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REVIEW ARTICLE

Key competencies in sustainability: a reference framework for academic program development

Arnim Wiek · Lauren Withycombe · Charles L. Redman

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Abstract The emerging academic field focused on sustainability has been engaged in a rich and converging debate to define what key competencies are considered critical for graduating students to possess. For more than a decade, sustainability courses have been developed and taught in higher education, yet comprehensive academic programs in sustainability, on the undergraduate and graduate level, have emerged only over the last few years. Considering this recent institutional momentum, the time is seemingly right to synthesize the discussion about key competencies in sustainability in order to support these relatively young academic programs in shaping their profiles and achieving their ambitious missions. This article presents the results of a broad literature review. The review identifies the relevant literature on key competencies in sustainability; synthesizes the substantive contributions in a coherent framework of sustainability research and problem-solving competence; and addresses critical gaps in the conceptualization of key competencies in sustainability. Insights from this study lay the groundwork for institutional advancements in designing and revising academic programs; teaching and learning evaluations; as well as hiring and training faculty and staff.

Keywords Education for sustainable development · Curriculum development · Sustainability expertise · Sustainability professional · Transformative learning

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A. Wiek (✉) · L. Withycombe · C. L. Redman
School of Sustainability, Arizona State University, PO Box 875502, Tempe, AZ 85287-5502, USA
e-mail: arnim.wiek@asu.edu

Introduction

The emerging academic field focused on sustainability[1] aims to address complex anthropogenic challenges with a variety of research and teaching approaches that are problem driven and solution oriented (Kates et al. 2001; Clark and Dickson 2003; Swart et al. 2004; Komiyama and Takeuchi 2006; Grunwald 2007; Robinson 2008; Turner and Robbins 2008; Sarewitz and Kriebel 2010). The field's development is a response to existing and anticipated complex problems including climate change, desertification, poverty, pandemics, war—all featuring high degrees of complexity, damage potential, and urgency, and all having no obvious optimal solution. To solve these and other 'wicked' sustainability problems, the field generates, integrates and links use-inspired knowledge to transformational action in participatory, deliberative, and adaptive settings (Bäckstrand 2003; Grunwald 2004; Bammer 2005; van Kerkhoff and Lebel 2006; Blackstock and Carter 2007; Talwar et al. 2011).

The sustainability field has gained significant institutional momentum over the past few years, as mirrored in new academic journals and journal sections, conferences and symposia, academic societies, large-scale research projects, and educational advancements from general to higher education (Clark 2003; Rowe 2007; Kajikawa 2008).

[1] Some scholars articulate apprehension regarding the term 'sustainability science' (e.g., Hirsch Hadorn et al. 2006). Even if used in a broad sense including natural sciences, social sciences, and humanities, other important fields addressing sustainability issues such as engineering, business, design, and planning are not sufficiently captured and recognized under the term 'science'. With the formulation used above, we propose to overcome *all* of these demarcations as the field develops its genuine program beyond disciplinary anchoring (Wiek et al. 2010).

Sustainability's increased prominence in higher education is demonstrated by the proliferation of international events and commissions, and by the growing number of academic programs in sustainability, nationally from Arizona State University to Harvard University in the United States, and internationally from Lund University, Sweden, Maastricht University, The Netherlands, Leuphana University Lüneburg, Germany, and the Technical University of Catalonia, Barcelona, Spain to Stellenbosch University, South Africa, and the University of Tokyo, Japan.[2]

Despite some criticism (e.g., Hyland 2006), there is convergence in the educational literature about the critical role of defining key competencies and specific learning outcomes in order to successfully design and teach in academic programs (Burke 1989; Spady 1994; Bowden and Marton 1998; Voorhees 2001; Baartman et al. 2007). Key competencies provide an explicit and commonly shared framework for developing distinct and recognizable profiles of the academic field, the schools, the graduates, the professions, and so forth. Moreover, key competencies provide the reference scheme for transparently evaluating student learning and teaching effectiveness. For these new sustainability programs, key competencies are a critical reference point for developing the ambitious knowledge and skill profile of students expected to be future "problem solvers," "change agents," and "transition managers" (Orr 2002; Rowe 2007; Loorbach and Rotmans 2006; McArthur and Sachs 2009; Willard et al. 2010).

The educational literature on competencies in general, and competencies in sustainability in particular, entails a great deal of terminological ambiguity, associating the term "competencies" with skills, abilities, capabilities, capacities, qualifications and other concepts (Baartman et al. 2007). We employ in this article the definition of competence as *a functionally linked complex of knowledge, skills, and attitudes that enable successful task performance and problem solving* (cf. Spady 1994; Baartman et al. 2007). Applied to competencies in sustainability, these are complexes of knowledge, skills, and attitudes that enable successful task performance and problem solving *with respect to real-world sustainability problems, challenges, and opportunities* (cf. Dale and Newman 2005; Rowe 2007; Barth et al. 2007). Based on this definition, we differentiate competencies from learning outcomes—the former being fairly abstract and therefore in need of translation into specific learning outcomes to be operational (e.g., for curriculum development). Moreover, we differentiate competencies from *key* competencies, the latter being critically important for *sustainability* efforts, distinguishing them from those of other professions and academic programs. This distinction does not imply that "regular" competencies, such as critical thinking and basic communication skills, are not important for sustainability professions and academic programs (they are!). Rather, it emphasizes the competencies considered essential for sustainability that have not been the focus of traditional education and therefore require special attention. Finally, this article focuses on key competencies in sustainability only related to higher education and not to the full breath of educational programs.

Over the last few years, numerous articles and reports have made significant progress in conceptualizing key competencies in sustainability (Byrne 2000; de Haan 2006; Barth et al. 2007; Sipos et al. 2008; Segalas et al. 2009; Willard et al. 2010). However, the literature is still dominated by "laundry lists" of competencies rather than conceptually embedded sets of interlinked competencies. Moreover, proposed sets of competencies are largely fragmented rather than systematic and comprehensive.

This article synthesizes the literature on sustainability competencies into an over-arching framework. The framework is based on competence as problem-solving capacity, specified as sustainability research and problem-solving competence. We embrace the convergence that sustainability education should enable students to analyze and solve sustainability problems, to anticipate and prepare for future sustainability challenges, as well as to create and seize opportunities for sustainability. Because sustainability problems and challenges have specific characteristics (different from problems addressed in other fields), analyzing and solving sustainability problems requires a particular set of interlinked and interdependent key competencies (Wiek et al. 2010).

Specifically, our study pursued three objectives, namely, (1) to identify the relevant literature on key competencies in sustainability; (2) to synthesize identified competencies into a coherent framework, and (3) to identify critical gaps in the conceptualization of these key competencies. This study deliberately does not address subsequent questions of conveying and acquiring these competencies (pedagogy) (e.g., Brundiers et al. 2010), nor how to evaluate the acquisition of these competencies (program evaluation). Both questions are critically important for curriculum design and institutionalization, yet, require different approaches and considerations (Sterling 2001) and first necessitate a thoroughly conceptualized set of key competencies.

Insights from this study could benefit a range of institutional processes from designing and revising academic

[2] This is a selected list of sustainability programs worldwide. The indicated universities are the pioneering ones to offer a PhD program specifically in Sustainability (Science); with the exception of Harvard University, which offers doctoral and post-doctoral fellowships in Sustainability Science. The PhD-granting programs are all members of the nascent International Network of Programs in Sustainability. All PhD programs were initiated between 2007 and 2010.

programs (in particular newly emerging programs) through teaching and learning evaluations, to institutional decisions such as hiring and training faculty and staff.

The framework of sustainability research and problem-solving competence

Frameworks or unifying themes for key competencies in sustainability are not frequently used or discussed in the literature. 'Laundry lists' without transparent selection criteria dominate the discourse. It seems that the field is still in search of over-arching concepts that would relate and integrate sustainability competencies in a meaningful way. The few frameworks proposed, applied, or discussed are inspired by transformative learning concepts and propose as key competencies: Gestaltungskompetenz (de Haan 2006; Barth et al. 2007; van Dam-Mieras et al. 2008); Heads, Hands, and Heart (Sipos et al. 2008); Values, Knowing, Skills, Understanding (Parkin et al. 2004; Sterling and Thomas 2006; Segalas et al. 2009) and a few others (e.g., Steiner and Posch 2006).

These contributions converge towards a comprehensive key competence, namely, sustainability research and problem-solving competence, as recognized in other literature on sustainability science (Kates et al. 2001; Clark and Dickson 2003; Bäckstrand 2003) and sustainability education (Jucker 2002; Warburton 2003; Dale and Newman 2005; Rowe 2007; Earth Institute at Columbia University 2008). This over-arching competence is generally conceptualized as "having the skills, competencies and knowledge to enact changes in economic, ecological and social behavior without such changes always being merely a reaction to pre-existing problems" (de Haan 2006, p 22).

We contribute to this convergence with our literature review by creating and applying a common framework of sustainability research and problem solving to define and integrate key competencies in sustainability. The five key competencies are: systems-thinking competence, anticipatory competence, normative competence, strategic competence, and interpersonal competence.

The rationale behind this framework is a comprehensive approach to sustainability research and problem solving that requires the integration of the five key competencies. Different ways of solving complex sustainability problems have been proposed as: integrated planning (Ravetz 2000); backcasting (Robinson 2003); implementation sciences (Bammer 2005); transition management (Kemp et al. 2005; Loorbach and Rotmans 2006); transdisciplinary case study research (Scholz et al. 2006; Wiek and Walter 2009); and other approaches. From these approaches, we derive an integrated research and problem-solving framework for sustainability that serves as an organizing concept for the key competencies. Figure 1 depicts this integrated sustainability research and problem-solving framework.

Let us look at an example by assuming the ultimate goal of a sustainability activity our sustainability graduates engage in would be to develop, test and implement strategies for sustainable urban development. This calls for a well-founded strategic competence. These strategies are intended to redirect urban social-ecological systems from unsustainable trajectories toward a sustainable future state. To this end, the current state, past developments, as well as future trajectories of the city are analyzed systemically and key leverage or intervention points in the system are identified. This requires systems-thinking competence, and these points are assessed against sustainability criteria (to identify critical trajectories and consider trade-offs), which requires normative competence. Based on new knowledge and learning, the strategies are conceptualized as being continuously adapted in order to redirect path-dependent future trajectories in the city toward the visions of a sustainable future, which requires anticipatory competence. The collaboration among a suite of urban stakeholders, including scientists, policy-makers, managers, planners, and citizens is critical for understanding the system's

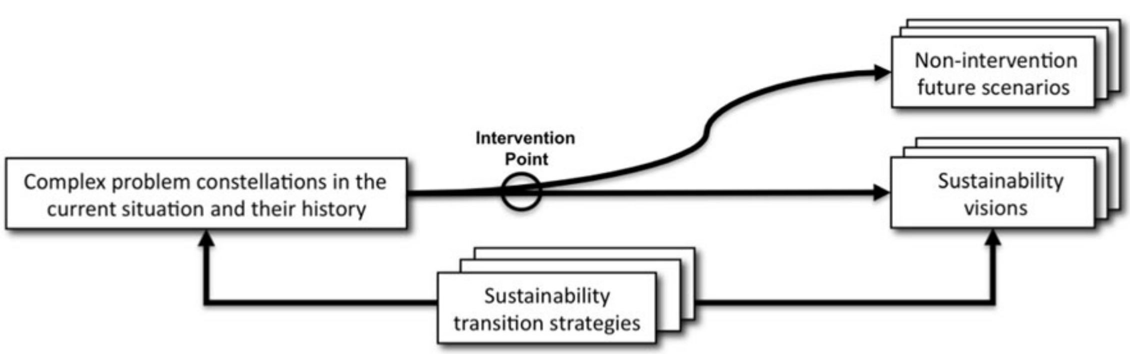

Fig. 1 Integrated sustainability research and problem-solving framework. The framework is structured in four modules: analyzing the current problem constellation(s); creating and crafting sustainability visions ("problem solved"); exploring less desirable future scenarios that might become reality without interventions towards sustainability; developing and testing strategies to transition from the current state to sustainable states without getting deflected towards undesirable pathways (critical intervention points) (adapted from: Wiek 2010)

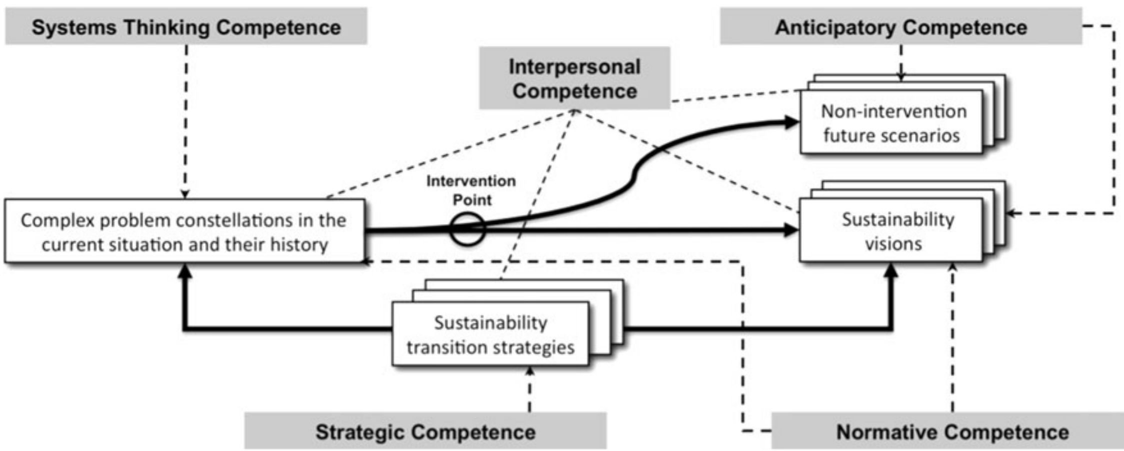

Fig. 2 The five key competencies in sustainability (*shaded in grey*) as they are linked to a sustainability research and problem-solving framework (see Fig. 1). The *dashed arrows* indicate the relevance of individual competencies for one or more components of the research and problem-solving framework (e.g., normative competence is relevant for the sustainability assessment of the current situation as well as for the crafting of sustainability visions)

complexity, exploring future alternatives, crafting sustainability visions, and developing robust strategies in ways that are scientifically credible, create shared ownership, and are conducive for action—all of which requires strong interpersonal competence.

Figure 2 depicts how the key competencies in sustainability are linked to the integrated research and problem-solving framework.

Methods

The literature review is based on data from peer-reviewed journal articles, grey literature (reports, white papers), university websites, and curricula publications. However, many university websites and curricula publications were still largely under construction or not fully accessible when this study was conducted. In addition, we found that grey literature overlapped significantly with the peer-reviewed literature (cf. Sterling and Thomas 2006; Svanström et al. 2008) and therefore primarily peer-reviewed journal articles and books are referenced in this article. Also included are sources that do not identify specific competencies, yet address the issue from a general perspective (e.g., Grunwald 2007). The literature search was conducted in *Google Scholar* (for scholarly articles and books) and *Google* (for grey literature and university documents) using the following keywords: "Sustainability" OR "Sustainable Development" AND "Higher Education," OR "Competencies," OR "Key Competencies," OR "Learning Goals," OR "Learning Outcomes." The literature search identified 43 relevant documents with a significant focus on competencies in sustainability, namely, 28 journal articles and books as well as 15 reports and white papers. The key journal articles analyzed are: Crofton 2000; Cusick 2008; de Haan 2006 (cf. Barth et al. 2007; van Dam-Mieras et al. 2008); Grunwald 2004, 2007; Jucker 2002; Kearins and Springett 2003; Kelly 2006; Kevany 2007; Ospina 2000; Rowe 2007; Segalas et al. 2009; Shephard 2007; Sipos et al. 2008; Steiner and Posch 2006; Sterling 1996; Sterling and Thomas 2006; Svanström et al. 2008; Wals and Jickling 2002; Warburton 2003; Welsh and Murray 2003.

In the literature review, we first listed, for each document, what each competence was entitled; what its definition and justification were (if available); and how it was linked to the other competencies (categorization or framework, if available). We subsequently cleaned the compilation by excluding elements that did not comply with the definition of competence (e.g., 'having fun'); competencies that did not comply with the definition of a key competence, such as critical thinking and basic communication skills; and competencies that appeared only once (no convergence).

We then clustered the compiled competencies according to conceptual similarities (across all sources) and guided by an integrated framework of key competencies for sustainability research and problem solving (see next section).

Finally, we synthesized and complemented the categorized competencies in short paragraphs including definition, justification, and examples. The justification was supported by additional literature on sustainability principles and basic concepts (e.g., Gibson 2006). Throughout the analysis, we ensured inter-rater reliability by independently conducting each step in part by two different raters. Nevertheless, the analysis of the literature data was not a mechanical but rather an interpretive process, guided by conceptual reasoning and based on continuous exchange with colleagues engaged in sustainability programs around the world (Wiek et al. 2011).

Results

Competencies compilation

The initial compilation indicates a rich picture of key competencies in sustainability; yet, convergence is obstructed by differing terminology in the majority of contributions and by the variety of frameworks that are not related to a common core concept (Table 1).

Synthesized sustainability research and problem-solving competencies

As suggested above, the goal of academic sustainability programs is to enable students to plan, conduct, and engage in sustainability research and problem solving based on the interplay of systems-thinking, anticipatory, normative, strategic, and interpersonal competencies. According to this framework, we characterize each of the competencies in short profiles based on the literature review and complementing arguments. The profiles provide for each competence: definition and justification; representative concepts, methodologies, and peer-reviewed "classics"; as well as links to other competencies, similar terms from literature, and a small set of excerpts from the reviewed literature (see Appendix). Examples of "classics" are used to illustrate what kind of work students should be familiar with in each competence domain but are not intended to be a comprehensive list of students' substantive knowledge. Excerpts are provided to convey a sense for the terminology and framing of competencies in the various strands of educational literature that informed this review.

Systems-thinking competence

Definition Systems-thinking competence is the ability to collectively analyze complex systems across different domains (society, environment, economy, etc.) and across different scales (local to global), thereby considering cascading effects, inertia, feedback loops and other systemic features related to sustainability issues and sustainability problem-solving frameworks. The term "complex system" has been used (along with "coupled human-environment systems" or "social-ecological systems") as an open notion to include qualitative data, quantitative data, narratives, "thick descriptions," etc. The ability to analyze complex systems includes comprehending, empirically verifying, and articulating their structure, key components, and dynamics. The capacity to analyze is based on acquired systemic knowledge including concepts such as structure, function, cause-effect relations, but also perceptions, motives, decisions, and regulations; peer-reviewed "classics" such as the Millennium Ecosystem Assessment report (MEA 2005); as well as methods and methodologies such as qualitative and quantitative modeling. Overall, these skills are specifically tailored to address key issues of sustainability including systems integrity, civility, and governance (see Table 3 in the Appendix).

Justification The concept of sustainability calls for a comprehensive systems understanding adequate to the complexity of coupled systems; the pursuit of systems integrity across the main domains, temporal and spatial scales; the understanding of cascading harmful effects and dynamics; and the transformation of individual actions and governance regimes (Gibson 2006; Clayton and Radcliffe 1996; Kates et al. 2001).

Concepts, methodologies, and peer-reviewed "classics" for systems-thinking competence

Concepts	Methodologies	Peer-reviewed "Classics"
Variables/indicators, sub-systems, structures, functions Feedback loops, complex cause-effect chains, cascading effects, inertia, tipping points, legacy, resilience, adaptation, structuration, etc. Across/multiple scales: local to global Across/multiple/coupled domains: society, environment, economy, technology, etc. People and social systems: values, preferences, needs, perceptions, (collective) actions, decisions, power, tactics, politics, laws, institutions, etc.	Qualitative and quantitative modeling Institutional, decision, governance, social systems analysis Multi-methodologies ("thick" description) Participatory systems approaches (e.g., participatory modeling)	Prominent comprehensive analyses of social-ecological systems (e.g., Millennium Ecosystem Assessment report: MEA 2005; Turner et al. 2003; Ostrom 2009); socio-technical systems (Perrow 1984; Collingridge 1980; Geels 2005) Prominent models (e.g., World3: Meadows et al. 1974)

Link to other competencies Systems-thinking competence is critically important for building transition strategies toward sustainability. An intimate understanding of the inner fabric and dynamics of complex social-ecological systems is a prerequisite for identifying intervention points, anticipating future trajectories and staging transition processes.

Similar terms from literature Systemic thinking, interconnected thinking, holistic thinking (see Table 3 in Appendix).

Anticipatory competence

Definition Anticipatory competence is the ability to collectively analyze, evaluate, and craft rich "pictures" of the

Table 1 Compilation of competencies in sustainability from selected peer-reviewed literature

Source	Competence in/being competent in …	Categorization/framework
Crofton (2000)	Anticipatory thinking extending to future generations	Sustainability obligations of professional engineers
	Identifying connections between multiple scales, holistic thinking	
	Understand the diversity of values and their implications	
	Communication and collaboration skills	
de Haan (2006)	Foresighted thinking	"Gestaltungskompetenz"
(cf. Barth et al. 2007; van Dam-Mieras et al. 2008)	Interdisciplinary work	
	Trans-cultural understanding and cooperation	
	Participation	
	Planning and implementation	
	Empathy, compassion and solidarity	
	Self-motivation and motivating others	
	Reflection on individual and cultural models	
Kearins and Springett (2003)	Reflexivity	Critical theory
	Critique	
	Social action/engagement	
Kelly (2006)	Global consciousness	"Globo sapiens"
	Considering changes to current ways of life	
	Trans-generational thinking	
	Generosity, openness, and serious engagement	
	Courage	
Rowe (2007)	Change-agent skills	Problem solving
	Problem-solving capacity	
Sipos et al. (2008)	Transdisciplinarity	Head, hands and heart
	Systems thinking	
	Conflict resolution	
	Collaboration	
	Empowering	
	Creativity	
	Inclusivity	
Sterling and Thomas (2006)	Valuing diversity, environment, justice	Values, knowing, skills, understanding
	Knowledge of interconnected ecological, social, economic systems	
	Knowledge of the principles of sustainable development	
	Holistic or systemic thinking and analysis	
	Knowledge of sustainability issues and problems	
	Working across disciplines	
	Cooperative action and conflict resolution	
	Dealing with uncertainty	
	Taking action to bring change	
ACPA.org (http://www2.myacpa.org/; cf. Svanström et al. 2008)	Mediating and resolving conflicts	Change agent
	Analyzing power structures of inequality	
	Recognizing global implications of actions	
	Spanning boundaries	
	Challenging the status quo	
	Solving sustainability problems	
	Collaboration, networking, developing alliances, building teams	
	Seeing the big picture, understanding need for systemic change	
	Being a leader and a follower	
	Scenario creation	
	Seeing the paths for change and following through	
	Understanding the functioning and interconnectedness of systems	
	Integrity	
	Courage	

future related to sustainability issues and sustainability problem-solving frameworks. The term “pictures” has been used (similar to “stories” or “images”) as an open notion to include qualitative information, quantitative information, narratives, imagery, etc. The ability to analyze pictures of the future includes being able to comprehend and articulate their structure, key components, and dynamics; the ability to evaluate refers to comparative skills that relate to the “state of the art”; finally, the ability to craft integrates creative and constructive skills. The capacities to analyze, evaluate, and craft are based on acquired future-oriented knowledge including concepts such as time and uncertainty; peer-reviewed “classics” such as the IPCC’s emission scenarios; as well as methods and methodologies such as simulation and scenario analysis. Overall, these skills are tailored to address key issues of sustainability, including unintended harmful consequences and intergenerational equity (see Table 4 in the Appendix).

Justification The concept of sustainability calls for long-term future orientation and envisioning (“sustaining”; “needs of future generations”), the anticipation and prevention of harmful unintended consequences, and the imperative of intergenerational equity (“future generations”) (Gibson 2006).

Concepts, methodologies, and peer-reviewed “classics” for anticipatory competence

Concepts	Methodologies	Peer-reviewed “classics”
Concepts of time including temporal phases (past, present, future), terms (short, long), states, continuity (dynamics, paths), non-linearity	Scenario methodology	Prominent scenarios and predictions (e.g., IPCC’s *Special Report on Emission Scenarios*: Nakicenovic et al. 2000)
	Forecasting from statistical and simulation models	
	Backcasting and envisioning methods	Prominent visions and “backcasts” (e.g., “The Great Transition”: Raskin et al. 2002)
Concept of uncertainty and epistemic status including possibility, probability, desirability of future developments (predictions, scenarios, visions)	Multi-methodologies	
	Participatory anticipatory approaches (e.g., Delphi, Future Workshop)	
Concepts of inertia, path dependency, non-interventions		
Concepts of consistency and plausibility of future developments		
Concepts of risk, intergenerational equity, precaution		

Link to other competencies Anticipatory competence is important in conjunction with sustainability assessments of future trajectories (cf. “anticipatory assessment”: Grunwald 2007), for the creation of transition strategies (cf. “backcasting”: Swart et al. 2004), as well as in conjunction with testing and continuously adapting transition strategies in order to redirect path-dependent future trajectories toward the visions of a sustainable future (cf. “anticipatory governance”: Guston 2008).

Similar terms from literature Anticipatory thinking, future thinking, foresighted thinking, trans-generational thinking (see Table 4 in Appendix).

Normative competence

Definition Normative competence is the ability to collectively map, specify, apply, reconcile, and negotiate sustainability values, principles, goals, and targets. This capacity enables, first, to collectively assess the (un-)sustainability of current and/or future states of social-ecological systems and, second, to collectively create and craft sustainability visions for these systems. This capacity is based on acquired normative knowledge including concepts of justice, equity, social-ecological integrity, and ethics (e.g., to know which practices can be transformed or discarded and which must be maintained to sustain viability of life-supporting systems); peer-reviewed “classics” such as the “Brundtland Report” (World Commission on Environment and Development 1987); as well as methods and methodologies such as multi-criteria assessment and structured visioning. Overall, these skills are tailored to address key issues of sustainability including socio-ecological systems integrity, intra- and intergenerational equity (see Table 5 in the Appendix).

Justification Addressing sustainability problems and opportunities requires going beyond descriptive questions of how complex social-ecological systems have evolved, are currently functioning, and might further develop. The concept of sustainability is unavoidably value laden and normative, since it addresses the question of how social-ecological systems ought to be developed, so that they balance and even enhance socio-economic activities and environmental capacities (Swart et al. 2004; Rockström et al. 2009). This quest is challenged by critical issues of dissent and unbalanced power relations that jeopardize principles of socio-ecological systems integrity, intra- and intergenerational equity, and democratic governance (Gibson 2006).

Concepts, methodologies, and peer-reviewed "classics" for normative competence

Concepts	Methodologies	Peer-reviewed "classics"
(Un-)sustainability of current or future states Sustainability principles, goals, targets, thresholds (tipping points) Concepts of justice, fairness, responsibility, safety, happiness, etc. Concept of risk, harm, damage Concept of reinforcing gains ("win–win") and tradeoffs Ethical concepts	Multi-criteria assessment methods (normative component of assessment methods, including Life-Cycle Assessment, Multi-Attribute Utility Theory, etc.) Risk analysis Sustainability efficiency analysis Envisioning methods[3] (e.g., backcasting) Participatory methods (e.g. negotiation methods, consensus conference)	Prominent (value-laden) tipping points of social-ecological systems (cf. Rockström et al. 2009) Prominent sets of sustainability principles (cf. Brundtland report: WCED 1987; Gibson, 2006).

Link to other competencies Normative competence is important for constructing direction and orientation about deliberative change. Transition strategies toward sustainability are based on identifying undesirable states and dynamics as well as envisioning desirable ones.

Similar terms from literature Value-focused thinking, orientation thinking/knowledge, ethical thinking (see Table 5 in Appendix).

Strategic competence

Definition Strategic competence is the ability to collectively design and implement interventions, transitions, and transformative governance strategies toward sustainability. This capacity requires an intimate understanding of strategic concepts such as intentionality, systemic inertia, path dependencies, barriers, carriers, alliances etc.; knowledge about viability, feasibility, effectiveness, efficiency of systemic interventions as well as potential of unintended consequences; peer-reviewed "classics" such as Lester Brown's "Plan B 3.0" (Brown 2008); as well as methods and methodologies of designing, testing, implementing, evaluating, and adapting policies, programs, and action plans, involving different societal actors, facilitating varying perspectives, and acknowledging inconclusive evidence. In simple terms, this competence is about being able to "get things done". This involves familiarity with real-world situations and relationships, political understanding, challenging positions at the right time, being able to solve logistical problems, using language that non-academics are comfortable with, working with deadlines that governments insist on, and so forth. Overall, these skills are tailored to address key issues of sustainability, enabling transitions toward a sustainable future (see Table 6 in the Appendix).

Justification Sustainability efforts are problem- and solution-oriented, "linking knowledge to action", or in other words, co-constructing knowledge and practical solutions. The complexity of sustainability problems demands a matching sophistication of transition strategies toward sustainability (Bammer 2005; Loorbach 2007; Sarewitz and Kriebel 2010).

Concepts, methodologies, and peer-reviewed "classics" for strategic competence

Concepts	Methodologies	Peer-reviewed "classics"
Intentionality Transitions and transformation Strategies, action programs, (systemic) intervention, transformative governance Success factors, viability, feasibility, effectiveness, efficiency Adaptation and mitigation Obstacles (resistance, reluctance, path dependency, habits) and synergies Instrumentalization and alliances Social learning Social movements	Methods to design governance arrangements, policies, institutions Planning methodologies Decision support methodologies Transition management methodology Methods to support learning and reflexivity Organizational (change) management Methods to support behavioral change	Prominent transition strategies (e.g., Lester Brown's "Plan B 3.0": Brown 2008) Prominent transformations (e.g., socio-technical transitions in The Netherlands: Loorbach 2007)

Link to other competencies Strategic competence is linked closely to the previous three competencies as strategies for transformative change attempt to effect the transition from the current state of the social-ecological system (identified through systems thinking) toward sustainable states and dynamics (through normative competence), taking into account existing path dependencies that might lead to undesirable future states (through anticipatory competence).

[3] Envisioning methods are a good example of methods that require two ore more competencies to be employed effectively. Here, envisioning requires anticipatory competence, as visions are future oriented, and normative competence, as they focus on desirable future states.

Similar terms from literature Action-oriented competence, transformative competence, implementation skills (see Table 6 in Appendix).

Interpersonal competence

Definition Interpersonal competence is the ability to motivate, enable, and facilitate collaborative and participatory sustainability research and problem solving. This capacity includes advanced skills in communicating (Crofton 2000; Byrne 2000), deliberating and negotiating (Sipos et al. 2008), collaborating (de Haan 2006; Sterling and Thomas 2006), leadership (Ospina 2000; Kevany 2007), pluralistic and trans-cultural thinking (de Haan 2006; Kelly 2006; McKeown and Hopkins 2003; van Dam-Mieras et al. 2008), and empathy (de Haan 2006; Sterling and Thomas 2006). All of these skills are particularly important for successful stakeholder collaboration and a necessity for the majority of methods assigned to previous competencies. The capacity to understand, embrace, and facilitate diversity across cultures, social groups, communities, and individuals is recognized as a key component of this competence (see Table 7 in Appendix).

Justification Sustainability challenges are caused by, and affect, multiple actors with specific experiences, resources, perspectives and preferences. Solving sustainability problems and generating sustainability opportunities requires strong stakeholder collaborations as well as negotiations among scientists from a variety of disciplines (interdisciplinarity), politicians, entrepreneurs, artists, farmers, business and community leaders, and many more. A critical competence for addressing these challenges is interpersonal competence, i.e., the capacity to understand, compare, and critically evaluate different positions, perspectives and preferences (epistemological pluralism).

Concepts, methodologies, and peer-reviewed "classics" for interpersonal competence

Concepts	Methodologies	Peer-reviewed "classics"
Functions, types, and dynamics of collaboration (within and beyond academia; interdisciplinarity, transdisciplinarity)	Participatory methods, including negotiation, mediation, deliberation, constructive conflict methodology	Prominent sets of participatory approaches (e.g., Rowe and Frewer 2005)
Strengths, weaknesses, success, and failure in teams	Teamwork methods	Prominent collaborative settings (e.g. Model United Nations: McIntosh 2001)
Concepts of leadership		
Limits of cooperation and empathy		
Concepts of solidarity and ethnocentrism		

Link to other competencies Interpersonal competence is closely linked to all other competencies, as all rely on collaborative approaches to create ownership for the (intermediate) results, to leverage implementation, and to build joint capacity to cope with complex sustainability challenges.

Similar terms from literature Collaborative, participatory, interdisciplinary, civic competence (see Table 7 in Appendix).

Discussion

With its "official" inception in 2001 (Kates et al. 2001), the academic field that addresses real-world sustainability challenges is still in its first decade. During these years, many scholars across the world have engaged in a rich debate on the key competencies that distinguish the sustainability field from other academic fields and are critical for students to acquire. The present study has identified the relevant literature on key competencies in sustainability and, from peer-reviewed contributions, synthesized them into a coherent framework of sustainability research and problem-solving competence (Table 2). Yet, there are several critical gaps and issues that must be addressed in order to move the field forward and realize its promising potential. In this section, we will revisit and discuss the following aspects: the link between key competencies in sustainability and "regular" academic competencies; the need for evidence, depth, and rigor in the elaboration of the key competencies; ideological aspects of key competencies in sustainability (the perceived conflict between including values in scientific endeavors and maintaining academic rigor); the integration of the key competencies into an overarching sustainability research and problem-solving competence; and finally, requirements and challenges for students to acquire the full set of key competencies in sustainability.

We have argued above that it is essential for the emerging sustainability field to collectively define a set of key competencies in sustainability that serve as an explicit and commonly shared reference framework. These key competencies represent a distinct and recognizable qualifications profile for research and teaching projects, academic schools, graduates, professions, and jobs in the sustainability field. Yet, there is no doubt about the necessity of building these distinguishing competencies in conjunction with "regular" or basic competencies conveyed in academic education (Brundiers and Wiek 2011). Basic capacities in critical thinking, communication, pluralistic thinking, research, data management, and so forth ought to be conveyed in every quality academic program—and thus serve as the foundation of academic sustainability education. In addition, a conceptual map with layers of competencies (Fig. 3) recognizes the special function of the interpersonal competence in sustainability as it cuts across the other four key competencies (systems-thinking competence, anticipatory competence, normative competence, strategic competence). For example, participatory methods such as participatory scenario construction combine interpersonal competence with anticipatory competence to create future scenarios based on a variety of expertise (Swart et al. 2004).

Moving on from this overview to the substance of key competencies in sustainability, our analysis draws attention to a lack of empirical evidence, depth, and rigor in the discourse on key competencies. First, the reviewed literature does not provide sufficient empirical evidence for the claim that these competencies enable successful real-world sustainability research and problem solving. The literature fails to demonstrate that graduates are skilled enough to tackle sustainability problems. Second the literature does not sufficiently operationalize the key competencies by listing specific learning outcomes and developing evaluative schemes. Third, the literature does not rigorously elaborate on all critical components, among others, the methodological components of key competencies. In addition, the literature is still dominated by "laundry lists" of competencies rather than conceptually embedded sets of interlinked competencies. Finally, we recognized a lack of theoretical justification for the proposed competencies for sustainability. Providing such justification would require detailing the theory of sustainability adopted for selecting and defining key competencies. Some relatively detailed perspectives, for instance, on systems-thinking competence (e.g., Sterman 2002) or anticipatory competence (Major et al. 2001), provide supporting material. However, they cannot substitute for the specific sustainability lens we need to adopt when defining and elaborating sustainability competencies (Porter and Córdoba 2009; Withycombe and Wiek 2010).

Making a case for the suggested competencies based on empirical evidence is the most critical step in the evolution of the field. This could be more difficult than it seems. It would not suffice to simply link the key competencies to existing "green" jobs and professions (cf. Willard et al. 2010), which is common practice in the promotion of sustainability programs. Coping with the complex sustainability problems our societies face requires a transformation of the job market, new business models, new professions, and societal change at large. So far, none of these transformations have fully emerged, since our societies and economies still operate without fully recognizing the sustainability challenges faced over the long-term. Maintaining the status quo will inevitably lead to a contentious situation in which sustainability graduates have the proper skills to address complex sustainability problems, but societies and economies are not yet prepared to absorb them. Paradoxically, the societal transition in all streams of our societies is supported by sustainability graduates, but at the same time, the ongoing transition process is a condition for their success.

When dealing with the substantive part of sustainability competencies, one might question the legitimacy of the content assigned to the normative competencies. Where and when does the training in a normative competence shift to the promotion of an ideology? Svanström et al. (2008) suggest, "in order to be a successful sustainability change agent, an individual must have […] a value system and self-concept to support and under gird the actions of a change agent (motivation)." Does an academic sustainability program teach specific values, and is this made explicit (cf. Orr 2002)? Divergent views are present in the literature. As indicated above, some authors argue that the normative character of sustainability requires the acquisition of certain values (social-ecological integrity, justice, etc.). Others argue that sustainability graduates need to know different value-laden concepts, but their role is to facilitate dialogue rather than position themselves in value-laden debates.

Our analysis emphasizes individual sustainability competence while positioning it within a sustainability research and problem-solving framework. Yet, the overarching competence in sustainability research and problem solving is more than the sum of its parts. It involves not only the mastery of the individual competencies but also the ability to combine these competencies in a meaningful and effective way. Analyzing and solving sustainability problems requires linking and activating all of the individual competencies, and there is no one single way but rather multiple ways to do so (Wiek 2010). The sustainability field is still in the initial stages of defining distinct frameworks of sustainability research and problem solving; understanding their strengths, weaknesses, and synergies; and developing educational settings to build the overarching sustainability research and problem-solving competence from an integrative perspective. As outlined by Clark and Dickson (2003), in its nascence, the field of sustainability is in flux. It is a creative arena where old and new ideas and approaches can be vetted and refined. Because the field is problem driven, sustainability will continue to be dynamic, and while the field and the problems are evolving our understanding of what kind of competencies are required will evolve as well. This article presents a summary of the current state of knowledge that will be revised and adjusted as the field matures over the coming years.

Table 2 Overview of core concepts and methods/methodologies as well as exemplary sources of the five key competencies in sustainability

Competence	Concepts	Methods/methodologies	Sources
Systems-thinking competence	Variables/indicators, sub-systems, structures, functions	Qualitative and quantitative modeling	Porter and Córdoba 2009; Crofton 2000; Sterling 1996
	Feedback loops, complex cause-effect chains, cascading effects, inertia, tipping points, legacy, resilience, adaptation, structuration	Institutional, decision, governance, social systems analysis	
	Across/multiple scales: local to global	Systems multi-methodologies (e.g., "thick" description methodology)	
	Across/multiple/coupled domains: society, environment, economy, technology	Participatory systems approaches, including participatory modeling	
	People and social systems: values, preferences, needs, perceptions, (collective) actions, decisions, power, tactics, politics, institutions		
Anticipatory competence	Concepts of time including temporal phases (past, present, future), terms (short, long), states, continuity (dynamics, paths), non-linearity	Scenario methodology Forecasting from statistical and simulation models	Major et al. 2001; Withycombe and Wiek 2010; de Haan, 2006; Grunwald 2007
	Concept of uncertainty and epistemic status including possibility, probability, desirability of future developments (predictions, scenarios, visions)	Backcasting and envisioning methods Anticipatory multi-methodologies	
	Concepts of inertia, path dependency, non-interventions	Participatory anticipatory approaches, including Delphi and future workshop	
	Concepts of consistency and plausibility of future developments		
	Concepts of risk, intergenerational equity, precaution		
Normative competence	(Un-)sustainability of current or future states Sustainability principles, goals, targets, thresholds (tipping points)	Multi-criteria assessment methods (including Life-Cycle Assessment, Multi-Attribute Utility Theory, etc.)	Gibson 2006; Sterling 1996; Grunwald 2004
	Concepts of justice, fairness, responsibility, safety, happiness, etc.	Risk analysis	
	Concept of risk, harm, damage	Sustainability efficiency analysis	
	Concept of reinforcing gains ("win–win") and tradeoffs	Envisioning methods (e.g., backcasting)	
	Ethical concepts	Participatory normative methods, including negotiation methods and consensus conference	
Strategic competence	Intentionality Transitions and transformation	Methods to design governance arrangements, policies, institutions	Bammer 2005; de Haan, 2006; Grunwald 2007
	Strategies, action programs, (systemic) intervention, transformative governance	Planning methodologies Decision support methodologies	
	Success factors, viability, feasibility, effectiveness, efficiency	Transition management methodology	
	Adaptation and mitigation	Methods to support behavioral change	
	Obstacles (resistance, reluctance, path dependency, habits) and synergies	Organizational (change) management	
	Instrumentalization and alliances		
	Social learning Social movements	Methods to support learning and reflexivity	
Interpersonal competence	Functions, types, and dynamics of collaboration (within and beyond academia) Strengths, weaknesses, success, and failure in teams	Participatory methods, including negotiation, mediation, deliberation, constructive conflict methodology	Crofton 2000; Kearins and Springett 2003; de Haan 2006
	Concepts of leadership	Teamwork methods	
	Limits of cooperation and empathy		
	Concepts of solidarity and ethnocentrism		

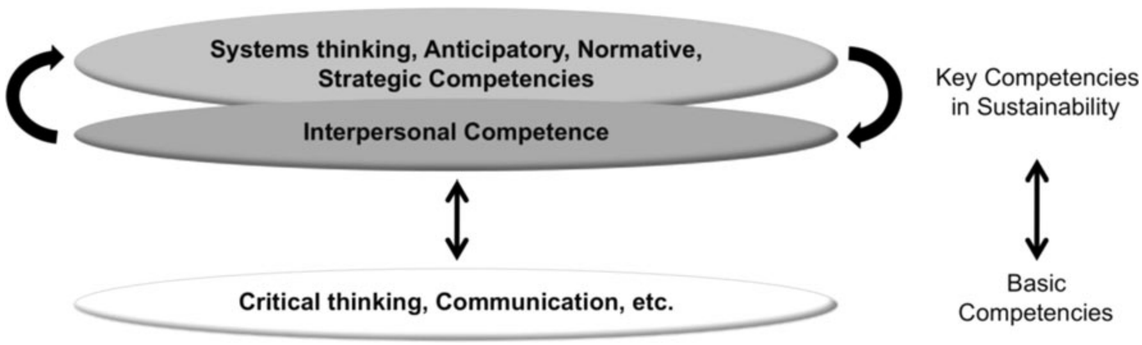

Fig. 3 A layered set of competencies in academic sustainability education, linking basic competencies and key competencies in sustainability, as well as recognizing interpersonal competence as cross-cutting key competence in sustainability

Students might be overwhelmed by the call to acquire all of these competencies: four individual key sustainability competencies, the fifth crosscutting key competence (interpersonal), "regular" academic or basic competencies, and the overarching sustainability research and problem-solving competence. Does each student need to acquire *all* competencies? As in any other field, it is advisable to strike a balance between specialization and generalization. Considering limited time and capacity, it seems reasonable that students would acquire in-depth expertise in one or two of the key competencies and a solid grounding in the others. The sufficient level of rigor also depends on the level of the academic program. Undergraduate, masters, and doctoral students ought to fulfill different requirements. However, it will still take a considerable amount of time to consolidate these standards across different universities, programs, and communities, which is imperative for establishing the sustainability field in the academic landscape and beyond. In addition, discussions on new teaching formats need to accompany this consolidation process. One might argue for a stronger emphasis on the expertise of teams in which team members complement each other's competencies. This concept has been discussed in educational contexts, for instance, as "distributed expertise" (Salomon 1993) but is still challenged by overemphasis on individual CVs and expertise.

Conclusions

This literature-based study on key competencies in sustainability reflects the growing interest in developing a converging set of key competencies that can guide the design of programs and courses in sustainability, teaching and learning evaluations, and hiring and training faculty and staff. But the study also reveals that there are several opportunities for improvement. First, we need thorough theoretical justifications why the proposed competencies are instrumental for sustainability research and problem solving. Second, we need to support proposed competencies with empirical evidence showing they enable successful real-world sustainability research and problem solving. Third, follow-up studies that spell out the specifics of the proposed competencies, including the kind of methodological expertise they aspire to, are needed.

Yet, the presented study is not intended to set key competencies "in stone." All of the following are needed to ensure high quality education in sustainability: continuous monitoring of performances within and beyond the programs; experimenting with teaching and learning settings; reflection on achievements and shortcomings; and adaptation of the competencies. Once more, the most critical check for the adequacy of the competencies is the degree to which graduates can improve sustainability in the world. Adapting the competencies is required as sustainability challenges and our insights on how to cope with them shift over time.

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Appendix

Table 3 Excerpts from the literature on systems-thinking competence

Clayton and Radcliffe (1996, p 6): "The sustainability of the human species can only be defined, ultimately, at the level of the interaction of the entire complex of human systems and all directly implicated environmental system. To understand sustainability therefore requires some understanding of the behavior of systems in general and of human and environmental systems in particular."

Crofton (2000, p 400): "Identify and account for individual and cumulative social, environmental and economic implications of decision or process based on an understanding of the systemic nature of the world, the interconnectedness of natural and human systems […] Identify and account for direct and indirect consequences for people and ecosystems based on an understanding of the global nature of the world and how local and regional issues are part of the whole […] As social, technological, economic, and ecological systems have grown more complex, the demand for technological and organizational expertise has increased. In particular, people with a broad interdisciplinary outlook ('specialists of the general') are being sought out to offer systemic approaches that are capable of dealing with the complexity of the problems and the tasks we face."

Sterling (1996, p 23): "Systemic and connective—putting emphasis on relation and pattern (including dynamics and flows, distortions, feedbacks and causation); encouraging a participative systemic awareness and wisdom."

The Cloud Institute (2010): "The extent to which one sees both the whole system and its parts as well as the extent to which an individual can place one's self within the system […] Students will know and understand the dynamic nature of complex systems and change over time. They will be able to apply the tools and concepts of system dynamics and systems thinking in their present lives."

Table 4 Excerpts from the literature on anticipatory competence

de Haan (2006, p 22) (cf. Barth et al. 2007; van Dam-Mieras et al. 2008): "Competence in foresighted thinking: The capacity to deal with uncertainty and future prognoses, expectations and plans characterizes the sub-competence of being able to think beyond the present. It is essential that the future be understood as open and something that we can help to shape. This attitude underpins the capacity to develop different options for action based on present conditions. Through foresighted thinking and acting, we can conceive of possible developments for the future and identify potential opportunities and risks inherent in present and future developments, as well as unexpected ones. Creativity, fantasy and imagination play an important role in this competence."

Grunwald (2007, p 248): "Providing knowledge-based, coherent pictures of the future: In many cases, illustrations of future developments, scenarios, or if possible, predictions are necessary in order to assess whether there will be sustainability problems (examples are the development of the global climate and of the world population). Although it is impossible to experiment with the real world, predictions can be made by modeling and simulating the system under consideration […]. In many fields, however, future outcomes cannot be predicted because either human actions, decisions and behavior are involved to a large extent, or simply the data are imperfect or cause-and-effect relationships have not been determined. In these cases, scenarios as illustrations of possible futures are used in order to structure the spectrum of further developments, to identify 'worst' and 'best' cases, to create common visions, and to acquire knowledge to draw up action strategies."

Table 4 continued

Crofton (2000, p 400): "Identify short and long term consequences of decisions or plans in the context of both immediate priorities as well as long term concerns (anticipatory thinking extending to future generations)".

Kelly (2006, p 702): "To predict and consider all possible repercussions of our actions and decisions prior to their implementation in order protect further generations and the lives of others throughout the world before. […] capable of trans-generational thinking".

Table 5 Excerpts from the literature on normative competence

Grunwald (2004, p 152): "Sustainable development is a normative societal principle, and science makes indispensable contributions to its realization […] The knowledge for [sustainable development] is provided on quite different levels and in various manners: […] Sustainability assessment: whether certain effects and tendencies are to be interpreted as sustainability problems cannot be ascertained from empirical observation or simulation alone, but, rather, criteria have to be defined according to which observations can be classified as more or less relevant for sustainability, or even as sustainability deficit […] Ranking of sustainability deficits: analysis of the sustainability situation also has to concern itself with assessment of the urgency of certain sustainability problems as opposed to others, and with setting priorities."

Gibson (2006, p 180): Ability to "adopt evaluation and decision criteria and trade-off rules that reflect the full set of core requirements for progress toward sustainability, recognize interdependencies and seek multiple reinforcing gains on all fronts; provide means of specifying the sustainability decision criteria and trade-off rules for specific contexts, through informed choices by the relevant parties (stakeholders); apply these insights in the full set of process elements, including identifying appropriate purposes and options for new or continuing undertakings; assessing purposes, options, impacts, mitigation and enhancement possibilities; choosing (or advising decision-makers on) what should or should not be approved and done, and under what conditions; and monitoring, learning from the results and making suitable adjustments through implementation to decommissioning or renewal".

Sterling (1996): "Ethical-clarifying ethical issues, but also nurturing normative ethical sensibility that relates and renders seamless the deeply personal and collective, i.e., it extends the boundary of care and concern beyond the immediate and personal to a participative sense of solidarity with others, distant people, environments, species and future generations […] This is neither monist nor relativist, but reflects an ecological pluralism."

Table 6 Excerpts from the literature on strategic competence

de Haan (2006) (cf. Barth et al. 2007; van Dam-Mieras et al. 2008): "Competence in planning and implementation skills means the capacity to assess the resources necessary for an action, and their availability, from the standpoint of sustainability, the capacity to create cooperative networks and to calculate side-effects and possible surprise effects, as well as to take the possibility of their occurring into account while planning. A significant factor in developing planning skills is learning to take into account the rapid changeability and temporary nature of knowledge relevant to planning. Only in this way can plans and actions be made 'error-friendly', and be corrected and revised when new insights appear and when conditions change. Such learning arrangements draw attention to correlations between various problem constellations and possible solutions. They thematize feedback, long-term consequences and delays, and offer a corresponding repertoire of methods. Implementation skills reach beyond intentions and plans to incorporate necessary and actual interests in acting."
Grunwald (2007, p 249): "Because—as a rule—competing courses of action and alternative strategies are proposed by different societal actors and are based on different scientific conceptions and normative presuppositions, ex ante comparisons of these different proposals have to be conducted prior to any decisions […] Action-guiding knowledge comprises answers to the questions as to how therapies can be applied to sustainability weak spots and how implementation problems can be tackled. It includes the development of strategies to convince and motivate actors and to induce societal change. Some of this knowledge consists in transparently revealing the uncertainty and incompleteness of the knowledge, and in indicating courses of action under uncertainty."

Table 7 Excerpts from the literature on interpersonal competence

Crofton (2000, p 400): "Develop communication, collaboration and related skills necessary for constructive involvement with other professionals, a range of stakeholders and the public in general."
Kearins and Springett (2003, p 194): "A key part of working out new possibilities for organizing and acting is to be able to resolve tensions between the collectivity and the individual in ways that support both […] Facilitative skills in collaboration and adaptation and a level of ease with more inclusive approaches are thus important aspects in any social action."
de Haan (2006, p 23) (cf. Barth et al. 2007; van Dam-Mieras et al. 2008): "A single scientific field and simple strategies for acting are no longer capable today of tackling the problems of non-sustainable development and the need for future-compliant change. These problems can only be addressed through the collaboration of many scientific fields, different cultural traditions and aesthetic, cognitive and other approaches. Knowing how to identify and understand system relations and how to deal appropriately with complexity requires the development of corresponding skills. These skills can be furthered through approaching problems in daily life contexts with a problem-solving strategy that opens up opportunities and alternative solutions through drawing on various subject positions and different ways of thinking."
Sterling (1996, p 26): "Whether the future holds breakdown or positive breakthrough scenarios—or, as seems likely, some of both—people will require flexibility, resilience, creativity, participative skills, competence, material restraint and a sense of responsibility and transpersonal ethics to handle the transition and provide mutual support."

References

Baartman LKJ, Bastiaens TJ, Kirschner PA, Van der Vleuten CPM (2007) Evaluation assessment quality in competence-based education: a qualitative comparison of two frameworks. Educ Res Rev 2:114–129

Bäckstrand K (2003) Civic science for sustainability: reframing the role of experts, policy-makers and citizens in environmental governance. Glob Environ Polit 3(4):24–41

Bammer G (2005) Integration and implementation sciences: building a new specialization. Ecol and Soc 10: article 6

Barth M, Godemann J, Rieckman M, Stoltenberg U (2007) Developing key competences for sustainable development in higher education. Int J Sust Higher Educ 8(4):416–430

Blackstock KL, Carter CE (2007) Operationalising sustainability science for a sustainability directive? Reflecting on three pilot projects. Geogr J 173(4):343–357

Bowden J, Marton F (1998) The university of learning: beyond quality and competence in higher education. Kogan, London

Brown LR (2008) Plan B 3.0—mobilizing to save civilization. Norton, New York

Brundiers K, Wiek A (2011) Sustainability research education in real-world settings—vision and implementation. Innov High Educ 36:107–124

Brundiers K, Wiek A, Redman CL (2010) Real-world learning opportunities in sustainability—concept, competencies, and implementation. Int J Sust Higher Educ 11(4):308–324

Burke JW (1989) Competence-based education and training. Falmer, London

Byrne J (2000) From policy to practice: creating education for a sustainable future. In: Wheeler KA, Bijur AP (eds) Education for a sustainable future: a paradigm of hope for the 21st century. Kluwer/Plenum, New York, pp 35–72

Clark W (2003) Institutional needs for sustainability science. Posted to the Initiative on Science and Technology for Sustainability (available: http://sustsci.harvard.edu/ists/docs/clark_governance4ss_030905.pdf)

Clark WC, Dickson NM (2003) Sustainability science: the emerging research program. Proc Natl Acad Sci USA 100(14):8059–8061

Clayton AMH, Radcliffe NJ (1996) Sustainability: a systems approach. Westview, Boulder

Collingridge D (1980) The social control of technology. St. Martin's, NewYork

Crofton F (2000) Educating for sustainability: opportunities in undergraduate engineering. J Clean Prod 8(5):397–405

Cusick J (2008) Operationalizing sustainability education at the University of Hawai'i at Manoa. Int J Sust Higher Educ 9(3):246–257

Dale A, Newman L (2005) Sustainable development, education and literacy. Int J Sust Higher Educ 6(4):351–362

de Haan G (2006) The BLK '21' programme in Germany: a 'Gestaltungskompetenz'-based model for education for sustainable development. Environ Educ Res 1:19–32

Earth Institute at Columbia University (2008) Report from the International Commission on Education for Sustainable Development Practice. New York: Earth Institute at Columbia University and the John D. and Catherine T. MacArthur Foundation

Geels F (2005) Technological transitions and system innovations: a co-evolutionary and socio-technical analysis. Elgar, Cheltenham

Gibson R (2006) Sustainability assessment: basic components of a practical approach. Impact Assess Project Apprais 24:170–182

Grunwald A (2004) Strategic knowledge for sustainable development: the need for reflexivity and learning at the interface between science and society. Int J Foresight Innov Policy 1(1–2):150–167

Grunwald A (2007) Working towards sustainable development in the face of uncertainty and incomplete knowledge. J Environ Policy Plan 9(3):245–262

Guston D (2008) Innovation policy: not just a jumbo shrimp. Nature 454:940–941

Hirsch Hadorn G, Bradley D, Pohl C, Rist S, WiesmannU (2006) Implications of transdisciplinarity for sustainability research.Ecol Econ 60:119–128

Hyland T (2006) Competence, knowledge and education. J Philos Educ 27:57–68

Jucker R (2002) "Sustainability? Never heard of it!" some basics we should not ignore when engaging in education for sustainability. Int J Sust Higher Educ 3(1):8–18

Kajikawa Y (2008) Research core and framework of sustainability science. Sust Sci 3(2):215–239

Kates RW, Clark WC, Corell R, Hall JM, Jaeger CC et al (2001) Sustainability science. Science 292(5517):641–642

Kearins K, Springett D (2003) Educating for sustainability: developing critical skills. J Manag Educ 27(2):188–204

Kelly P (2006) Letter from the oasis: helping engineering students to become sustainability professionals. Futures 38:696–707

Kemp R, Parto S, Gibson R (2005) Governance for sustainable development: moving from theory to practice. Int J Sust Dev 8:12–30

Kevany K (2007) Building the requisite capacity for stewardship and sustainable development. Int J Sust Higher Educ 8(2):107–122

Komiyama H, Takeuchi K (2006) Sustainability science: building a new discipline. Sust Sci 1(1):1–6

Loorbach D (2007) Transition management: new mode of governance for sustainable development. International Books, Utrecht

Loorbach D, Rotmans J (2006) Managing transitions for sustainable development. In: Olshoorn X, Wieczorek AJ (eds) Understanding industrial transformation—views from different disciplines. Springer, Dordrecht, pp 187–206

Major E, Asch D, Cordey-Hayes M (2001) Foresight as a core competence. Futures 33:91–107

McArthur JW, Sachs J (2009) Needed: a new generation of problem solvers. Chron High Educ 55(40):A64–A66

McIntosh D (2001) The uses and limits of the model United Nations in an international relations classroom. Int Stud Perspect 2:269–280

McKeown R, Hopkins C (2003) EE $\neq$ ESD: defusing the worry. Environ Educ Res 9(1):117–128

Meadows DL et al (1974) Dynamics of growth in a finite world. Pegasus, Waltham

Millennium Ecosystem Assessment (MEA) (2005) Ecosystems and human well-being. Millennium Ecosystem Assessment, 3 volumes. Island, Washington

Nakicenovic N, Alcamo J, Davis G, de Vries B, Fenhann J et al (2000) Special report on emissions scenarios: a special report of working group III of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

Orr D (2002) Four challenges of sustainability. Conserv Biol 16:1457–1460

Ospina G (2000) Education for sustainable development: a local and international challenge. Prospects 30(1):31–40

Ostrom E (2009) A general framework for analyzing sustainability of social-ecological systems. Science 325:419–422

Parkin S, Johnston A, Buckland H, Brookes F, White E (2004) Learning and skills for sustainable development: developing a sustainability literate society. Higher Education Partnership for Sustainability (HEPS), London

Perrow C (1984) Normal accidents: living with high-risk technologies. Basic Books, New York

Porter T, Córdoba J (2009) Three views of systems theories and their implications for sustainability education. J Manag Educ 33:323–347

Raskin P, Banuri T, Gallopin G, Gutman P, Hammond A, Kates R, Swart R (2002) Great transition: the promise and lure of the times ahead. Stockholm Environment Institute, Stockholm

Ravetz J (2000) Integrated assessment for sustainability appraisal in cities and regions. Environ Impact Assess Rev 2000(20):31–64

Robinson J (2003) Future subjunctive: backcasting as social learning. Futures 35: 839–856

Robinson J (2008) Being undisciplined—transgressions and intersections in academia and beyond. Futures 40:70–86

Rockström J, Steffen W, Noone K, Persson A, Chapin FS et al (2009) A safe operating space for humanity. Nature 461:472–475

Rowe D (2007) Education for a sustainable future. Science 317(5836):323–324

Rowe G, Frewer L (2005) A typology of public engagement mechanisms. Sci Technol Hum Val 30:251–290

Salomon G (ed) (1993) Distributed cognitions: psychological and educational considerations. Cambridge University Press, Cambridge

Sarewitz D, Kriebel D (2010) The Sustainable Solutions Agenda. Consortium for Science, Policy and Outcomes, Arizona State University and Lowell Center for Sustainable Production, University of Massachusetts, Lowell

Scholz RW, Lang DJ, Wiek A, Walter AI, Stauffacher M (2006) Transdisciplinary case studies as a means of sustainability learning: historical framework and theory. Int J Sustain Higher Educ 7:226–251

Segalas J, Ferrer-Balas D, Svanstrom M, Lundqvist U, Mulder KF (2009) What has to be learnt for sustainability? A comparison of bachelor engineering education competencies at three European universities. Sust Sci 4(1):17–27

Shephard K (2007) Higher education for sustainability: seeking affective outcomes. Int J Sust Higher Edu 9(1):87–98

Sipos Y, Battisti B, Grimm K (2008) Achieving transformative sustainability learning: engaging heads, hands and heart. Int J Sust in Higher Educ 9(1):68–86

Spady WG (1994) Outcome-based education: critical issues and answers. American Association of School Administrators, Arlington

Steiner G, Posch A (2006) Higher education for sustainability by means of transdisciplinary case studies: an innovative approach for solving complex, real-world problems. J Clean Prod 14(9–11):877–890

Sterling S (1996) Education in change. In: Huckle J, Sterling S (eds) Education for sustainability. Earthscan, London, pp 18–39

Sterling S (2001) Sustainable education—re-visioning learning and change. Schumacher Briefing No. 6. Green Books, Dartington

Sterling S, Thomas I (2006) Education for sustainability: the role of capabilities in guiding university curricula. Int J Innov Sust Dev 1(4):349–370

Sterman JD (2002) All models are wrong: reflections on becoming a systems scientist. Syst Dynamics Rev 18(4):501–531

Svanström M, Lozano-García FJ, Rowe D (2008) Learning outcomes for sustainable development in higher education. Int J Sust Higher Educ 9(3):339–351

Swart RJ, Raskin P, Robinson J (2004) The problem of the future: sustainability science and scenario analysis. Glob Environ Chang 14(2):137–146

Talwar S, Wiek A, Robinson J (2011) User engagement in sustainability research. Sci Public Policy (in press)

The Cloud Institute (2010) Education for sustainability. Online source (retrieved January 4, 2010): http://www.sustainabilityed.org/education/

Turner BL II, Robbins P (2008) Land-change science and political ecology: similarities, differences, and implications for sustainability science. Annu Rev Environ Resour 33:295–316

Turner BL II, Matson PA, McCarthy JJ, Corell RW, Christensen L et al (2003) Illustrating the coupled human-environment system for vulnerability analysis—three case studies. Proc Natl Acad Sci USA 100:8080–8085

van Dam-Mieras R, Lansu A, Rieckmann M, Michelsen G (2008) Development of an interdisciplinary, intercultural master's program in sustainability: learning from the richness of diversity. Innov High Educ 32(4):251–264

van Kerkhoff L, Lebel L (2006) Linking knowledge and action for sustainable development. Annu Rev Environ Resources 31:445–477

Voorhees RA (2001) Competence-based learning models: a necessary future. New Dir Instit Res 110:5–13

Wals A, Jickling B (2002) Sustainability in higher education: from doublethink and newspeak to critical thinking and meaningful learning. Int J Sust Higher Educ 3(3):221–232

Warburton K (2003) Deep learning and education for sustainability. Int J Sust Higher Educ 4(1):44–56

Welsh MA, Murray DL (2003) The ecollaborative: teaching sustainability through critical pedagogy. J Manag Educ 27(2):220–235

Wiek A (2010) Transformative sustainability science. Working Paper. School of Sustainability. Arizona State University

Wiek A, Walter A (2009) A transdisciplinary approach for formalized integrated planning and decision-making in complex systems. Eur J Oper Res 197(1):360–370

Wiek A, Withycombe L, Redman CL (2010) From eclectic to genuine sustainability curricula in higher education. Working Paper. School of Sustainability. Arizona State University

Wiek A, Withycombe L, Redman CL (2011) Moving forward on competencies in sustainability. Environment- Sci Policy Sustain Dev 53:3–13

Willard M, Wiedmeyer C, Flint RW, Weedon JS, Woodward R, Feldmand I, Edwards M (2010) The sustainability professional: 2010 competency survey report. International Society of Sustainability Professionals

Withycombe L, Wiek A (2010) Anticipatory competence as a key competence in sustainability. Working Paper. School of Sustainability. Arizona State University

WCED (1987) Our common future. World Commission on Environment and Development. Oxford University Press, Oxford