment procedures, observation-based assessment procedures, and test-based assessment procedures (see Table 3). The critical characteristic of the tool which determines the cluster is who is doing the assessment of the students' competencies. For self-perceiving-based procedures (e.g., reflective writing), the student himself/herself is assessing his/her own competence level and/or development. In applying observation-based procedures, instructors or experts assess students' competencies. The test-based assessment procedures use a predefined set of criteria (or "correct" answers) to evaluate students' competencies. This distinction in who assesses students' competencies leads to the tools within each cluster sharing much in common in terms of strengths and weaknesses.

Based on the analysis of the sample articles and review of broader education science literature, we compiled a distilled set of strengths, weaknesses, and best practices for each tool (Table 3). An exemplary citation was provided for each point whenever possible, typically representing many other sources. The column on current practice in Table 3 offers a generic description of the tool based on the full scope of examples, in contrast to the detailed, but specific examples offered in Table 2.

Discussion

We conducted a systematic review of the growing body of published research on the assessment of sustainability competencies. This review identified a wide range of assessment tools currently in use (more than 120 specific tools). Yet, despite this diversity on the surface, we argue for a typology containing eight major tool types that can be further grouped into three clusters of assessment procedures (Table 3). The tool types we specify overlap meaningfully with those utilized by Nicolaou and Constantinou (2014) in their systematic review of assessing a competence closely related to sustainability (modeling in science). In-depth insights into the tools comes via the examples included in Table 2 and through the appraisal summarized in Table 3.

There are clear signs of substantial investment in model and tool building (Waltner et al. 2019), multi-methodological triangulations (Kricsfalusy et al. 2018), and the piloting of innovative assessment tools (see box 1, below). However, this appraisal also reveals flaws in the current assessment practice in sustainability (science) education: there is too little connectivity across studies, in particular regarding agreement on outcomes; an over-reliance on scaled self-assessment; and general insufficiency of actual tool development. The implications of these flaws can be seen in Fig. 1—unclear learning objectives (1) or the lack of a baseline assessment (2) undermine the effectiveness of even well-developed assessment tools.

et al. (2011), a handful of studies explicitly proposed "new" competencies such as sustainability and social responsibility (SSR) (Albareda Tiana and Alférez Villarreal 2016); others leave it quite unclear what competencies were actually being assessed (e.g., Azeiteiro et al. 2015). Apart from making comparisons across assessments impossible, this ambiguity of learning outcomes undermines recognition and career trajectories of graduates from sustainability (science) programs.

Scaled self-assessment was by far the most commonly chosen assessment tool (56% of cases); yet, only rarely (Migliorini and Lieblein 2016) has the tool choice been justified. In their descriptive review, Bernat et al. (2019) hypothesize that this type of tool is often selected, because "it is less time-consuming, easy to distribute amongst a larger number of students, and in turn it provides a larger amount of information." Several authors make the case for its pedagogical uses in sustainability science (Galt et al. 2013), in line with educational scholars who have advocated for self-reflection as a tool for formative assessment (Andrade 2019). However, as a tool of robust, reliable, and valid measurement of sustainability competencies, self-assessment falls much too short to warrant such popularity.

Box 1. Novel assessment tools use *in-vivo simulated professional situations* to assess students' sustainability competencies – following a model from medical and social work education programs. A recently published study (Foucrier & Wiek, 2020) presents the results of testing such an assessment tool for an interdisciplinary graduate course in sustainability entrepreneurship at Arizona State University (several graduate programs involved). The students were provided with material and asked to prepare as sustainability consultants for a simulated city council meeting on infusing sustainability into the local economy. The tool was tested in two different settings, one deployed with four of the graduate students at the local city hall with actual professionals (city council member, local government administrator, local business association representative), and one with five of the graduate students at the university with "actors" (sustainability graduates and researchers). Student performances were evaluated against a set of 22 criteria. The test results indicate that the tool is valid/reliable against a number of these criteria and provided an assessment of student performance very close to actual practice. Such an in-vivo assessment proved both resource and time intensive, but there are guidelines under which conditions this assessment tool seems most effective and a worthy investment.

Other than the studies, where the same research group builds off of their previous work (scenario/case test type), there are no obvious connections (e.g., citations) made across research efforts. Even in the cases, where the same competencies are assessed (e.g., Wiek et al. 2011) and the same assessment tool is applied (e.g., scaled self-assessment), new studies are not building off the tool previously used (e.g., Molderez and Fonseca 2018). The reviewed competency-like constructs that are currently used in assessments are often so differently described that a comparison across assessments is impossible. Besides drawing on Wiek

As Metzler and Kurz (2018, p. 8) conclude in their report on educational assessment procedure, "data gleaned from easy measurement tell us little about the student learning that matters most."

Even among the assessment studies carefully selected for inclusion in this review, there is a tendency for development of assessment tools to be an apparent afterthought. The main topics of the studies are the pedagogical approach, case description, or programmatic innovation. Assessment as such is used to produce some empirical evidence to validate those initiatives' success. Little effort goes into tool development ahead of time or reflection afterwards. But there are many studies from the educational sciences (Barth and Michelsen 2013) that have rigorously developed assessment tools, which the practice of sustainability competencies assessment should adopt going forward. Some, such as the recent work of Mehren et al. (2018) are highly relevant (assessing systems thinking in geography), yet are not being learned from in sustainability science. We recommend four steps. First, developing a clear set of learning objectives/outcomes to be assessed, properly operationalized for the given context; second, providing a theoretical and empirical basis for selecting a particular assessment tool to be used; third, articulating a psychometric model which links the learning outcomes to the tool to be used; fourth, pilot testing the tool with a relevant sample population.

Many disciplines have adopted some form of sustainability (science) education and instructors ought to look for assessment tools to fit their specific teaching situation. The experiences so far suggest that combining assessment tools may be the best way to address the shortcomings of any particular assessment tool. For example, assessment tools with reasonable validity due to narrow learning objectives, e.g., (Bögeholz et al. 2014), will likely have low reliability across contexts and content (Schuwirth and Van Der Vleuten 2011). Each assessment tool has inherent weaknesses even with proper development (which the typology helps to foresee); thus, triangulation should happen on two levels—within the clusters and between them. For example, combining scaled self-assessment with reflective writing (within a cluster) provides a more complete and meaningful picture of the students' views of their own competencies, while triangulating these results with a testing approach (between clusters) checks the validity of students' self-perception against an objective (if typically narrower) measure.

As mentioned above, individual cases of developing assessment tools seem quite promising. Beyond just the increase in the quantity of publications, some tools have been developed with rigor, along the lines of the four steps outlined above (e.g., Waltner et al. 2019). Additionally, it is critical to plan for ultimate deployment on a scale sufficient to the needs of sustainability (science) education (Arima 2009), a topic that Holdsworth et al. (2019b) have explicitly grappled with over a series of articles. Yet, for all the innovation that sustainability (science) education purports to offer pedagogically, the field has so far little to offer in terms of assessment. Inspiration could be drawn from many other educational fields (Leutner et al. 2017), in particular from medical education, with its innovative approaches to competency assessment (Lockyer et al. 2017). This is in line with other intriguing parallels between medical and sustainability (science) education. The recent in-vivo assessment described in box 1 drew its inspiration from the long and established practice of competencies assessment in medical education. Sustainability (science) education researchers and practitioners would do well to find inspiration in such corners.

Conclusions

This article offers a typology which provides guidance for instructors, researchers, and program directors interested in assessing students' competencies in sustainability. This typology, based on a systematic review and synthesis of the academic literature through the end of 2019, goes beyond description to offer an appraisal of eight types of assessment tools. The analysis of their strengths, weaknesses, and best practices distills the key lessons from the 75 peer-reviewed publications included.

Reflective of the rest of the field of sustainability (science) education, there is a lack of explicit agreement on what is being assessed. This makes comparison of results impossible but also challenges comparisons of the process of assessment (i.e., the tools themselves). Perhaps due to assessment not being the topic of primary research interest, the assessment tools are not typically well-developed and often inappropriately used. This is particularly true of scaled self-assessment, for which weaknesses are well documented, yet, continues to dominate current assessment practice. In response to the lack of robust assessment tools, many instructors, researchers, and program directors have chosen to apply more than one, an approach which is likely to have value even if utilizing tools with extensive development. The proposed typology provides a structure of the field as it is today. As more tools are being developed and refined, we would expect to distinguish more specific tools such as Concept Mapping (specific to systems-thinking competence) within each of the broader categories. Ultimately, it would be the meta-types (e.g., self-perceiving) which would form the critical organizing structure. Despite a bumpy beginning, current trends are quite positive, as more rigor is being applied in combination with meaningful innovations.

Considering the need for broad sustainability (science) education, efforts ought to be accelerated. If education is going to contribute to the needed global transformations, the scholarly community needs to generate more evidence

about "what works" for teaching and learning (evidence-supported practices), and this requires robust assessment tools. As we briefly touched on, sustainability (science) education researchers need to draw much more heavily on work being done in other education research fields. These efforts should extend beyond just the research perspective to include coordination across the relevant parties. Researchers, for example, need to focus on linking outcomes to the actual learning processes, while instructors may emphasize the formative aspect, and program directors be concerned about objective and comparable measures for reporting. In these efforts, there is a need for innovative assessment approaches that more directly prepare students for their professional paths and the challenges they will be facing.

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Appendix

Synthesizing a growing body of research, such as that on sustainability competency assessment, is best done through a literature review (Snyder 2019). For this study, we conducted a literature review following the procedures laid out by Fink (2014). This appendix describes, how we followed Fink's (2014) approach to be systematic, explicit, comprehensive and reproducible. We sought to identify all articles that were published on assessing sustainability competencies. To be sure that definitional differences did not accidentally exclude relevant articles, we searched for synonyms of competencies and did not include assessment in the search procedures (it is used in many other ways in sustainability fields, e.g., LCA), rather using it as a screening criterion. We drew from as broad a pool of publications as possible, so we conducted our search on Web of Science, SCOPUS, ERIC, and Google Scholar. Based on other reviews, we expected these databases to provide comprehensive coverage. The following search strings were used:

a. Scopus
   i. Search the title, abstract and keywords; English; Through 2019
   ii. TITLE-ABS-KEY ("competency" OR "competence" OR "competencies" OR "competences" OR "attribute" OR "attributes" OR "capability" OR "capabilities" OR "learning outcome" OR "learning outcomes") AND TITLE-ABS-KEY (education) AND KEY ("sustainable development" OR "sustainability") AND LANGUAGE (english) AND PUBYEAR < 2019 AND (EXCLUDE (SUBJAREA, "MEDI") OR EXCLUDE (SUBJAREA, "NURS") OR EXCLUDE (SUBJAREA, "PHAR") OR EXCLUDE (SUBJAREA, "HEAL") OR EXCLUDE (SUBJAREA, "DENT") OR EXCLUDE (SUBJAREA, "IMMU"))
   iii. 1398 results

a. Web of Science
   i. Topic search (TS); English; Through 2019
   ii. TS = (("competency" OR "competence" OR "competencies" OR "competences" OR "attribute" OR "attributes" OR "capability" OR "capabilities" OR "learning outcome" OR "learning outcomes") AND "education" AND ("sustainable development" OR "sustainability"))
   iii. 1198 results

a. ERIC (proquest)
   i. Search Anywhere; 2 separate command lines; English; Through 2019
   ii. "competency" OR "competence" OR "competencies" OR "competences" OR "attribute" OR "attributes" OR "capability" OR "capabilities" OR "learning outcome" OR "learning outcomes" | "sustainable development" OR "sustainability"
   iii. 830 results

a. Google Scholar- search
   i. Used the software Harzing's Publish or Perish https://harzing.com/resources/publish-or-perish which searches and downloads up to 1,000 citations but has a character limit on searches
   ii. Through 2019| Sustainability, education |Competencies: 750; Attributes: 250; Capabilities: 250; "Learning Outcomes": 250
   iii. 1,000 results

After duplicates were removed, 3898 publications constituted the first sample. Following the structured review approaches of Moher et al. (2009) and Fink (2014), we then iteratively excluded publications. We excluded irrelevant publications first based on titles (1747), abstracts (1241) and other content (108). Of the remainder, the full text was downloaded (except for 52 which could not be) and reviewed

for a final exclusion (559). A detailed reading of each article was carried out resulting in a few more exclusions (64) and a final sample of 75 articles. At the title stage, only the most obviously unfit publications were excluded. An example title to remove was: "What attributes do Australian midwifery leaders identify as essential to effectively manage a Midwifery Group Practice?" The abstracts and full text were given more than one critical reading to determine inclusion or exclusion. The selection of articles was carried out primarily by the first author, with checks done by the co-author. Other experts in the field were consulted for missing publications. The criteria used to include publications (i.e., not put them in the exclusion group at each step) were:

- English
- Published or in-press by the end of 2019
- Education type (any level) of the following domains:
    - Sustainability focused education
    - Adding sustainability focus to other degrees/programs/general etc.
    - Environmental education with a strong sustainability related focus
- Included specific learning objectives (e.g., competencies, capabilities, learning outcomes, attributes)
- Includes an evaluation or assessment of impact of a program on learning objectives

See Table 4.

Table 4 Publications which used each tool type

Tool	*N*	Publications using the tool
Scaled self-assessment	42	Albareda Tiana S, Alférez Villarreal A (2016) A collaborative programme in sustainability and social responsibility. Int J Sustain High Educ 17:719–736. https://doi.org/10.1108/IJSHE-07-2016-0134 Alvarez-García O, Sureda-Negre J, Comas-Forgas R (2018) Assessing environmental competencies of primary education pre-service teachers in Spain. Int J Sustain High Educ 19:15–31. https://doi.org/10.1108/IJSHE-12-2016-0227 Anderson EL (2015) Developing key sustainability competencies through real-world learning experiences: evaluating community environmental services. search.proquest.com Ateskan A, Lane JF (2018) Assessing teachers' systems thinking skills during a professional development program in Turkey. J Clean Prod 172:4348–4356. https://doi.org/10.1016/j.jclepro.2017.05.094 Azeiteiro UM, Bacelar-Nicolau P, Caetano FJPP, Caeiro S (2015) Education for sustainable development through e-learning in higher education: experiences from Portugal. J Clean Prod 106:308–319. https://doi.org/10.1016/j.jclepro.2014.11.056 Baggen Y, Kampen JK, Naia A, et al. (2017) Development and application of the opportunity identification competence assessment test (OICAT) in higher education. Innov Educ Teach Int 55:1–11. https://doi.org/10.1080/14703297.2017.1348962 Besong F, Holland C (2015) The Dispositions, Abilities and Behaviours (Dab) Framework for profiling learners' sustainability competencies in higher education. J Teach Educ Sustain 17:5–22. https://doi.org/10.1515/jtes-2015-0001 Biasutti M, Surian A (2012) The students' survey of education for sustainable development competencies: a comparison among faculties. Discourse Commun Sustain Educ 3:75–82. https://doi.org/10.2478/v10230-012-0005-y Božić M (2016) Competence development in a project and problem based learning professional practice module in engineering education based on ill-structured problem. ddd.uab.cat Brandt J-O, Bürgener L, Barth M, Redman A (2019) Becoming a competent teacher in education for sustainable development. Int J Sustain High Educ 20:630–653. https://doi.org/10.1108/IJSHE-10-2018-0183 Brassler M, Dettmers J (2017) How to enhance interdisciplinary competence—interdisciplinary problem-based learning versus interdisciplinary project-based learning. Interdiscip J Probl Learn 11:15. https://doi.org/10.7771/1541-5015.1686 Cabral C, Lochan Dhar R (2019) Green competencies: construct development and measurement validation. J Clean Prod 235:887–900. https://doi.org/10.1016/j.jclepro.2019.07.014 Cazorla-Montero, de los Ríos-Carmenado, Pasten (2019) Sustainable development planning: master's based on a project-based learning approach. Sustainability 11:6384. https://doi.org/10.3390/su11226384 Cebrián G, Pascual D, Moraleda Á (2019) Perception of sustainability competencies amongst Spanish pre-service secondary school teachers. Int J Sustain High Educ 20:1171–1190. https://doi.org/10.1108/IJSHE-10-2018-0168 Ceulemans G, Severijns N (2019) Challenges and benefits of student sustainability research projects in view of education for sustainability. Int J Sustain High Educ 20:482–499. https://doi.org/10.1108/IJSHE-02-2019-0051 Clevenger CM, Ozbek ME (2013) Service-learning assessment: sustainability competencies in construction education. J Constr Eng Manag 139:A4013010. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000769 Faham E, Rezvanfar A, Movahed Mohammadi SH, Rajabi Nohooji M (2017) Using system dynamics to develop education for sustainable development in higher education with the emphasis on the sustainability competencies of students. Technol Forecast Soc Change 123:307–326. https://doi.org/10.1016/j.techfore.2016.03.023 Fuertes-Camacho M, Graell-Martín M, Fuentes-Loss M, Balaguer-Fàbregas M (2019) integrating sustainability into higher education curricula through the project method, a global learning strategy. Sustainability 11:767. https://doi.org/10.3390/su11030767 Galt RE, Parr D, Jagannath J (2013) Facilitating competency development in sustainable agriculture and food systems education: a self-assessment approach. Int J Agric Sustain 11:69–88. https://doi.org/10.1080/14735903.2012.683569 Gosselin D, Cooper S, Bonnstetter RJ, Bonnstetter BJ (2013) Exploring the assessment of twenty-first century professional competencies of undergraduate students in environmental studies through a business-academic partnership. J Environ Stud Sci 3:359–368. https://doi.org/10.1007/s13412-013-0140-1 Gosselin D, Cooper S, Lawton S, et al. (2016) Lowering the walls and crossing boundaries: applications of experiential learning to teaching collaboration. J Environ Stud Sci 6:324–335. https://doi.org/10.1007/s13412-015-0312-2 Hilser S (2016) Key competencies to action: transdisciplinary learning of key competencies for sustainability. lup.lub.lu.se Kanbar N (2012) Can education for sustainable development address challenges in the Arab region? Examining business students' attitudes and competences on education for sustainable development: a case study. Discourse Commun Sustain Educ 3:41–62. https://doi.org/10.2478/v10230-012-0003-0 Kricsfalusy V, George C, Reed MG (2018) Integrating problem- and project-based learning opportunities: assessing outcomes of a field course in environment and sustainability. Environ Educ Res 24:593–610. https://doi.org/10.1080/13504622.2016.1269874 Lans T, Blok V, Wesselink R (2014) Learning apart and together: towards an integrated competence framework for sustainable entrepreneurship in higher education. J Clean Prod 62:37–47. https://doi.org/10.1016/j.jclepro.2013.03.036

Table 4 (continued)

Tool	*N*	Publications using the tool
		Lengieza ML, Hunt CA, Swim JK (2019) Travel-induced learning: a validation of the sustainability insight scale. Curr Issues Tour 0:1–4. https://doi.org/10.1080/13683500.2019.1584160 MacDonald L, Shriberg M (2016) Sustainability leadership programs in higher education: alumni outcomes and impacts. J Environ Stud Sci 6:360–370. https://doi.org/10.1007/s13412-015-0344-7 Meza Rios MM, Herremans IM, Wallace JE, et al. (2018) Strengthening sustainability leadership competencies through university internships. Int J Sustain High Educ 19:739–755. https://doi.org/10.1108/IJSHE-06-2017-0097 Migliorini P, Lieblein G (2016) Facilitating transformation and competence development in sustainable agriculture university education: an experiential and action oriented approach. Sustainability 8:1–15. https://doi.org/10.3390/su8121243 Molderez I, Fonseca E (2018) The efficacy of real-world experiences and service learning for fostering competences for sustainable development in higher education. J Clean Prod 172:4397–4410. https://doi.org/10.1016/j.jclepro.2017.04.062 Osagie ER, Wesselink R, Runhaar P, Mulder M (2017) Unraveling the competence development of corporate social responsibility leaders: the importance of peer learning, learning goal orientation, and learning climate. J Bus Ethics. https://doi.org/10.1007/s10551-017-3638-8 Ploum L, Blok V, Lans T, Omta O (2019) Educating for self-interest or -transcendence? An empirical approach to investigating the role of moral competencies in opportunity recognition for sustainable development. Bus Ethics 28:243–260. https://doi.org/10.1111/beer.12214 Ploum L, Blok V, Lans T, Omta O (2018) Toward a validated competence framework for sustainable entrepreneurship. Organ Environ 31:113–132. https://doi.org/10.1177/1086026617697039 Ploum L, Blok V, Lans T, Omta O (2018) Exploring the relation between individual moral antecedents and entrepreneurial opportunity recognition for sustainable development. J Clean Prod 172:1582–1591. https://doi.org/10.1016/j.jclepro.2017.10.296 Roy SG, de Souza SP, McGreavy B, et al. (2019) Evaluating core competencies and learning outcomes for training the next generation of sustainability researchers. Sustain Sci. https://doi.org/10.1007/s11625-019-00707-7 San Carlos Arce RO, Yoshida Y, Kudo S (2017) Fostering the next generation of sustainability professionals—assessing field-based courses in a sustainability science graduate program. Challenges Sustain 5:52–61. https://doi.org/10.12924/cis2017.05010052 San Carlos RO, Tyunina O, Yoshida Y, et al. (2016) Assessment of fieldwork methodologies for educational purposes in sustainability science: exercise on resilience, Tohoku Unit 2015. In: Sustainability science: field methods and exercises. Springer International Publishing, Cham, pp 67–91 Sánchez-Hernández, Maldonado-Briegas (2019) Sustainable entrepreneurial culture programs promoting social responsibility: a European regional experience. Sustainability 11:3625. https://doi.org/10.3390/su11133625 Savage E, Tapics T, Evarts J, et al. (2015) Experiential learning for sustainability leadership in higher education. Int J Sustain High Educ 16:692–705. https://doi.org/10.1108/IJSHE-10-2013-0132 Stock T, Kohl H (2018) Perspectives for international engineering education. Procedia Manuf 21:10–17. https://doi.org/10.1016/j.promfg.2018.02.089 Weijs R, Bekebrede G, Nikolic I (2016) Sustainable competence development of business students: effectiveness of using serious games. Springer Zemler L (2016) The convergence of societal advancement and the education of future sustainability professionals : a solution-oriented approach to place-based environmental challenges
Reflective writing	17	Albareda Tiana S, Alférez Villarreal A (2016) A collaborative programme in sustainability and social responsibility. Int J Sustain High Educ 17:719–736. https://doi.org/10.1108/IJSHE-07-2016-0134 Anderson EL (2015) Developing key sustainability competencies through real-world learning experiences: evaluating community environmental services. search.proquest.com Azeiteiro UM, Bacelar-Nicolau P, Caetano FJPP, Caeiro S (2015) Education for sustainable development through e-learning in higher education: experiences from Portugal. J Clean Prod 106:308–319. https://doi.org/10.1016/j.jclepro.2014.11.056 Božić M (2016) Competence development in a project and problem based learning professional practice module in engineering education based on ill-structured problem. ddd.uab.cat Ceulemans G, Severijns N (2019) Challenges and benefits of student sustainability research projects in view of education for sustainability. Int J Sustain High Educ 20:482–499. https://doi.org/10.1108/IJSHE-02-2019-0051 Clevenger CM, Ozbek ME (2013) Service-learning assessment: sustainability competencies in construction education. J Constr Eng Manag 139:A4013010. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000769 Galt RE, Parr D, Jagannath J (2013) Facilitating competency development in sustainable agriculture and food systems education: a self-assessment approach. Int J Agric Sustain 11:69–88. https://doi.org/10.1080/14735903.2012.683569 Gardiner S, Rieckmann M (2015) Pedagogies of preparedness: use of reflective journals in the operationalisation and development of anticipatory competence. Sustainability 7:10,554–10,575. https://doi.org/10.3390/su70810554 Gordon S, Thomas I (2018) 'The learning sticks': reflections on a case study of role-playing for sustainability. Environ Educ Res 24:172–190. https://doi.org/10.1080/13504622.2016.1190959 Halberstadt J, Timm J-M, Kraus S, Gundolf K (2019) Skills and knowledge management in higher education: how service learning can contribute to social entrepreneurial competence development. J Knowl Manag 23:1925–1948. https://doi.org/10.1108/JKM-12-2018-0744 Kricsfalusy V, George C, Reed MG (2018) Integrating problem- and project-based learning opportunities: assessing outcomes of a field course in environment and sustainability. Environ Educ Res 24:593–610. https://doi.org/10.1080/13504622.2016.1269874 Meza Rios MM, Herremans IM, Wallace JE, et al. (2018) Strengthening sustainability leadership competencies through university internships. Int J Sustain High Educ 19:739–755. https://doi.org/10.1108/IJSHE-06-2017-0097 Migliorini P, Lieblein G (2016) Facilitating transformation and competence development in sustainable agriculture university education: an experiential and action oriented approach. Sustainability 8:1–15. https://doi.org/10.3390/su8121243 Roy SG, de Souza SP, McGreavy B, et al. (2019) Evaluating core competencies and learning outcomes for training the next generation of sustainability researchers. Sustain Sci. https://doi.org/10.1007/s11625-019-00707-7 Savage E, Tapics T, Evarts J, et al. (2015) Experiential Learning for sustainability leadership in higher education. Int J Sustain High Educ 16:692–705. https://doi.org/10.1108/IJSHE-10-2013-0132 Soini K, Korhonen-Kurki K, Asikainen H (2019) Transactional learning and sustainability co-creation in a university—business collaboration. Int J Sustain High Educ 20:965–984. https://doi.org/10.1108/IJSHE-11-2018-0215 Sroufe R, Sivasubramaniam N, Ramos D, Saiia D (2015) Aligning the PRME. J Manag Educ 39:244–275. https://doi.org/10.1177/1052562914560795

Table 4 (continued)

Tool	*N*	Publications using the tool
Scenario/ Case Test	16	Baggen Y, Kampen JK, Naia A, et al. (2017) Development and application of the opportunity identification competence assessment test (OICAT) in higher education. Innov Educ Teach Int 55:1–11. https://doi.org/10.1080/14703297.2017.1348962 Bögeholz S, Böhm M, Eggert S, Barkmann J (2014) Education for Sustainable Development in German science education: Past—present—future. Eurasia J Math Sci Technol Educ 10:231–248. https://doi.org/10.12973/eurasia.2014.1079a Böhm M, Eggert S, Barkmann J, Bögeholz S (2016) Evaluating sustainable development solutions quantitatively: competence modelling for GCE and ESD. Citizensh Soc Econ Educ 15:190–211. https://doi.org/10.1177/2047173417695274 Brandt J-O, Bürgener L, Barth M, Redman A (2019) Becoming a competent teacher in education for sustainable development. Int J Sustain High Educ 20:630–653. https://doi.org/10.1108/IJSHE-10-2018-0183 Connell KH, Remington S, Armstrong C (2012) Assessing systems thinking skills in two undergraduate sustainability courses: a comparison of teaching strategies. J Sustain Educ 3: Eggert S, Bögeholz S (2009) Students' use of decision-making strategies with regard to socioscientific issues: an application of the rasch partial credit model. Sci Educ 94:230–258. https://doi.org/10.1002/sce.20358 Gresch H, Bögeholz S (2013) Identifying non-sustainable courses of action: a prerequisite for decision-making in education for sustainable development. Res Sci Educ 43:733–754. https://doi.org/10.1007/s11165-012-9287-0 Holdsworth S, Sandri O, Thomas I, et al. (2019) The assessment of graduate sustainability attributes in the workplace: Potential advantages of using the theory of planned behaviour (TPB). J Clean Prod 238:117,929. https://doi.org/10.1016/j.jclepro.2019.117929 Holdsworth S, Sandri O, Thomas I, et al. (2019) The use of the theory of planned behaviour to assess graduate attributes for sustainability. Environ Educ Res 1–21. https://doi.org/10.1080/13504622.2019.1700218 Holdsworth S, Thomas I, Sandri O (2018) Assessing graduate sustainability attributes using a vignette/scenario approach. J Educ Sustain Dev 12:120–139. https://doi.org/http://dx.doi.org/10.1177/0973408218792127 Holdsworth S, Thomas I, Sandri O, et al. (2017) Producing sustainability professionals: assessing graduate attributes in sustainability. researchbank.rmit.edu.au Holdsworth S, Thomas I, Wong P, et al. (2019) Graduate attribute for minimising environmental harm—assessing effectiveness in the graduates' workplaces. J Clean Prod 211:396–407. https://doi.org/10.1016/j.jclepro.2018.11.169 Ploum L, Blok V, Lans T, Omta O (2019) Educating for self-interest or -transcendence? An empirical approach to investigating the role of moral competencies in opportunity recognition for sustainable development. Bus Ethics 28:243–260. https://doi.org/10.1111/beer.12214 Ploum L, Blok V, Lans T, Omta O (2018) Exploring the relation between individual moral antecedents and entrepreneurial opportunity recognition for sustainable development. J Clean Prod 172:1582–1591. https://doi.org/10.1016/j.jclepro.2017.10.296 Remington-Doucette SM, Hiller Connell KY, Armstrong CM, Musgrove SL (2013) Assessing sustainability education in a transdisciplinary undergraduate course focused on real-world problem solving. Int J Sustain High Educ 14:404–433. https://doi.org/10.1108/IJSHE-01-2012-0001 Remington-Doucette S, Musgrove S (2015) Variation in sustainability competency development according to age, gender, and disciplinary affiliation. Int J Sustain High Educ 16:537–575. https://doi.org/10.1108/IJSHE-01-2013-0005
Focus Group/ Interview	15	Brandt J-O, Bürgener L, Barth M, Redman A (2019) Becoming a competent teacher in education for sustainable development. Int J Sustain High Educ 20:630–653. https://doi.org/10.1108/IJSHE-10-2018-0183 Cazorla-Montero, de los Ríos-Carmenado, Pasten (2019) Sustainable development planning: master's based on a project-based learning approach. Sustainability 11:6384. https://doi.org/10.3390/su11226384 Dai Y, Hwang S–H (2019) Technique, creativity, and sustainability of bamboo craft courses: teaching educational practices for sustainable development. Sustainability 11:2487. https://doi.org/10.3390/su11092487 Feriver Ş, Olgan R, Teksöz G, Barth M (2019) Systems thinking skills of preschool children in early childhood education contexts from Turkey and Germany. Sustainability 11:1478. https://doi.org/10.3390/su11051478 Gardiner S, Rieckmann M (2015) Pedagogies of preparedness: use of reflective journals in the operationalisation and development of anticipatory competence. Sustainability 7:10,554–10,575. https://doi.org/10.3390/su70810554 Habron G, Goralnik L, Thorp L (2012) Embracing the learning paradigm to foster systems thinking. Int J Sustain High Educ 13:378–393. https://doi.org/10.1108/14676371211262326 Halberstadt J, Timm J-M, Kraus S, Gundolf K (2019) Skills and knowledge management in higher education: how service learning can contribute to social entrepreneurial competence development. J Knowl Manag 23:1925–1948. https://doi.org/10.1108/JKM-12-2018-0744 Hilser S (2016) Key competencies to action: transdisciplinary learning of key competencies for sustainability. lup.lub.lu.se Kieu TK, Singer J (2017) Involvement of NGOs in Training Teachers In Education For Sustainable Development in Vietnam: A Case Study. Eur J Sustain Dev 6:153–166. https://doi.org/10.14207/ejsd.2017.v6n1p153 Konrad T, Wiek A, Barth M (2020) Embracing conflicts for interpersonal competence development in project-based sustainability courses. Int J Sustain High Educ 21:76–96. https://doi.org/10.1108/IJSHE-06-2019-0190 Lambrechts W, Gelderman CJ, Semeijn J, Verhoeven E (2019) The role of individual sustainability competences in eco-design building projects. J Clean Prod 208:1631–1641. https://doi.org/10.1016/j.jclepro.2018.10.084 Migliorini P, Lieblein G (2016) Facilitating transformation and competence development in sustainable agriculture university education: an experiential and action oriented approach. Sustainability 8:1–15. https://doi.org/10.3390/su8121243 Molderez I, Fonseca E (2018) The efficacy of real-world experiences and service learning for fostering competences for sustainable development in higher education. J Clean Prod 172:4397–4410. https://doi.org/10.1016/j.jclepro.2017.04.062 Soini K, Korhonen-Kurki K, Asikainen H (2019) Transactional learning and sustainability co-creation in a university – business collaboration. Int J Sustain High Educ 20:965–984. https://doi.org/10.1108/IJSHE-11-2018-0215 Zemler L (2016) The convergence of societal advancement and the education of future sustainability professionals: a solution-oriented approach to place-based environmental challenges

Table 4 (continued)

Tool	*N*	Publications using the tool
Observation	11	Albareda-Tiana S, García-González E, Jiménez-Fontana R, Solís-Espallargas C (2019) Implementing Pedagogical Approaches for ESD in Initial Teacher Training at Spanish Universities. Sustainability 11:4927. https://doi.org/10.3390/su11184927 Božić M (2016) Competence development in a project and problem based learning professional practice module in engineering education based on ill-structured problem. ddd.uab.cat Charatsari C, Lioutas ED (2019) Is current agronomy ready to promote sustainable agriculture? Identifying key skills and competencies needed. Int J Sustain Dev World Ecol 26:232–241. https://doi.org/10.1080/13504509.2018.1536683 Dai Y, Hwang S–H (2019) Technique, Creativity, and Sustainability of Bamboo Craft Courses: Teaching Educational Practices for Sustainable Development. Sustainability 11:2487. https://doi.org/10.3390/su11092487 Fuertes-Camacho M, Graell-Martín M, Fuentes-Loss M, Balaguer-Fàbregas M (2019) Integrating sustainability into higher education curricula through the project method, a global learning strategy. Sustainability 11:767. https://doi.org/10.3390/su11030767 Habron G, Goralnik L, Thorp L (2012) Embracing the learning paradigm to foster systems thinking. Int J Sustain High Educ 13:378–393. https://doi.org/10.1108/14676371211262326 Konrad T, Wiek A, Barth M (2020) Embracing conflicts for interpersonal competence development in project-based sustainability courses. Int J Sustain High Educ 21:76–96. https://doi.org/10.1108/IJSHE-06-2019-0190 Kricsfalusy V, George C, Reed MG (2018) Integrating problem- and project-based learning opportunities: assessing outcomes of a field course in environment and sustainability. Environ Educ Res 24:593–610. https://doi.org/10.1080/13504622.2016.1269874 Molderez I, Fonseca E (2018) The efficacy of real-world experiences and service learning for fostering competences for sustainable development in higher education. J Clean Prod 172:4397–4410. https://doi.org/10.1016/j.jclepro.2017.04.062 Roy SG, de Souza SP, McGreavy B, et al. (2019) Evaluating core competencies and learning outcomes for training the next generation of sustainability researchers. Sustain Sci. https://doi.org/10.1007/s11625-019-00707-7 Zemler L (2016) The convergence of societal advancement and the education of future sustainability professionals : a solution-oriented approach to place-based environmental challenges
Concept Mapping	7	Ateskan A, Lane JF (2018) Assessing teachers' systems thinking skills during a professional development program in Turkey. J Clean Prod 172:4348–4356. https://doi.org/10.1016/j.jclepro.2017.05.094 Benninghaus J, Mühling A, Kremer K, Sprenger S (2019) Complexity in education for sustainable consumption—an educational data mining approach using mysteries. Sustainability 11:722. https://doi.org/10.3390/su11030722 Clevenger CM, Ozbek ME (2013) Service-learning assessment: sustainability competencies in construction education. J Constr Eng Manag 139:A4013010. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000769 Foley RW, Archambault LM, Hale AE, Dong H-K (2017) Learning outcomes in sustainability education among future elementary school teachers. J Educ Sustain Dev 11:33–51. https://doi.org/http://dx.doi.org/10.1177/0973408217725861 Habron G, Goralnik L, Thorp L (2012) Embracing the learning paradigm to foster systems thinking. Int J Sustain High Educ 13:378–393. https://doi.org/10.1108/14676371211262326 Segalàs J, Ferrer-Balas D, Mulder KF (2010) What do engineering students learn in sustainability courses? The effect of the pedagogical approach. J Clean Prod 18:275–284. https://doi.org/10.1016/j.jclepro.2009.09.012 Warren E, Foley R, Archambault L (2015) Building sustainability literacy among preservice teachers: An initial evaluation of a sustainability courses designed for K-8 educator. In: Educating science teachers for sustainability. pp 49–67
Test (other)	7	Alvarez-García O, Sureda-Negre J, Comas-Forgas R (2018) Assessing environmental competencies of primary education pre-service teachers in Spain. Int J Sustain High Educ 19:15–31. https://doi.org/10.1108/IJSHE-12-2016-0227 Brandt J-O, Bürgener L, Barth M, Redman A (2019) Becoming a competent teacher in education for sustainable development. Int J Sustain High Educ 20:630–653. https://doi.org/10.1108/IJSHE-10-2018-0183 Habron G, Goralnik L, Thorp L (2012) Embracing the learning paradigm to foster systems thinking. Int J Sustain High Educ 13:378–393. https://doi.org/10.1108/14676371211262326 Sandri O, Holdsworth S, Thomas I (2018) Vignette question design for the assessment of graduate sustainability learning outcomes. Environ Educ Res 24:406–426. https://doi.org/10.1080/13504622.2016.1263280 Schuler S, Fanta D, Rosenkraenzer F, Riess W (2018) Systems thinking within the scope of education for sustainable development (ESD)—a heuristic competence model as a basis for (science) teacher education. J Geogr High Educ 42:192–204. https://doi.org/10.1080/03098265.2017.1339264 Waltner E-M, Rieß W, Mischo C (2019) Development and validation of an instrument for measuring student sustainability competencies. Sustainability 11:1–20. https://doi.org/10.3390/su11061717 Weijs R, Bekebrede G, Nikolic I (2016) Sustainable Competence Development of Business Students: Effectiveness of Using Serious Games. Springer
Assess Assignments	6	Albareda Tiana S, Alférez Villarreal A (2016) A collaborative programme in sustainability and social responsibility. Int J Sustain High Educ 17:719–736. https://doi.org/10.1108/IJSHE-07-2016-0134 Fuertes-Camacho M, Graell-Martín M, Fuentes-Loss M, Balaguer-Fàbregas M (2019) Integrating sustainability into higher education curricula through the project method, a global learning strategy. Sustainability 11:767. https://doi.org/10.3390/su11030767 Habron G (2015) Integrating ePortfolios into sustainability education. Int J ePortfolio 5:123–134 Habron G, Goralnik L, Thorp L (2012) Embracing the learning paradigm to foster systems thinking. Int J Sustain High Educ 13:378–393. https://doi.org/10.1108/14676371211262326 Roy SG, de Souza SP, McGreavy B, et al. (2019) Evaluating core competencies and learning outcomes for training the next generation of sustainability researchers. Sustain Sci. https://doi.org/10.1007/s11625-019-00707-7 Soini K, Korhonen-Kurki K, Asikainen H (2019) Transactional learning and sustainability co-creation in a university—business collaboration. Int J Sustain High Educ 20:965–984. https://doi.org/10.1108/IJSHE-11-2018-0215

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