Assessing the Development of Key Competencies in Sustainability

by

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ABSTRACT

Making significant progress on the U.N. Sustainable Development Goals (SDGs) needs change agents equipped with key competencies in sustainability. While thousands of sustainability programs have emerged at various educational levels over the past decade, there is, as of yet, no reliable way to assess if these programs successfully convey key competencies in sustainability. This dissertation contributes to addressing this gap in three ways. First, it reviews the body of work on key competencies in sustainability. Based on broad agreement around five key competencies as well as an emerging set of three, an extended framework is outlined that can be used as unified set of learning objectives across sustainability programs. The next chapter reviews the scholarly work on assessing sustainability competencies. Based on this review, a typology of assessment tools is proposed offering guidance to both educators and researchers. Finally, drawing on experience of the four-year "Educating Future Change Agents" project, the last chapter explores the results from a diverse set of competency assessments in numerous courses. The study appraises assessment practices and results to demonstrate opportunities and challenges in the current state of assessing key competencies in sustainability. The results of this doctoral thesis are expected to make a practical and scholarly contribution to the teaching and learning in sustainability programs, in particular with regards to reliably assessing key competencies in sustainability.

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INTRODUCTION

1. Problem Statement

The sustainability problems which the world faces today are unlikely to be solved by the same incremental, narrow way of thinking which generated these problems in the first place. Rather what is needed are meaningful and global-scale transformations towards sustainability. These transformations, while requiring advances in technology, will need to be fundamentally social in nature if they are to be robust and long lasting. Driving these social transformations will require individuals or groups who are the agents of change. They will need to be capable of addressing unprecedented problems through the generation and implementation of solutions. These must go beyond the typical incrementalism (e.g. increasing recycling by a few percent) and rather strive for transformations (e.g. closed-loop production). As seen through Fridays for the Future, Black Lives Matter, and other recent upsurges in activism, there are legions out there desiring to lead transformative rather than incremental change such as rapid carbon neutrality or police abolition.

To some degree, universities have responded to the demand to train change agents by creating numerous sustainability programs. How to educate and equip such change agents is a critical question for these programs. As with many of the more practice-oriented fields (e.g. medicine), most of these programs define the outcomes in terms of competencies (or similar concepts with various names, e.g. attributes). Despite a shared objective, sustainability education has not come to an explicit shared understanding of what these competencies should be. The need for this shared understanding is well recognized among scholars as well as organizations such as the National Council for Science and the Environment (NCSE) (Brundiers et al., 2020).

Regardless of the lack of consensus on the specifics, competencies have begun to be implemented in universities seeking to graduate sustainability change agents. For example Laval University in Canada has used competencies to infuse sustainability across the campus(Richard et al., 2017), while the University of South Dakota initiated a PhD program around the competencies(Jarchow et al., 2018), as well as many other programs around the world(Salovaara et al., 2020). At the same time, research has suggested that if universities aspire that their students develop sustainability competencies, novel teaching and learning approaches will be required (M Barth, 2015; Matthias Barth & Michelsen, 2013; Brundiers et al., 2010; Frisk & Larson, 2011). A wide range of new teaching approaches has emerged such as project-based learning(Konrad et al., 2020a), experiential learning(Birdman et al., 2020), and living laboratories(Pretorius et al., 2019) to name a few. Yet, so far there is a lack of evidence if and to what extent these (or more traditional approaches) are successful in developing sustainability competencies in students.

Individual faculty have made some attempts to assess the impact of their novel teaching approaches on development of the key competencies in students (Lans et al., 2014; Remington-Doucette et al., 2013; Savage et al., 2015), but these efforts are as of yet insufficient to offer any generalizable insights. Universities that have incorporated sustainability competencies as explicit program-level learning outcomes are generally *assuming* that students who complete their curriculum will develop these competencies, but not evaluating if this is actually the case. While this lack of outcome evaluation is quite typical in higher education (Keeling, Hersh 2011), it is a flawed practice, in particular, in a field that needs to graduate change agents with the highest levels of competencies possible. A key missing piece needed to inform both sustainability programs and individual educators are valid and reliable ways to assess students' sustainability

competencies. This will allow to determine the extent a course or curriculum contributes to students' competencies development and if graduates of a program deserve the distinction of sustainability change agents.

2. State of the Research

A re-orientation of educational outcomes towards competencies has received widespread support from both researchers and practitioners (Frey, Hartig 2009). Definitions of competencies vary between authors (Baartman et al. 2007; Frey, Hartig 2009; Hartig et al. 2007), but not so much as to be an impediment for progress. A definition of competence is as "a complex combination of knowledge, skills, understanding, values, attitudes and desire which lead to effective, embodied human action in the world, in a particular domain."(Crick, 2008) Competencies are most often defined independent of domain-specific content knowledge, which allows articulating competencies across different disciplines and professions. Competencies differ from more traditional learning objectives for three key reasons: 1) inclusion of skills and non-cognitive dispositions along with the typical focus on cognitive knowledge, 2) clustering inter-related knowledge, skills and attitudes which may span traditional disciplinary boundaries, and 3) an emphasis on their applicability to performance in real-world and/or job contexts.

A decade ago, Wiek and colleagues (2011) surveyed the literature and distilled from it a framework of key competencies in sustainability. These five competencies have proven to resonate with many scholars and a recent review of the sustainability education literature overall found this article to be "the most influential paper" in the field (Grosseck et al., 2019). Nonetheless, "new" sets of competencies continue to crop up making the claim there is still a lack of consensus (Wolbring & Burke, 2013). Much of this work has been found to have a poor theoretical and conceptual grounding (Galleli et al., 2019). And little help in terms of consensus

building comes from the UNESCO. Yet, NCSE has recently undertaken an expert Delphi that largely supports the Wiek et al. (2011) framework (Brundiers et al., 2020). The experts who participated proposed several modifications including two additional competencies. Yet there remains unsettled issues such as whether to include an intrapersonal competence. While no one doubts the importance of its components whether this is a competency and if not how it might be integrated into educational programs is controversial. To instructors and program directors, however, learning objectives for sustainability courses and programs might continue to seem disperse and ambivalent.

Even without explicit consensus, the theoretical and practical development of competencies has run ahead of developing tools to adequately evaluate them. Traditional methods of assessment are generally seen as inadequate for measuring multi-dimensional and performance-oriented competencies (Frey, Hartig 2009). Therefore, new approaches are needed and much exploratory work in this direction has begun (Hartig et al. 2007). The medical field in particular has led the way in assessing competency with Miller (1990) proposing a general framework for assessment 30 years ago. This long history has enabled the extraction of generalizable insights from a large body of practice. Out of these experiences, Anderson et al. (2005) described three aspects that should underpin any assessment of competencies: 1) be systematic and continuous, 2) focus on student learning, and 3) design to support improvement of educational programs. The complexity of a competency suggests that it can only validly be assessed through a combination of different methods or what Baartman et al. (2007) call a “Competence Assessment Program” (CAP). They identify ten quality criteria: authenticity, cognitive complexity, fairness, meaningfulness, directness, transparency, educational consequences, reproducibility of decisions, comparability, and costs & efficiency.

For sustainability in particular, Barth (2009) proposed a set of necessary steps to be carried out before the measurement of key competencies can be done. First, that the specific characteristics of the key competency construct be considered. Second, that the key competencies chosen for measurement have a strong theoretical and conceptual foundation. Third, that they be operationalized and described in detail. Fourth, the balance between assessing the individual components versus the interactions between those components needs to be explicitly considered. Finally, he advises that it is "imperative to define and to empirically verify relevant competency levels and their effects on action in different context, and to test the adequacy of different approaches."

Unfortunately, although numerous attempts to assess the impact of novel teaching and learning methods on sustainability competencies have been published, no comprehensive approach as outlined by Barth (2009) or Baartman et al. (2007) have so far been attempted. Rather, these endeavors have used instruments ranging widely in quality. One of the more coherent efforts was the case study approach deployed over several years by Remington-Doucette and colleagues (Hiller Connell et al. 2012; Remington-Doucette, Musgrove 2015; Remington-Doucette et al. 2013). The more common approach is the self-assessment (Savage et al. 2015), and while some are quite critical of its usefulness and validity (Sandri et al. 2016), others think it be useful if carefully developed (Khaled et al. 2014; Galt et al. 2013). Interviews(Feriver et al., 2019), focus groups(Konrad et al., 2020a), reflections(Gardiner & Rieckmann, 2015), and assessment of class work(Habron et al., 2012) are some of the other ways that researchers have attempted to assess students' sustainability competencies.

There have been no systematic attempts to analyze sustainability competencies in students. Individual efforts have neither been repeated over sufficient time (i.e. repeatedly with multiple

groups of different or the same students), nor have the same tools been applied broadly. The ability to implement either of these approaches is hampered by a lack of comparative studies which examine the tools in use. This has in the end resulted in there being little reliable information about the current state of students' sustainability competencies. Individual cases have used assessment to demonstrate their own success but how this compares to each other or to a counterfactual baseline is completely unknown.

3. Research Questions

The aim of this dissertation is to produce insights on current practice and framings of learning objectives in sustainability and their assessment in response to the problems and research gaps described above. This research sought to answer three questions:

1. Study #1: Despite the proliferation of publications, is there an implicit consensus around key competencies in sustainability which can be articulated into a shared framework broadly useful for sustainability education?
2. Study #2: What is the current state of assessment of sustainability competencies and what has been learned from practice and research so far?
3. Study #3: What can numerous recent assessments of competencies tell us about the practice of assessment and the current state of students' sustainability competencies?

This dissertation is situated within the larger scope of the "Educating Future Change Agents" project – a collaboration between Leuphana University of Lüneburg and Arizona State University.

4. Research Design

Study #1 systematically reviews the published literature on key competencies in sustainability. The review narrowed down an initial pool of 3898 publications to a pool of 235,

which described sustainability competencies (or similar concepts). These were analyzed using a variety of approaches and found an implicit convergence below a surface of dispersed diversity. This convergence is articulated into a proposed framework to provide a consensus foundation for operationalization in diverse sustainability education programs.

Study #2 applies a similar process of systematically reviewing the literature around sustainability competency assessment in order to assess the current state of practice. The criteria for inclusion for this study was publications which described actual assessments carried out of competencies in students. From reviewing these assessments it became clear that there was a typology of tool types. With this typology of tools the strengths and weaknesses are appraised, providing guidance for future research and practice.

Finally, in Study #3, the various competency assessments carried out as part of the Educating Future Change Agents project are examined in detail. The project provides a unique opportunity to look at a diverse array of tools which were applied across a variety of settings. By examining the results I reveal insights both into the practice of developing and using tools but also the results of such a set of assessments and what that says in terms of students' level of sustainability competencies.

CHAPTER 2

STUDY 1: COMPETENCIES FOR ADVANCING TRANSFORMATIONS TOWARDS SUSTAINABILITY

To achieve the Sustainable Development Goals (SDGs) by addressing persistent sustainability challenges such as climate change, biodiversity loss, and socio-economic injustices, requires new competencies in professionals and society at large(I. J. Gordon et al., 2019a; UNESCO, 2017). The number of sustainability programs at universities and colleges conveying such sustainability competencies has substantially increased worldwide (over 1,500 in the U.S. alone(Weiss & Barth, 2019)), driven in part by the United Nations Decade on Education for Sustainable Development (UNDESD, 2005-2014)(UNESCO, 2014). Yet, there still remains a lack of clarity and coordination regarding a unified framework of sustainability competencies as learning objectives(O'Byrne et al., 2015), which undermines effectiveness, innovation, and legitimacy of such programs(Vincent & Focht, 2009). Guidance is unlikely to come via high-level policy(Mochizuki, 2016), as neither the UNDESD, nor the more recent SDG 4.7, which calls for Education for Sustainable Development (ESD) globally(Giangrande et al., 2019), provide any explicit learning objectives, let alone a competencies framework. At the same time, the growing number of scholarly works on sustainability competencies in diverse disciplines, from science and engineering to teacher education, has remained dispersed and thus does not offer coherent direction either. In summary, there is a need for a unified framework of sustainability competencies to provide guidance to sustainability educators and to accelerate progress on achieving the SDGs.

Increasing publication efforts and the challenge of convergence

Publishing on sustainability competencies only began in earnest this millennium and has grown continuously between 1997 and 2019 (Fig. 1). Across the most relevant publications (n=235) [for the sampling, see methods section below], many perspectives are being represented across diverse scientific journals (more than 100), with the top 3 journals accounting for about one third (32%). Half of the sampled articles (n=117) were written for a particular discipline including business/entrepreneurship (n=27), engineering (n=25), teacher education (n=25) and many more such as design, computer science, health, tourism, facility management, agriculture/food, and construction. Geographically, the sample is far less diverse with only 7% of publications coming from outside of OECD member countries.

This diverse body of literature converges in the intention to prepare students for tackling sustainability challenges. Publication abstracts and titles typically include phrases explicitly referring to sustainability challenges (80%) and pointing to the need to address them (78%). This is grounded, to some extent, in the literature, with *Our Common Future* and the *UN Decade of Education for Sustainable Development* being the two most cited background references (by 25% and 24% of articles, respectively).

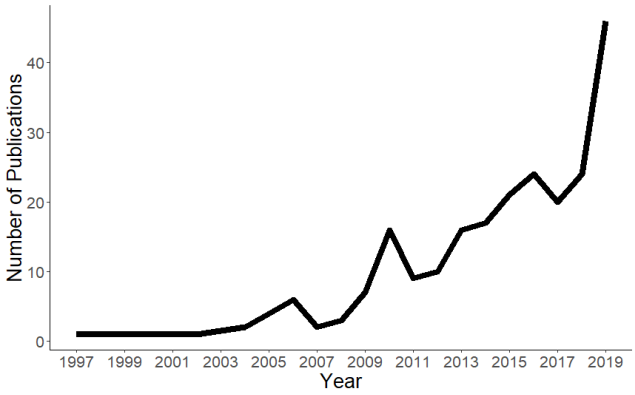

Figure 1: Number of publications on sustainability competencies in sample (n=235) by year (1997-2019)

The conducted literature search included common synonyms for learning objectives, e.g., "literacy"(Dawe et al., 2005) and "attributes"(Barrie, 2006), with "competencies" emerging as the most widely used term (Fig. 2). A competence is defined as "a complex combination of knowledge, skills, understanding, values, attitudes and desire which lead to effective, embodied human action in the world, in a particular domain."(Crick, 2008) Competencies are most often defined independent of domain-specific content knowledge, which allows articulating competencies across disciplines and professions. The competencies approach to education was broadly popularized decades ago through efforts such as the OECD-led initiative on "Definition and Selection of Competencies (DeSeCo)"(Rychen & Salganik, 2000). Yet, as late as in 2008, it was not seen as commonly used in sustainability education(Van Dam-Mieras et al., 2008), though with increased adoption since(M Barth, 2015).

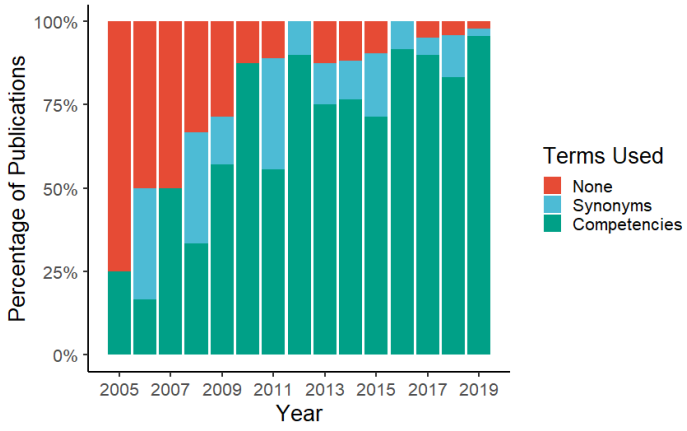

Figure 2. Percentage of sampled publications subset (n=225) mentioning competencies versus all other synonyms("literacy" etc.) in title or abstract by year (2005-2019) (publications prior to 2005 (n=10) were excluded for better presentability)

A common theme in the literature is that "no consensus has been reached within ESD discourses as to the process of how to identify essential abilities and as to a list of abilities seen as important".(Wolbring & Burke, 2013) This position lends legitimacy to the current practice of continuously re-inventing sustainability competencies in the literature. At the same time, there is

little explicit connectivity in the literature, with 40% of the articles (prior to 2019) not being cited by any others (in the whole sample).

Convergence on key competencies in sustainability

Yet, when looking beyond terminological differences, we find convergence in the literature on what graduates and professionals need to be capable of to advance transformations towards sustainability. The 2011 review article "Key competencies in sustainability – a reference framework for academic program development"(Wiek et al., 2011) was the first articluation of this convergence. The authors synthesized from the literature a framework of sustainability-problem solving competence, integrating five key competencies, namely, systems-thinking, anticipatory, normative, strategic, and interpersonal competence. This article has been received as a unifying framework[•] and identfied as "the most influential paper" in ESD(Grosseck et al., 2019, p. 26). Over the past decade, it has been cited by over 64% (n=115) of the sampled articles published in 2011 or after (n=179), and is already being used second hand (without citation)(Dlouhá et al., 2019). The second most cited publication(Matthias Barth et al., 2007) (by 32%) focuses on how competencies may be developed rather than offering a framework, while the third most cited publication(Rieckmann, 2012) (by 26%) distills expert opionions into a list of competencies, without synthesizing a framework. Beyond citations, the 2011 key competencies framework has facilitated explicit convergence, being used as the full foundation in 26 articles (15% of the sampled articles published 2011 and after) and as a partial foundation in 67 articles (37%), which has been continuously increasing year-by-year (Fig. 3a). Mapping this framework over the entire sample (n=235) between 1997 and 2019 demonstrates con-

[•] As of May 11, 2020: Google Scholar-1,293, Web of Science-576, SCOPUS-643.

vergence on these competencies (Fig. 3b). In addition, this framework has been applied in many real-world contexts from university programs(Boone, 2015; Jarchow et al., 2018; Richard et al., 2017) to K-12 teacher training(Archambault et al., 2013; Kieu et al., 2016), K-12 education directly(Rodríguez-Aboytes & Nieto-Caraveo, 2018; Wiek et al., 2016), and training for in-service professionals(Thomas & Millar, 2016).

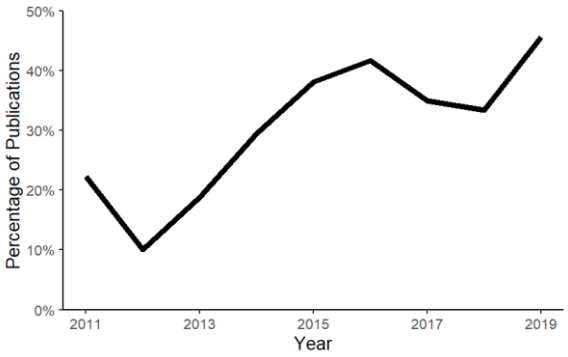

Figure 3a. Explicit use of the 2011 framework in sampled publications since its publication (n=179) (2011-2019)

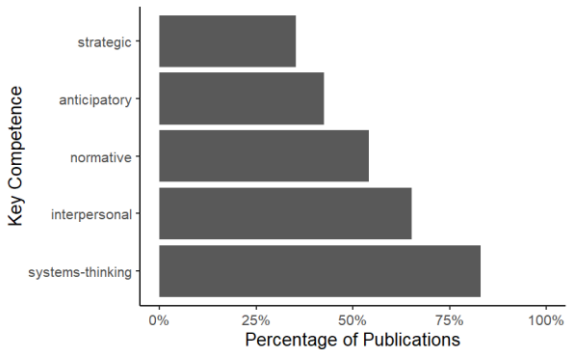

Figure 3b. Percentage of sampled publications (n=235) on competencies that can be mapped onto the 2011 framework (1997-2019)

Updating the 2011 key competencies framework

In the eight years since the publication of the 2011 key competencies framework (2011-2019), 179 articles were published that substantively engaged with the framework (beyond just citing it). Analysis of this body of literature identifies both insufficient receptions and productive suggestions relevant to an update.

Indicative of the deficient, yet prevailing *list*-approach to competencies, scholars often acknowledge the relevance of the five competencies and then add a competence or two without offering how those might integrate into the framework and specifically contribute to sustainability problem solving(Heiskanen et al., 2016). Beyond the lack of adopting the *framework*-approach, many articles lack concise definitions and clear conceptual development of new competencies, a flaw called out by several other reviews(Brundiers et al., 2020; Galleli et

al., 2019; Shephard et al., 2019; Sterling et al., 2017; Wilhelm et al., 2019). One example is "action competence" (Mogensen & Schnack, 2010), which is frequently added to the 2011 framework, but often confounded with strategic competence(Lans et al., 2014). Another common reception is to emphasize general and disciplinary competencies such as creativity(Lozano et al., 2017; Steiner & Scherr, 2013) or critical thinking(Fukushima et al., 2017; Rieckmann, 2012). As explained in the 2011 framework (p. 211), while these are necessary competencies for solving sustainability problems, they are not *key* competencies, as they are not distinct to *sustainability* but considered learning objectives of education *in general*(Voogt & Roblin, 2012).

Yet, there have also been a number of productive suggestions to expand the framework. Most relevant are three emerging competencies (for definitions, see Tab. 1), which have been proposed with varying frequencies (Fig. 4). *Intra*personal competence has been called out in several conceptual(Anderson, 2013) and empirical(Brundiers et al., 2020; Giangrande et al., 2019) studies; yet, there remains some disagreement on whether this is a competence or an underlying disposition(Brundiers et al., 2020). *Integration* competence has already been mentioned in the original framework (p. 212) and elaborated in an early update of the framework(Wiek et al., 2016); it has been mentioned frequently thereafter(Evans, 2019). The least frequent explicit proposal is for an implementation competence (see Fig 4). The 2011 framework focuses on the competence to *plan* sustainability problem solving, and only touches on competence to *implement* sustainability interventions and solutions. Some authors have argued that implementation competence deserves the status of a *key* competence in sustainability(Perez Salgado et al., 2018), which is in line with other more vague descriptions of strategic action competence(Frisk & Larson, 2011). There is emerging agreement that sustainability education ought to prepare students for *taking action*(Frisk & Larson, 2011;

Mogensen & Schnack, 2010); more specifically, for “collective interventions”(Clark, 2016; Perez Salgado et al., 2018) towards “transformative social change”(Glasser & Hirsh, 2016). As indicated in the original version of the framework (p. 214), this is a call for *collective* sustainability problem-solving competence that goes beyond the capacity of individuals(M Barth, 2015).

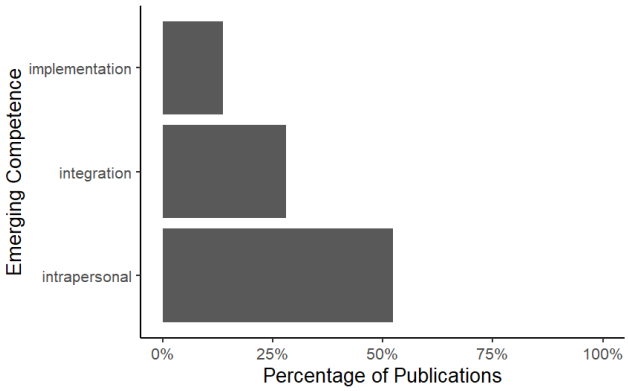

Figure 4. Percentage of sampled publications (n=235) that can be mapped onto the three emerging competencies (1997-2019)

Framework of competencies for advancing sustainability transformations

The extended framework of competencies for advancing sustainability transformations centers on 8 key competencies in sustainability (with 5 established and 3 emerging), and is complemented by disciplinary, general, and other professional competencies (Fig. 5). As a framework, the key competencies are *not* compiled as a *list* to select from; instead, *all* key competencies need to be integrated for advancing sustainability transformations. Systems-thinking, futures-thinking, values-thinking, and strategies-thinking enable crafting sustainability action plans that yield sustainability outcomes if successfully implemented (which requires implementation competence). Inter- and intra-personal competencies (key professional skills) enable that planning and implementation is undertaken in collaborative and self-caring ways – key factors for success(Frisk & Larson, 2011; Sipos et al., 2008). Finally, integration competence

enables a coherent combination of collaborative and self-caring planning and implementation efforts, using established procedures for sustainability problem solving(Angelstam et al., 2013; Henry, 2018; Polk, 2014; Wiek & Lang, 2016). Complementary competencies are organized on two axes: disciplinary competencies complement the (content-independent) key competencies through content-dependent expertise; general competencies such as critical thinking and creativity as well as other professional skills such as responsive project management are generic competencies (used in many different fields) that complement the sustainability-specific key competencies in efforts to advance sustainability transformations.

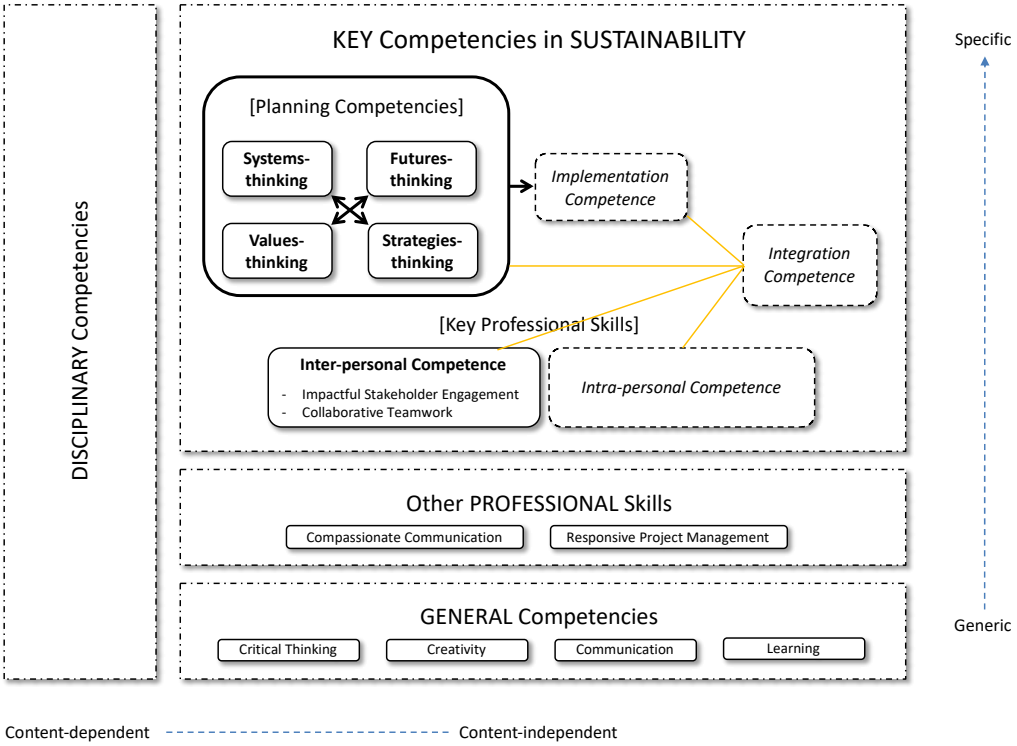

Figure 5. Integrated framework of competencies for advancing sustainability transformations; centered on 8 key competencies in sustainability with 5 established (bold) and 3 emerging (italic); and complemented by disciplinary, general, and other professional competencies.

Table 1. Definition and most common descriptors from the literature for each key competence in sustainability

Competence	Definition	Descriptors from the Literature
Systems-Thinking Competence	Ability to apply modeling and complex analytical approaches: (1) to analyze complex systems and sustainability problems across different domains (environmental, social, economic) and across different scales (local to global), including cascading effects, inertia, feedback loops, and other system dynamics; (2) to analyze the impacts of sustainability action plans (strategies) and interventions (how they change systems and problems).	Understand, identify, describe, analyze sustainability challenges and problems, complex issues, effects, relationships, impacts, patterns, structures, unintended consequences, feedback loops, context, interactions, etc. across different domains (environmental, social, economic), scales (local to global), and perspectives (interdisciplinary), etc.(Connell et al., 2012; Gray, 2018; Levy et al., 2018; Mahaffy et al., 2017; O. J. Sandri, 2013; Schuler et al., 2018)
Futures-Thinking Competence	Ability to carry out or construct simulations, forecasts, scenarios, and visions: (1) to anticipate future states and dynamics of complex systems and sustainability problems; (2) to anticipate how sustainability action plans (strategies) might play out in the future (if implemented).	Anticipate, foresight, envision, craft, analyze, and evaluate long-term future consequences, scenarios (multiple futures), and visions regarding intergenerational equity, future generations, uncertainty, etc.(Gardiner & Rieckmann, 2015; Ojala, 2017; Withycombe, 2010)
Values-Thinking Competence	Ability to identify, map, specify, negotiate, and apply sustainability values, principles, and goals: (1) to assess the sustainability of current and/or future states of complex systems; and (2) to construct sustainability visions for these systems; (3) to assess the sustainability of action plans (strategies) and interventions.	Identify, assess, negotiate, reconcile, reflect on, map, apply sustainability principles, morals, norms, ethics, goals, integrity, justice, conflicts, trade-offs, etc.(Komasinkski & Ishimura, 2017; Remington-Doucette et al., 2014; Verma et al., 2016)
Strategies-Thinking Competence	Ability to construct and test viable strategies (action plans) for interventions, transitions, and transformations toward sustainability.	Design, create, develop, test transformative, innovative, viable, feasible interventions, transitions, strategies, action plans, solutions, etc. considering barriers, inertia, path dependence, carriers, assets, etc.(de Haan, 2006; Fukushima et al., 2017; Wesselink et al., 2015)
Implementation Competence	Ability to put sustainability strategies (action plans) into action, including implementation, adaptation, transfer and scaling, in effective and efficient ways.	Implement, enact, adapt, manage, transfer, scale action plans, strategies, change plans, intervention plans, governance initiatives, etc.(de Haan, 2006; Perez Salgado et al., 2018; Schank & Rieckmann, 2019)
Interpersonal Competence	Ability (1) to collaborate successfully in inter-disciplinary and -professional teams; and (2) to involve diverse stakeholders, in meaningful and effective ways, in advancing sustainability transformations.	Enable, motivate, facilitate interdisciplinary, transdisciplinary, cross-cultural collaboration in teams and among stakeholders through listening, compassionate communication, negotiation, conflict resolution, empathic leadership, etc.(Brundiers & Wiek, 2017; Sarpin et al., 2018; Ulrich, 2016)
Intrapersonal Competence	Ability to avoid personal health challenges and burnout in advancing sustainability transformations through resilience-oriented self-care (awareness and self-regulation).	Reflect, motivate, have respect for, be responsible, be empathetic, self-care for identity, commitment, feelings, burnout, personal boundaries, limits of capacity, etc.(Giangrande et al., 2019; Glasser & Hirsh, 2016; Lozano et al., 2017)
Integration Competence	Ability to apply collective problem-solving procedures to complex sustainability problems: (1) to develop viable sustainability strategies (action plans); and (2) successfully implement them, in collaborative and self-caring ways.	Develop, apply, promote, make decisions to advance sustainability by using viable, equitable, and inclusive solution processes, procedures, frameworks, schemes, etc.(Hull et al., 2016; Jegstad & Sinnes, 2015; Wiek et al., 2016)

Competencies that fulfill important functions complementary the key competencies in sustainability can be differentiated into disciplinary, general, and other professional competencies.

Disciplinary competence: There is broad agreement that advancing sustainability transformations requires content-dependent competencies, e.g., on climate, water, energy, food, international development(Dale & Newman, 2005; Demssie et al., 2019). Disciplinary specialties will be critical complements to the content-independent sustainability competencies, resulting in "t-shaped" professional profiles(Conley et al., 2017; Uhlenbrook & de Jong, 2012).

General: Although there are no universally agreed-upon general competencies, Binkley and colleagues(Binkley et al., 2012) distilled a broad sample of literature into a set of ten so-called "21st century skills". Four of these general competencies were also frequently mentioned in the literature reviewed in the present study(Lozano et al., 2017) and can therefore be considered important complementary general competencies for advancing sustainability transformations, namely, the abilities of critical thinking, creativity, communication, and learning.

Other Professional skills: As indicated above, inter- and intra-personal competencies are considered key competencies in sustainability, shared mostly with other caring professions, e.g., medicine, nursing, social work. In addition, two other, more 'regular', professional skills, namely (advanced) compassionate communication and responsive project management, are important for advancing sustainability transformations on a more basic level(Brundiers & Wiek, 2017; Lozano et al., 2017; MacDonald & Shriberg, 2016).

Discussion

This systematic review of the growing body of literature found, despite appearances to the contrary, convergence on what competencies sustainability education ought to convey. In particular, the five key competencies described through a framework in 2011(Wiek et al., 2011), namely, systems-thinking, anticipatory, normative, strategic, and interpersonal competence, have gained widespread use and several productive propositions have emerged as well. Integrating the advances of the last decade, a framework of eight key competencies in sustainability is described, along with three classes of complementary competencies which form the best published scholarly knowledge of how to equip sustainability change agents to advance sustainability transformations. While this study focused on the perspectives captured in the literature, reviews of university sustainability programs(Salovaara et al., 2020; Trencher et al., 2018) and expert surveys(Brundiers et al., 2020; Demssie et al., 2019; Rieckmann, 2012) largely align with the findings presented here.

Zooming into the review results, systems thinking is the most established of the planning competencies, followed by interpersonal competence, which is addressed in many project-based sustainability courses(Konrad et al., 2020b) (Fig. 3b). However, these are the less transformative of the key competencies. Futures-, values-, and strategies-thinking competencies, so far established to a lesser extent, are critical for change that disrupts the status quo. These competencies enable graduates and professionals to envision sustainable futures, based on the SDGs, and develop effective and efficient strategies (action plans) to achieve them.

Beyond this, the three emerging competencies are much more unconventional, if not controversial. First, the aspects included as intrapersonal competence (self-awareness and self-care) are not part of typical learning objectives(Shephard, 2008) , and do not fit well with how

competencies are generally defined(Shephard et al., 2019). Yet, this points more to a broader issue in education: medical schools, for example, having long realized they need to address emotional, and not just intellectual development in students.(COOMBS & VIRSHUP, 1994) Second, while addressing sustainability problems is a common theme in sustainability education at the university level(Brundiers et al., 2010), this does usually not imply fully preparing graduates for *doing* sustainability(Alvarez & Rogers, 2006). Implementation competence calls for that to change, yet, this is a largely unexplored space for university programs. And third, this review showed that like other scientists, those in sustainability continue to dissect holistic processes (i.e. problem-solving), into constituent parts (i.e. lists of competencies)(Lozano et al., 2017). Integration competence pushes against this tendency and urges an emphasis on educating for the connections between competencies.

Sustainability science has developed and adopted a variety of approaches to solving problems(Angelstam et al., 2013; Henry, 2018; Polk, 2014; Wiek & Lang, 2016), and the extended framework centers on this evidence how professionals can best collectively engage in sustainability problem solving. Through this foundation, the framework is explicitly *not* intended to serve any specific discipline but should be adoptable by all disciplines and fields (with some relevance to sustainability). The framework offers a base from which to build off and specify learning objectives in life science, engineering, business, or teachers' education, to name a few. To this end, the language of the extended framework has been further universalized (e.g., "normative" is often mistranslated), and disciplinary competencies are now situated within the extended framework.

The reviewed literature focused on publications in English, which underrepresents large regions of the world; a problem confirmed in other studies(Weiss & Barth, 2019). Yet, little on

this topic has been published by researchers from outside the OECD. After many early calls for it(Mochizuki & Fadeeva, 2010), publications from underrepresented countries have recent increased (15 of 17 identified were published in the last 4 years), but more comprehensive inclusion of these perspectives is needed.

Conclusions

The results of this study show that, despite terminological differences, there is substantive convergence in the literature on what graduates and professionals need to be capable of to advance transformations towards sustainability. On this basis, the article describes a framework of eight key competencies in sustainability, broadly applicable to sustainability education in all disciplines. The extended framework of key competencies in sustainability links science, education, and society in the joint effort of broadening and accelerating transformations towards the Sustainable Development Goals. This does not mark the endpoint of needed research, rather an opportunity to make more substantive advances. Three immediate needs include: (1) research and development of the emerging competencies; (2) operationalization of the framework across disciplines, learning settings, and global contexts; and (3) testing the framework in real-world problem-solving settings. Even more fundamental though is the need for the community of scholars to come together and better coordinate their efforts. Complementary and comparative studies would overcome the current fractured structure of the field and allow for more robust and accelerated advances.

Methods

Collection and Selection of Literature. The primary academic databases, SCOPUS and Web of Science, as well as the education specific ERIC, and the more comprehensive Google Scholar, were used. Search terms included "education" AND "sustainability" OR "sustainable development" AND "competencies" OR "capabilities" OR "learning outcomes" OR "attributes" and were limited to English and publication through the end of 2019. This resulted in 3,898 publications once duplicates were removed. The exact search strings and conditions for each database are available in the supplementary material along with the full bibliographic file. This collection was then screened for publications which were focused on sustainability education of any type which described "competencies". The screening process was completed iteratively. First irrelevant publications based on titles (1747), abstracts (1241) and other (108) were excluded. Of the remainder, the full text was downloaded (except for 52 which could not be) and reviewed for a final exclusion (463). A detailed review of each of the remaining articles resulted in a few more exclusions (64) and a final sample of 235 articles. Supplementary materials provide more details and documentation of the procedure.

Analysis of Literature. Bibliographic information as well as any information coded or extracted from the publications was imported into R(R Core Team, 2020) which was utilized for all of the analysis. Counting publications per year and per journal was done based on bibliographic information. All other analyses necessitated additional coding as well as processing outside of R. Each publication was categorized by its intended target discipline and whether it represented a non-OECD member country. The publications were also reviewed and synthesized qualitatively.

Citations. For each publication, the citation count as of May 11, 2020 in Google Scholar was recorded and the references they cited was copied into a database. The frequency of inter-citation

was calculated by counting the number of times each publication was cited by others in the sample and dividing by the number of years since publication. The most cited publications by publications in the sample were examined, which identified two pieces of foundational literature. Having identified the Wiek et al. (2011) publication as the most influential publication in the sample, all publications which cited it were identified and reviewed. These were additionally coded if the proposed competencies came partially or fully from what Wiek et al. (2011) described.

Text Mining. The text of the titles and abstracts was searched using a basic text mining approach, namely, the synonyms for educational objectives and counts per year for each was calculated (results in figure 2.). This text was also searched for references to sustainability challenges and the need to solve them.

Capturing Learning Objectives. The descriptions of the proposed educational objectives for each article were copied out into a database. These descriptions were iteratively reviewed and mapped onto the original five key competencies, the three emerging, as well as the complementary competencies. The content of the descriptions was analyzed both with text mining techniques and with qualitative content analysis.

CHAPTER 3
STUDY 2: CURRENT PRACTICE OF ASSESSING STUDENTS' SUSTAINABILITY COMPETENCIES -- A REVIEW OF TOOLS

1. 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 (Matthias 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., 2020a), 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 (Matthias Barth & Michelsen, 2013; Brundiers et al., 2010; Frisk & Larson, 2011).

Yet, the practice of assessing students' sustainability competencies is still in its infancy (Eva-Maria 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 & Holland, 2015). Despite a growing body of research describing innovative pedagogies (Hallinger & Chatpinyakoop, 2019), there is a shortage of empirical evidence of

whether and in what ways these pedagogies are successful in developing students' sustainability competencies (Garrecht et al., 2018; Mindt & Rieckmann, 2017; Osagie et al., 2016). 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.

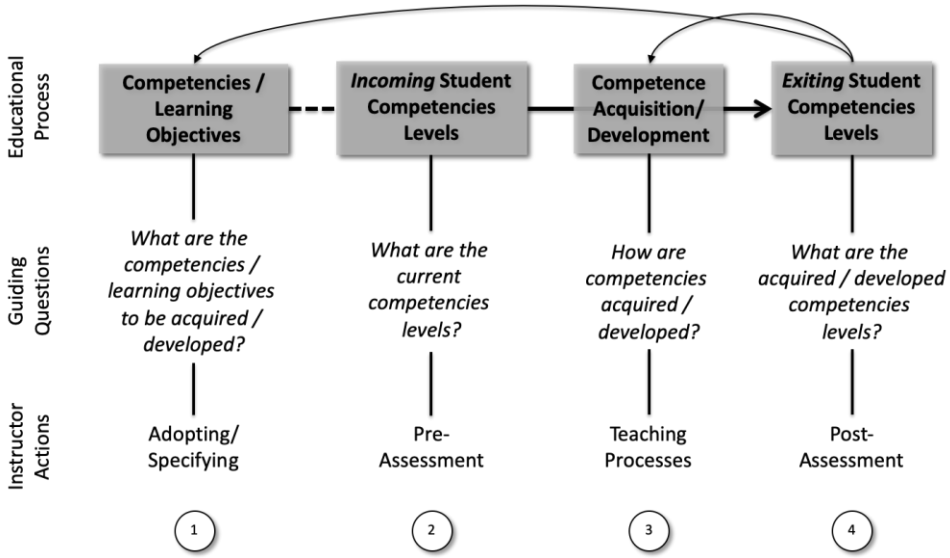

Figure 6. Framework which indicates the crucial role assessment plays in supporting student learning

Education science researchers have called out traditional methods of assessment as inadequate for measuring multi-dimensional and performance-oriented competencies (Frey & 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.

2. 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 3,908 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

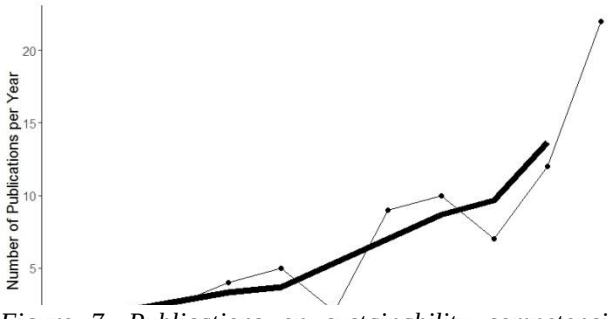

Figure 7. Publications on sustainability competencies assessments per year in final sample (solid line is rolling 3-year average)

the full text. This yielded 75 publications focused on sustainability competencies assessments (see appendix for a full description of procedures). For this sample, figure 2 shows the steady growth of publications on sustainability competencies assessments over the last ten years. But 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 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 fifteen 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 (Tab. 1). We then analyzed each tool (type) independently and in contrast to each other using a set of common attributes (Tab. 2). We finally appraised strengths and weaknesses of each tool (type), as well as explored potential improvements (Tab. 3). This appraisal was informed by insights on competencies assessments gleaned from the broader educational literature.

3. 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) (Tab. 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.

Table 2. 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

We first present examples of each tool (Tab. 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 and colleagues

(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 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.

Table 3. Examples of each Assessment Tool with Description and Application

	Example Tool Used				Example Tool Application					Source
Tool	**Competencies**	**Assessment Data**	**Testing Time**	**Analysis**	**Location**	**Program**	**Part**	**Timespan**	**N***	
Scaled Self-Assessment	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 undergraduate students (4 years)	Whole program	Single Cohort	32	Savage et al. (2015)
Reflective Writing	Five responsible leadership competencies (Maak & 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. (2020b)
Performance	Professional skills	Community "clients" are asked to provide	Post	Calculates and compares	University of	Professional Master program	Mandatory first	1 year	13	Kricsfalusy et al. (2018)

	Example Tool Used				Example Tool Application					Source
Tool	**Competencies**	**Assessment Data**	**Testing Time**	**Analysis**	**Location**	**Program**	**Part**	**Timespan**	**N***	
Observation	from various sources (Fallows & Steven, 2000)	feedback on student performance by rating their agreement with seven statements (e.g. "Students were well-prepared") as well as providing opened-ended feedback.		agreement percentages for each statement. Open responses were analyzed unsystematically	Saskatchewan, Canada	of Sustainable Environmental Management (1 year)	course "Field Skills in Environment and Sustainability			
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 reflections are also analyzed	Michigan State University, USA	Minor in Sustainability (4 years)	Graduation requirement of program	3 years	13	Habron (2015)
Concept Mapping	Systems thinking of the framework from Wiek et al. (Wiek et al., 2011)	Students are asked to create a concept (system) map for a sustainability issue (20 minutes)	Pre and Post	Uses a rubric to guide counts of nodes, connections, and levels of hierarchy as well as evaluating content knowledge. 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)

Tool	Example Tool Used				Example Tool Application					Source
	Competencies	**Assessment Data**	**Testing Time**	**Analysis**	**Location**	**Program**	**Part**	**Timespan**	**N***	
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)
Conventional 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)

*N is the number of students assessed in the example application

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 Tab. 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 (Tab. 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.

Table 4. Appraisal of the Assessment Tools Organized by Cluster

Cluster 1: Self-perceiving-based assessment procedures				
Tool	**Current Practice**	**Strengths**	**Weaknesses**	**Potential Improvements**
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 & 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 & Lieblein, 2016) • Statistically test constructs with appropriate samples (Lans et al., 2014) • Build psychometric models which robustly link competencies to tool (Cabral & 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 & Ozbek, 2013) and as a sustainability-relevant competence (Migliorini & 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) (S. Gordon & Thomas, 2018) • Students are unreliable evaluators of their competence (Clevenger & Ozbek, 2013)	• Train students in reflection, specifically on their learning and competencies (Gardiner & Rieckmann, 2015) • Develop a reliable coding book via qualitative content analysis (Sroufe et al., 2015) • Tailor reflection assignment to the instructional goals (Migliorini & Lieblein, 2016) • Integrate with other forms of assessment (Clevenger & 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 (Molderez & Fonseca, 2018) • 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 (Acocella, 2012)	• 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., 2020b)
Cluster 2: Observation-based assessment procedures				
Tool	**Current Practice**	**Strengths**	**Weaknesses**	**Potential Improvements**
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 & 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 & 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 & 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				
Tool	**Current Practice**	**Strengths**	**Weaknesses**	**Potential Improvements**
Concept Mapping	• Students draw a concept (system) map based on a prompt within a time limit (15-20 minutes) • Analysis is done by 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 & 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	• Students demonstrate competence in a real situation (O. Sandri et al., 2018) • The cases can be designed based on the types of challenges that competencies are supposed to help with (Eggert & Bögeholz, 2009) • Rigorous work to craft and then to improve tools has	• 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 in order to get sincere effort • Significant time is required to analyze open responses and develop quality criteria for responses (Baggen et al., 2017)	• 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 & Musgrove, 2015) • Include as part of course to ensure full and sincere student participation

	• Rubric to evaluate open responses on a scale (e.g. 0-5) • Before and After the course; One-off • Quantitative and/or qualitative analysis	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)	• Evaluates primarily conceptual aspects of competencies (Böhm et al., 2016)	• Apply published rubrics in additional cases (Remington-Doucette & Musgrove, 2015)
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 (O. 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 (O. Sandri et al., 2018) • Lack of psychometric models linking the test questions to actual competencies (O. Sandri et al., 2018) • Rigor (including pilot testing, etc.) is needed for proper development (Eva-Maria Waltner et al., 2019) • Significant burden on students/class time in order to get sincere effort (O. 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 (Eva-Maria Waltner et al., 2019) • Include as part of course to ensure full and sincere student participation

4. 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 (Eva-Maria 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 figure 1 – unclear learning objectives (1) or the lack of a baseline assessment (2) undermine the effectiveness of even well-developed assessment tools.

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 & 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 et. al. (2011), a handful of studies explicitly proposed "new" competencies such as *Sustainability and Social Responsibility (*SSR) (Albareda Tiana & 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 & 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. 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 (Matthias Barth & 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 and colleagues (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 & Van Der Vleuten, 2011). Each assessment tool has inherent weaknesses even with proper development (which the typology helps to

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.

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 (Crow, 2012). 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.

5. 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.

CHAPTER 4

STUDY 3: ASSESSING SUSTAINABILITY COMPETENCIES: LESSONS FROM EMPIRICAL STUDIES

Introduction

Highlights

- The current practice of assessing key competencies in sustainability as cataloged in the literature uses eight distinct tools.
- Most of these tools are not adequately developed, tested, and validated across different learning formats and settings.
- Few explicit links are made to the progress in educational science on competence assessment
- Most studies assess competencies, but do not link them to specific teaching and learning processes.
- Recent empirical studies that assessed competencies have moved beyond scaled self-assessment.
- A review of recent empirical studies that assessed competencies suggests that while qualitative competence development can be captured, quantifying progress remains a challenge.

Research on education for sustainable development has grown at an increasing pace (Grosseck et al., 2019), with nearly 2/3 of publications appearing in the last five years (through 2018) (Hallinger & Chatpinyakoop, 2019). Despite this growth, reviews have found a lack of empirical studies (Garrecht et al., 2018; Mindt & Rieckmann, 2017), including studies on the assessment of learning outcomes (Metzler, E.T, & Kurz, 2018; Zlatkin-Troitschanskaia et al., 2019). While efforts by institutions (Yousey-Elsener et al., 2010) and individual scholars (Matthias Barth, 2009) laid groundwork for assessment within ESD over a decade ago, the actual practice of assessing competencies in sustainability has gotten off to a slower start, though it is now rapidly growing (Redman et al., 2020b).

There are critical gaps though. As with ESD in general, there is too little connection to work in the education sciences (Matthias Barth & Michelsen, 2013), where research into the assessment of competencies is well advanced (Leutner et al., 2017). Studies that report on assessing sustainability competencies are scattered over various publication outlets with little cohesion and low connectivity (Redman et al., 2020b). This makes it difficult to introduce

newcomers to the range of available assessment tools and to explore good practices across them. In addition, while many assessments are undertaken, substantive meta-studies are missing, and thus the field offers little insights on the current state of sustainability competencies across student populations.

In this chapter, we briefly (i) review the current practice of assessing key competencies in sustainability; (ii) portray and appraise a number of tools used in recent empirical studies; and (iii) offer preliminary insights on sustainability competencies from these studies.

The Current Practice of Assessing Key Competencies in Sustainability

Much initial efforts with ESD focused on developing assessment tools which measured non-cognitive dispositions, such as the New Ecological Paradigm (Hawcroft & Milfont, 2010). In parallel, assessments which focus on knowledge, have advanced significantly, the most prominent example being the Sulitest, which has been deployed with tens of thousands of students around the globe (Décamps et al., 2017). Yet, if learning outcomes are to shift from specific bits of knowledge and certain non-cognitive dispositions to sustainability competencies, assessment practices will need to change, too. Yousey-Elsener and colleagues (2010) describe an initial framework relating different aspects of competencies to different assessment tools.

Publications describing assessment approaches to key competencies in sustainability have been growing steadily over the last decade, with over 20 published in 2019 (Redman et al., 2020b). Across all relevant publications (n=75), eight distinct types of tools are currently being used. These are scaled self-assessment, reflective writing, scenario/case test, focus group/interview, performance observation, concept mapping, conventional test, and regular course work. These can be clustered into three meta-types, namely, self-perceiving-based, observation-based, and test-based assessment procedures (Tab. 1).

Table 5. Tools broadly used to assess key competencies in sustainability (Redman et al., 2020a)

Meta Cluster	Tool	Description	Example Source
Self-perceiving	Scaled Self-Assessment	*Students are asked to rate their own competence development based on a pre-determined scale*	Savage et al. (2015)
	Reflective Writing	*Students respond in writing to prompts reflecting on their competence development*	Sroufe et al. (2015)
	Focus Group/ Interview	*Students respond to prompts verbally reflecting on their competence development*	Konrad et al. (2020)
Observation	Performance Observation	*Students are evaluated for competence while carrying out course activities in the classroom or in professional settings*	Kricsfalusy et al. (2018)
	Regular Course Work	*Students complete regular course work which is analyzed for evidence of competencies*	Habron (2015)
Test	Concept Mapping	*Students are given a prompt and asked to create a two-dimensional image with nodes and connections (specific to systems-thinking competence)*	Foley et al. (2017)
	Scenario/ Case Test	*Students are presented with a case and asked to respond to specific competence-requiring prompts*	Remington-Doucette et al. (2013)
	Conven-tional Test	*Students take a test which may include multiple choices or short answers which are linked to competencies*	Álvarez-García et al. (2015)

There are several areas for improving the current assessment practice. First, research ought to build upon work already done on key competence assessment. While there is good convergence on a set of key competencies in sustainability (Redman et al., 2020a; Wiek et al., 2011, 2016), there is still a lot of variance in learning objectives across assessment studies. A unified approach to learning objectives or key competencies would allow for comparative studies and broader generalization (Redman et al., 2020a). Second, scaled self-assessment, the most commonly used tool, ought to be complemented by other assessment tools to account for its limitations in verifying students' learning outcomes. Some researchers have taken the promising approach of triangulating across several tools (Kricsfalusy et al., 2018), a practice which needs to

be done more frequently and systematically. Third, while a good number of assessment tools are in use, they are often not adequately developed, tested, and validated across different learning formats and settings (Redman et al., 2020b; Eva-Maria Waltner et al., 2019). Some authors have demonstrated how to thoroughly develop and test assessment tools (Foucrier & Wiek, 2020; Eva-Maria Waltner et al., 2019). Yet, these initial studies need to inspire broader validation efforts. Finally, the practice of competence assessment needs to experiment with more innovative approaches. This can be facilitated by drawing on ideas from other fields such as professional in-vivo simulation assessment, which were pioneered in medical and social work education (Foucrier & Wiek, 2020).

Table 6. Tools used in Educating Future Change Agents studies to assess key competencies in sustainability

Tool	Competencies assessed	Context	Instructions	When	Data Analysis	Appraisal of Application	Source
Scaled Self-Assessment	All key competencies in sustainability (Wiek et al., 2011)	ASU & Leuphana, graduate, sustainability, N=9	Rate own level of theoretical and practical competence on a scale of 1-9	Post each semester (x4)	Changes in responses were tracked and used as entry points for interviews	+ Easily administered and analyzed + Providing a critical entry point for reflection and interviews – Students had limited experiences on which to base their self-assessments – Students admittedly spent little time/effort on their responses	(Birdman et al., 2020) Ch. 7
Reflective Writing (w/interviews)	All key competencies in sustainability (Wiek et al., 2011)	ASU & Leuphana, graduate, sustainability, N=9	Write down specific examples from previous semester which justify competence rating	Post each semester (x4)	Written responses, transcribed interviews, and self-assessed scores were tracked	+ Noted by students to have supported their competence development + Enhanced the accompanying	(Birdman et al., 2020) Ch. 7

			Describe the activities you noted and explain why you selected them [interview]		across four semesters	scaled self-assessment – Time consuming to analyze – Challenge of comparability between students	
Focus group (w/photovoice)	All key competencies in sustainability (Wiek et al., 2011)	ASU, Leuphana, UPC, ETH, graduate, sustainability, N=46 Leuphana, undergraduate, teacher education, N=98 ASU & Leuphana, graduate, sustainability, N=9	Select a learning outcome and use a “skill tracing” handout to trace your learning journey Add key moments of learning to the course timeline and explain the associated photos you took	Post	Sessions were transcribed and researcher marked when a learning outcome was mentioned and linked those to a key competence	+ Noted by students to have supported their competence development + Discussions prompted more insights by students – Time consuming to analyze – Unable to provide much insight into complete individual competence development	(Birdman et al., 2020; Brandt et al., 2019; Konrad et al., 2020a, 2020b) Ch. 3, 4, 7
Performance Observation	All key competencies in sustainability	ASU, Leuphana, UPC, ETH, graduate,	Researchers observed students in and outside of classrooms,	During	Notes were qualitatively analyzed Provided context	+ Added extra data and validation without burdening students	(Birdman et al., 2020; Konrad

	(Wiek et al., 2011)	sustainability, N=46 ASU & Leuphana, graduate, sustainability, N=9	linking them to competencies (taking free notes)		which supported interviews and focus groups	+ Competence development was observed externally – Too challenging to track more than a few students – Interpretation is subjective, in particular without a rubric	et al., 2020b) Ch. 3, 7
Scenario/ Case Test	Pedagogical content knowledge (PCK)*	Leuphana, undergraduate, teacher education, N=98	Indicate in how far ESD didactic principles could be implemented for a given lesson plan on a scale of 1-5, and provide a short justification	Pre, Post	Scores were based on how close answers corresponded to the score of experts Justifications were rated by the researchers	+ Cases were carefully designed to reflect real performance challenges + Quantified scores enabled statistical analysis + Pre-existing scales – Closed responses proved limiting for generating data – May have measured student	Brandt et al., 2019 Ch. 4

						effort more than competence	
Conventional Test	Content knowledge (CK)* Attitude, teacher specific scales (e.g. ESD-related self-efficacy scale (Tomas et al., 2017)	Leuphana, undergraduate, teacher education, N=98	Define sustainability (your understanding) Rate agreement with a series of ESD-related statements on a scale from 1 to 4/5	Pre, Post	Answers were coded on a scale of 0-2 for a time perspective and 0-3 on a dimension perspective Paired t-tests were utilized to compare changes	+ Integrated into existing survey and administered at scale + Quantified scores enabled statistical analysis – Link to competencies was indirect* – May have measured student effort more than competence	Brandt et al., 2019 Ch. 4
In-vivo Simulation Test	Sustainability entrepreneurship competencies (linked to key competencies in sustainability; Foucrier and Wiek, 2019)	ASU, graduate, various programs, N=9	With a mock report as background material students responded to a set of five prompts in front of an actor panel which simulated testifying before a city council	Post	Using the examiners assessments (based on rubric), examiner notes, and transcripts, examination scorecards were completed	+ Case was designed to reflect real performance challenges + Rubric for rigorous performance assessment – Expensive in terms of both time and money	(Foucrier & Wiek, 2020) Ch. 5

					for each student	– Motivating students to prepare and engage is a challenge	

* While it is important that students in teacher education develop sustainability competencies, the ability to design teaching and learning settings that support development of sustainability competencies *in their future students* is important, too. Therefore, Brandt et al. (2019) assessed Pedagogical Content Knowledge (PCK, i.e. how to teach) *and* Content Knowledge (CK, what to teach); the latter informed by key competencies in sustainability.

Tools Used in Recent Competence Assessment Studies

As part of the Educating Future Change Agents project, a number of empirical studies (Birdman et al., 2020; Brandt et al., 2019; Foucrier & Wiek, 2020; Konrad et al., 2020b), summarized in chapters 3, 4, 5, and 7, used tools for assessing key competencies in sustainability. Table 2 portrays and appraises the assessment tools used, organized by the tool types presented above (Redman et al., 2020b). One of these studies (Foucrier & Wiek, 2020), pioneered in-vivo simulation assessment and thus adds a new assessment tool to the original ones identified.

While studies on sustainability competence assessment are dominated by scaled-self assessment (Redman et al., 2020b), the Educating Future Change Agents assessment studies applied a much wider range of assessment tools. Nonetheless, a number of these studies also relied on self-perception-based assessment tools. Yet, these tools, i.e., reflective writing (w/interviews) and focus group, were systematically developed, not only for assessment purposes but for wider didactical utility as well. Confirming previous findings, these studies suggest that self-perception-based tools not only allow for a qualitative assessment of competence development but – if designed accordingly – also advance students' learning through in-depth reflections.

The more innovative attempts to develop 'objective' measures of students' competence development yielded mixed success and demonstrated the challenges such efforts continue to encounter. Both the in-vivo simulation tool and the scenario/case test offer promise if they can be further developed and refined. For example, the cases which were used for the scenario/case test described in chapter 4 (Brandt et al., 2019), turned out to vary significantly in difficulty level while some of the questions provided little

useful data, i.e. response justifications (interview with author). Both these flaws could be resolved with further iterations and testing and with triangulation with other tools to validate the results. However, one concern is that all tools apart from scaled self-assessment were found to require a burdensome level of work, particularly in the analysis and interpretation of the data, calling for stronger institutional support to enhance the quality of competence assessments.

Results of Recent Sustainability Competence Assessments

The main purpose of assessing key competencies in the Educating Future Change Agents assessment studies was to provide empirical evidence for the efficacy of specific teaching and learning processes and less to thoroughly assess progress of individual students. Nonetheless, the different studies provided some evidence of students' competence development across a range of tools. The assessment results from each tool application are briefly described in Table 3.

Table 7. Results of assessing students' competence development in the Educating Future Change Agents assessment studies (by tool type)

Tool	Competence Assessment Results	Source
Scaled Self-Assessment	Self-rating of competence development at three times across two years and a final self-rating showed improvement in 80% of cases (# of students / 5 competencies).	(Birdman et al., 2020) Ch. 7
Reflective Writing (w/interviews)	Interviews revealed that students' confidence in their competence often declined as they learned more before going back up (in most cases). Success of course projects (outside of the student's individual control, at times) also played a role in the self-rating of their competence level.	(Birdman et al., 2020) Ch. 7
Focus group (w/photovoice)	One study found that students self-identified increased interpersonal competence as the main learning outcome of project-based sustainability courses. In the larger, teacher education courses, the focus groups yielded general patterns of improvement in key competencies, without individual tracking.	(Birdman et al., 2020; Brandt et al., 2019; Konrad et al., 2020a, 2020b) Ch. 3, 4, 7
Performance Observation	N/A. Was only used to study context, i.e., teaching characteristics and moments of learning, and did not directly measure competence development.	(Birdman et al., 2020; Konrad et al., 2020b) Ch. 3, 7
Scenario/ Case Test	Students showed improvement on implementing ESD didactic principles into lesson plans, but not on justifying those.	Brandt et al., 2019 Ch. 4
Conventional Test	Students showed significant improvement in defining sustainability by the end of the semester. Significant improvements across most of the scales, in particular the ESD-related self-efficacy.	Brandt et al., 2019 Ch. 4
In-vivo Simulation Test	Student performance (demonstration of entrepreneurship competencies) was low with only 4 out of 9 students receiving a passing score (> 50%).	(Foucrier & Wiek, 2020) Ch. 5

On the one hand, self-perception-based tools consistently found improvements in competence development. The scaled self-assessment data offered a few new insights but

only at the cohort level. For example, in the study by Brandt and colleagues (2019), the scaled self-assessment showed cohort level improvements but efforts to look at the profiles of individuals to find patterns did not succeed. On the other hand, the focus groups yielded evidence that students could identify improvements in their own competencies; for example, strong development of interpersonal competence in project-based sustainability courses. Focus groups also revealed that many students had only a superficial understanding of the competencies, particularly among the teacher education students. The reflective interviews with scaled self-assessment prompts generated more reliable insights into students' competence development for several reasons. First the repeated interviews can be used to check the students' memories for both the interviewer and the interviewee. Second, the interviewer is able to follow-up to ensure coverage of all competencies and clarify any misunderstandings. Most importantly, competence development is measured not by comparing between individuals who may have different interpretations but rather by tracking the development and change for each individual.

The other tools provided more ambiguous data about student development of competencies. Both the PCK written test and the in-vivo simulation test asked students to respond to professional situations which the course was designed to prepare them for. In both cases, students' responses to these situations showed major deficits. This was surprising as for both assessments the tools had been tailored to the learning objectives and contents of the courses. These results should be interpreted with caution as both tools were piloted and assessment results were partly depended on external factors (e.g., insufficient institutional support and embedding in curriculum). Yet, the poor results

might indicate that ‘objective’ competencies measure do not align with students’ self-assessment.

Discussion

The Educating Future Change Agents assessment studies analyzed in this chapter used a wide range of tools to assess students’ development of key competencies in sustainability. These tools contributed to the research in each study as was their primary purpose (demonstrating the outcomes of the studied learning and teaching processes). In addition, the assessments offer a non-representative account of current students’ development of key competencies in major sustainability education fields (general sustainability education, teacher education, management education). In general, positive progress by students in competence development was found, in particular when examined across an entire multi-year program (as opposed to a single course). But these results, while useful for the research questions at hand (specific learning and teaching processes), provided little evidence which could be used as an ‘objective’ and comparative measure of an individual student’s competence level.

These studies provide critical insights into the three meta-clusters of assessment tools identified in Redman et. al (2020b). Research in the Educating Future Change Agents project relied largely on students’ perceptions (cluster 1) to establish links between competencies and learning/teaching characteristics. Reflective interviews using self-assessment as a starting point showed it was possible to track students’ competence development over time in a robust fashion. While the formative potential of these approaches was confirmed (Andrade, 2019), its unreliability as an empirical tool was confirmed, too. Students’ self-assessments were influenced by what *appears* an obvious

learning outcome (although it might not be the only or the most salient one), recent events (e.g. successful final event), and a lack of experience with what to base self-assessments on. Assessments from cluster 2 (observations) provided qualitative confirmation of some self-perceptions results and highlighted the above-mentioned weaknesses. While helpful, cluster 2 assessments require resource-intensive and specific development of rubrics (cf. Albareda-Tiana et al., 2018).

The Scenario/Case Testing and In-vivo assessment tools (cluster 3) both ask students to respond to a simulated situation. Their responses are assessed against a rubric and an 'objective' measurement of the student's level of competence can be distilled. Properly developing these tools takes front-end development and piloting. There is also a question of whether these can be properly developed *and* be transferable to other contexts. For example, the scenario/case test developed for use with teacher education majors at Leuphana was not seen as directly transferable to ASU's program because the questions themselves were not seen as relevant to the US education system (interview with author). As other fields have already identified, e.g. medicine (Howley, 2004; Rethans et al., 2002) and social work (Crisp et al., 2006), advanced approaches are needed to assess competencies. This has begun to be recognized in ESD where multi-stage research projects have focused just on assessment tool development (Böhm et al., 2016; Holdsworth et al., 2019b; Remington-Doucette & Musgrove, 2015; E.-M. Waltner et al., 2018). The most significant progress in terms of assessing key competencies has come in systems thinking with assessment tools such as concept mapping (Foley et al., 2017) but also because of its broad appeal across disciplines (Mehren et al., 2018; York et al., 2019). Yet, with cluster 3 assessment tools it is also clear that the fact they were not

"graded" certainly influenced student effort, as other studies have found variance in scores may be largely driven by effort invested (Zamarro et al., 2019).

Triangulating assessment tools to address weaknesses of any individual tool has been utilized before but often in a haphazard manner (e.g. Kricsfalusy et al., 2018). Yet, assessments results can vary significantly among assessment tools (Levesque & Blackstone, 2020). It can be a challenge to square ambiguous assessment results from an 'objective' tool with apparent student progress yielded through another assessment tool. Similarly, ambiguous results were produced when the team attempted to develop a generic tool to use across cases. The insufficiency of these results demonstrated that while the cases were all grounded in the key competencies (Wiek et al., 2011), it was nonetheless necessary to specify assessment for the particular context in order to produce useful results (Schuwirth & Van Der Vleuten, 2011). One assessment tool which was used across a range of contexts was the focus group with photovoice. But the results from this tool, while useful for the research, are not easily comparable between studies or helpful in providing measurements of an individual student's progress.

Conclusions

Despite significant resources and explicit support from both institutions and instructors, the Educating Future Change Agents project did not administer a consistent and robust set of assessments across its studies. Efforts to move beyond scaled self-assessment and to apply more 'objective' assessment tools were met with mixed results but did reveal some evidence about what works and what does not (and why), as well as trade-offs which are inherent in these efforts. For example there is a trade-off between being able to measure changes at a group level versus track individual progress. Some

tools such as the scenario/case test showed improvements at the course level but were unhelpful in understanding the individual student's journey. There appears to be also a trade-off between specifying an assessment tool for a particular context, and its ability to be used for comparative and generalization purposes. These trade-offs can be somewhat addressed through the purposeful and systematic triangulation of different tools beyond what was even done in the examined studies (e.g. instructor interviews, assignment analysis). The context dependence of successful assessment of key competencies may point to the need for the sub-fields (e.g. teacher education), to focus on their own specific approaches, rather than attempt to develop tools that bridge the entire field of ESD.

The development and preparation of effective tools for assessing competencies takes more work than the average research instrument. Thus, thoroughly planning the assessment strategy should become a priority in research projects on sustainability education, so that there is sufficient time for development and piloting. The most promising instruments, i.e. case/scenario test and in-vivo simulation test, also require the most preparation, development, and piloting. Researchers interviewed all expressed the sentiment that they were too pressed to have sufficient time to develop instruments at the beginning and too little time to analyze all the data they did collect afterwards. These challenges mean that despite recognizing the weaknesses of self-perception-based assessment tools, research in this project still heavily relied on it. In addition, despite explicit instructor and institutional support getting cluster 3 style assessment integrated into courses proved at times an insurmountable barrier. A key lesson to derive from our project is, therefore, that future projects should be cautious not to underestimate the strong path dependence of conventional assessment practice that might undermine even

the best intentions. It is not only ingenuity of researchers that is needed, but also overcoming various institutional inertia and barriers of our field that we all have internalized (our team included) and that take major extra efforts to overcome.

Yet, despite these institutional and other challenges of assessing competencies in higher education, this is the educational setting with the most potential to develop meaningful assessment procedures that capture the complexity of key competencies in sustainability. Systematic efforts so far have almost exclusively focused at the K-12 level; yet, higher education offers more flexibility to develop performance-oriented and real-world assessment approaches. Given that higher education students will shortly be entering the workforce, it is incumbent upon sustainability programs to show that teacher education students can implement ESD in the classroom (PCK test) or that entrepreneurs can launch sustainability enterprises (in-vivo simulation). We call upon the creativity of sustainability scholars to initiate and implement new and meaningful assessment procedures that will provide us with a much more nuanced feedback on the actual competence development of our students.

CHAPTER 5

CONCLUSION

1. Summary of Research

This research sought to fill several critical gaps in existing sustainability education research. The field of sustainability education has grown rapidly by the metrics of both research (articles published) and practice (new programs and enrolled students). This large body of work is overly diverse and redundant, which hinders programmatic development, teaching, and evaluation. Additionally, this also hinders the advancement of the field as work continues to be repeated rather than being built upon. This dissertation demonstrates that there is in fact a convergence in the learning objectives for sustainability programs, namely an extended framework of key competencies in sustainability; articulates a typology for assessing these key competencies that can guide practitioners and researchers alike; and appraises how initial empirical work in this direction has proceeded and what future directions seem promising.

Study #1 (Chapter 2) sought to answer the question, if, despite the proliferation of publications, there is an implicit consensus around a set of key competencies in sustainability which can be articulated into a shared framework broadly useful for sustainability education. A systematic review of the literature published through 2019 which defined key competencies (or closely related concepts) for sustainability education found an increasing convergence on an extended framework of key competencies in sustainability.

Study #2 (Chapter 3) investigates the current state of assessing sustainability competencies and asks what has been learned from practice and research so far. A

systematic literature review of publications which describe an assessment procedure used to measure competencies (through 2019) analyzes tools regarding their main features, including what competencies were assessed, the type of data that generated, how this data was analyzed, when and in what learning settings the assessments were carried out, to name the primary ones. Based on this analysis, a typology of assessment tools and specific examples of practice is provided, alongside with 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.

Study #3 (Chapter 4) utilizes the typology outlined in study #2 to assess a set of recent assessments carried out as part of the "Educating Future Change Agents" project. This study investigated what these systematic efforts to empirically measure competency could tell us about both the practice of assessment as well as the measurement results themselves. How the tools were designed and utilized was summarized and appraised, with strengths and weaknesses discussed.

2. Overall Findings and Contribution

The first main finding of this dissertation is that despite the increasing number of learning objectives being proposed in sustainability education, scholars are in fact coalescing around a distinct set of key competencies. There surely are some substantive differences between publications, but most of the differences are terminological in nature. By taking the extended framework described in chapter 2 as a starting point, the research and practice community can more properly address the substantive disagreements while

not hampering the advancement of the field in other directions. This includes operationalizing the key competencies for the numerous settings within sustainability education, developing assessment procedures, and designing programs among many others.

The second main finding is that while convergence may be implicitly occurring in objectives, the assessment of these competencies is not. The tool typology described in chapter 3 attempts to organize the field. One critical finding is that tools widely recognized as weak (e.g. scaled self-assessment) continue to predominate and insufficient effort is being invested in developing innovative tools to properly assess competencies.

The third main finding is that one critical barrier to productive sustainability education research is that projects are underestimating the challenge of assessing competencies both in terms of conceptual, technical and institutional challenges. In part this is because traditional assessments does a poor job of assessing competencies and thus significant innovation is needed. But taking innovation from idea to systematic practice is very challenging and both research into and the sustainability education programs themselves need to make sustained investments for any novel approaches to truly pay off.

Many higher education institutions have created programs with the express purpose of creating change agents. These change agents are indeed critically needed if society is to address its sustainability challenges. This dissertation contributes to supporting this process in several ways. Most importantly, it shows that there is a core framework of key competencies that should serve as a reference point for all sustainability programs. By building off the same framework, programs can better learn from each other and the research about what they need to be doing to most improve their

educational offering. On a similar vein, the research into the assessment of these competencies will be the key next step, largely untaken, by institutions seeking to educate sustainability change agents. Being able to assess how well they are doing in any systematic way is basically never done, yet of critical importance. Additionally, proper assessment will enable the students themselves to better direct their own learning. Sustainability students are among the most motivated in the world. This dissertation shows them what they need to be aiming for (key competencies) and ways they can measure their progress towards their goals (assessment), and using this guidance, institutions can further unleash these future leaders to create a better world.

3. Research Limitations and Future Research Needed

The research included in this dissertation has several limitations. While the key competency framework presented in study #1 is the best we can do with our available knowledge, it still falls short of what is truly needed. It remains largely based on a combination of theoretical framings and status quo needs (i.e. survey of current professionals). In contrast, the stated objective of these competencies is to prepare students to solve *future* sustainability challenges whose solutions we do not yet know. A critical next stage to this research is to validate this framework in the real-world as a check to whether these competencies are indeed what best supports change agents in creating such lasting solutions.

The analysis in study #2 was limited by a problem that study #1 seeks to address; that is the proliferation of slightly varying sets of competencies. While the literature was collected systematically, it was not possible to conduct a meta-analysis of the results of

the assessment tools. The limited quantity of studies using tools outside of scaled self-perception combined with limited reporting of details also hampered detailed appraisals of the more innovative approaches. Finally, similar to study #1, the literature review focused on studies in the academic literature published in English which makes it unrepresentative of a global perspective as well as efforts which are never published in such outlets.

Study #3 was only able to provide limited evidence, if the methods used in the "Educating Future Change Agents" project provide a template for future research and praxis because the diversity of tools used limited the sample population for each one. The solidification of these diverse tools will necessitate future work and development. Additionally, this study was only able to make tentative statements about how much competency development actually occurred in the students due to a combination of qualitative (non-comparable) results from some tools and ambiguous results from others. This study was a tentative first step of future research which builds off study #2. That is to utilize the typology proposed to conduct analysis and appraise those efforts systematically in a way that advances the field progressively.

Competencies are not a straightforward concept and one advantage of taking assessment seriously is that it forces one to confront this complexity. Part of the complication is the use of the same word to mean many things. Action competence is largely about the process of education, while narrow, vocational skills are often described as competencies, particularly in the Australian context. But aside from these, even if one sticks with the OECD sense of the word as it is used in this dissertation, competencies may just seem like a random jumble of things crammed together. Competencies are about

action in the real-world. But action in the real-world is messy and will never cleanly align with a narrow and specified construct of skills, knowledge, and attitude. I would argue that competencies emerge from the skills, attitudes, and knowledge that most frequently are used together. Hypothetically one could do a statistical analysis of thousands of change agents taking action in the real world and find that certain skills etc. tended to cluster and be used together more often…and these are competencies. The competencies are not built behind impenetrable walls. In fact this implies that there are skills etc. which are at the core and others which are more shared between competencies, something for future research.

I see the implications of this perspective to have several positive impacts on the discourse. Firstly, this moves away from the idea that we are confining students to a narrow set of learning so that they can fit in to the economic machine. Second, it pushes back against the idea that we need to come up with absolute, indisputable, and detailed universal definitions of each competency. And finally, it focuses the emphasis on assessment to be more about the outcome of successful action by the learner. As an example, there is no single right way to do a systems analysis when confronted with a real-world situation, and in fact there may even be multiple right answers and change agents will bring each their own configuration of systems thinking competence to the table.

Using competencies to structure learning outcomes, certainly makes things more complicated but it is necessary if we want students to become agents of transformational change. Incremental change can be driven by learning how to do what we already know. One can learn content knowledge and other traditional types of knowledge about

recycling, become an expert and maybe help increase the recycling rate by one or two percent. But transforming are linear, consumer system into a closed-loop, carbon neutral one is going to take transformation. And most importantly no one knows how to do it. We cannot "teach" students with a cookbook of how to make transformations to each problem. A focus on transformational change has significant implications for assessment. At the core it means assessment needs to confront students with the need for these type of transformations and assess their response to them. It also should force us as assessors to be more humble about the right answer. Proper assessment of competencies is and should be understand as a mutual learning exercise.

This dissertation has largely discussed assessment as it is (or isn't) happening at the course-level but that is not a reflection of how it should be, rather it is because this is where the most interesting research (in sustainability education at least) is happening. This is unfortunate because the challenges of truly effective sustainability competency assessment can probably only be overcome at the programmatic level. Sustainability education programs need to tackle this on two fronts. First they should be providing guidance and structure on how instructors can implement small scale assessments of competencies and use that to inform themselves and their students. More significantly, programs should work to develop major, perhaps multi-day assessments that take place multiple times over the course of a student's education. This is not just about satisfying administrators that you are doing what you say. Much more importantly, is that this should support the students in their own learning and finding a path to change agency.

I argued that competencies need to be articulated in frameworks rather than the common trope of lists, and this is also true of assessment approaches. Chapter 3 begins to

create this framework by identifying the three meta-clusters but this is only a start. A framework of competency assessments would provide guidance to an instructor (or program-level administrator) who is looking select, develop, and implement assessments. Beyond the meta-clusters another aspect of a future framework would be to show how assessments might be triangulated with each other. Which ones provide complementary information, which ones more overlapping? Thirdly, the framework should indicate whether there are certain competencies, or aspects of them with which a tool is particularly strong or weak. Put together a framework which are articulates these three elements would provide meaningful guidance.

In closing it is worth reflecting on the reliability of both the studies included here and competency assessments overall. Using a single researcher to conduct the selection process of the literature review and to analyze the selected articles is not ideal from a reliability perspective. None the less it was sufficient for the type of research conducted here. Firstly, I took a very conservative approach to article selection, tending to include rather than exclude, so feel confident that little if anything was ultimately missed. Secondly, inter-coder reliability testing within research teams offers less than it would appear, as our experience with EFCA project shows. After years of working together researchers converge in many ways and thus are likely to rate thing similarly when compared to a random outsider. Finally, the reliability was not a critical factor in the validity of the results of the studies, which are about how I synthesized the literature. Someone very well may synthesize it in a different way then I did, but any of the relevant results should be easily replicable (e.g. citation counts etc.), while the critical results (e.g. competency frameworks) are results not related to reliability (or unreliability) directly.

When it comes to assessment directly, there are well developed approaches to assessing the reliability of testing instruments. Proper reliability measurements would be crucial before initiating large-scale, high stakes assessment of sustainability competencies. But we are a long ways from that, and it should be questioned whether this somewhere we would ever want to be. I think of greater concern than reliability of the tools is whether they are valid in measuring what they claim to do (i.e. competence). Reliability should not be ignored, but for the purposes of supporting transformational change agents, it is not a top priority.

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APPENDIX A

IRB APPORVAL

ASU Knowledge Enterprise Development

EXEMPTION GRANTED

Arnim Wiek
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Dear Arnim Wiek:

On 11/28/2016 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Educating Future Change Agents-Higher Education as a Motor of the Sustainability Transformation
Investigator:	Arnim Wiek
IRB ID:	STUDY00005109
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• IRB_ConsentForm_V3.pdf, Category: Consent Form; • Website Content, Category: Recruitment Materials; • IRB_InterviewQs.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • IRB_RecruitmentScript.pdf, Category: Recruitment Materials; • IRB_Protocol_WP1_v4.docx, Category: IRB Protocol;

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2) Tests, surveys, interviews, or observation on 11/28/2016.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

APPENDIX B

STATEMENT OF PERMISSION FOR USE OF CO-AUTHORED ARTICLES

Dr. Arnim Wiek and Dr. Matthias Barth gave permission to publish coauthored work in this dissertation.

APPENDIX C
SUPPLEMENTARY MATERIALS FOR STUDY #1

Synthesizing a growing body of research such as that on sustainability competency assessment, is best done through a literature review (Snyder, 2019). For study #1 we conducted a literature review following the procedures laid out by Fink (2014) . This appendix describes how we followed Fink's guide to be systematic, explicit, comprehensive and reproducible. We sought to identify everything that has been published on sustainability competencies. In order to be sure that definitional differences did not accidentally exclude relevant articles we searched for synonyms of competencies. We sought to draw from as broad a pool of publications as possible thus we conducted our search on Web of Science, SCOPUS, ERIC, and Google Scholar. Based on other reviews we expected these databases to together 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
b. 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
c. 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
d. 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 this yielded 3,908 publications. Following PRISMA (Moher et al., 2009) and Fink's (2014) guide we then iteratively excluded publications by

first reviewing the titles, then abstracts and finally the fully text. This ultimately yielded 235 publications which were chosen for selection in this sample. The criteria we 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)

The following publications were included in the final sample:

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APPENDIX D

SUPPLEMENTARY MATERIALS FOR STUDY #2

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. In order 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:

b. 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
c. 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
d. 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
e. Google Scholar- search
    iv. 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
    v. Through 2019| Sustainability, education |Competencies: 750; Attributes: 250; Capabilities: 250; "Learning Outcomes": 250
    vi. 1,000 results

After duplicates were removed, 3,898 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 in order 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 said learning objectives

Table A1. 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

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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
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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

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