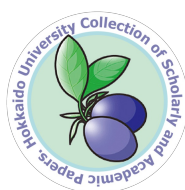




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Critical Thinking and Normative Competencies for Sustainability Science Education

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サステナビリティ学教育に対する クリティカル・シンキング的と規範的コンピテンシー

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Abstract — In this paper, we extend the competencies framework of education for sustainability development (ESD) to argue that critical thinking should be taught as a core competency and that normative dialogue functions as a key competency. We then develop a pedagogy for teaching these competencies, reviewing the results of our teaching implementation, and drawing conclusions about the effectiveness of both the framework and the pedagogy.

We establish the need for education in critical thinking and normative dialogue by rehearsing and building on the history of ESD. We begin by looking at how ESD has focused on competencies to solve wickedly complex problems. In light of this, we propose critical thinking as a core competency necessary for tackling these difficult issues outside of the expertise of specific fields. Building on the Delphi report of the American Philosophical Association, we suggest that this can be accomplished when critical thinking is understood as purposeful, self-reflective judgment that also evaluates the considerations used in making such judgments. We also show that normative dialogue is necessary to bridge disagreements in complex human problems, and should thus function as a key competency.

We then turn to our pedagogical approach, which involves teaching critical thinking through introductory sentential logic and fostering normative dialogue skills by familiarizing students with frameworks from both philosophical ethics and contemporary frameworks for human rights. We then describe our implementation at the Center for Sustainability Science of Hokkaido University as four sessions in an *Environmental Ethics* course. Using pre- and post-test surveys, we then evaluate the effectiveness of our curriculum and hold that our pedagogy needs revision to require more student work as it failed to produce the competencies we sought to foster. Finally, we conclude that further work can be done to refine the theoretical framework as well, clarifying the sort of critical thinking that is necessary for ESD, and considering additional tools to help students better engage in normative dialogue.

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1. Introduction

In Japan, both the government and leading universities have been active in education for sustainability development (hereafter, ESD) (Kadoya & Goto 2013, p. 48; Itoh et al. 2008; Nomura & Abe 2010). Ryan et al. (2010) have catalogued the ESD efforts undertaken at universities in Japan. Universities established sustainability and teacher development programs related to ESD. This has led to a general increase in environmental literacy and awareness, cooperation among national and international inter-university partnerships, and regional cooperation with business interests.

While these efforts affect many parts of Japanese society, they do not delineate a curriculum for sustainability science education (Ryan et al. 2010). In the academic literature, ESD has primarily been structured in terms of competencies (a term we explain below). Our paper argues that ESD, especially in Japan, should include developing competencies for normative dialogue and critical thinking. We define these terms more thoroughly in the second section of our paper, but briefly here explain “critical thinking” as the ability to step back from the immediate problem and reframe how one defines and solves the problem and “normative dialogue” as the ability to communicate about value-issues in objectively neutral terms within a pluralistic environment.

This paper first outlines the role of competencies in ESD. It then looks more carefully at the nature of critical thinking and its role as a core competency tying this with OECD framework. We follow this by considering normative dialogue as a key competency. We then explain how we tried to teach these as a module in an *Environmental Ethics* class at Hokkaido University — one of Japan’s model higher education programs and a member of the Integrated Research System for Sustainability Science (IR3S) (See Nomura & Abe 2010; Kitamura & Hoshii 2009). Finally, we look at the results of teaching efforts and draw conclusions based on our results and make suggestions for further research.

2. Towards a Competencies Approach in ESD

A competencies approach responds to the nature of sustainability science and ESD. In their seminal paper in *Science*, Kates et al. (2001) argued for the establishment of a discipline devoted to understanding on a global scale, “the fundamental character of interactions between nature and society.” In this respect, sustainability science is unlike physics in that its subject matter is defined not by its methods but by its desired outcome: a “sustainable future” built on use-inspired research (Clark 2007).

This means that sustainability science has an abstract definition, which we need to flesh out. The first thing we note is that sustainability science is about solving complex problems, which are facing our planet:

[Sustainability science]’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 (Wiek et al. 2011, p.203)

To even describe these types of problems requires us to simultaneously address the social, environmental, and economic aspects and to balance between long and short term concerns. These problems cannot be solved by considering just a single aspect or feature (Dobson & Tomkinson 2012). In other words, the key feature of sustainability science methodology is that it faces problems in their full complexity and in each relevant aspect. Thus, sustainability science is the science that deals with wickedly-difficult problems which have “no definitive formulation” (Dobson & Tomkinson 2012, p. 266; Sadowski et al. 2013). Further compounding these problems is a “russian-doll” effect wherein these problems tend to require recursive definition (Lang et al. 2012, p.29).

Another feature this definition requires of sustainability science is that it must integrate knowledge from many different disciplines in order to solve real-world sustainability programs (Fortuin & Bush 2010; Jerneck et al. 2011, p.72). This integration cannot be accomplished through merely sharing information; instead, researchers with a novel skill set must be developed who can work in transdisciplinary and interdisciplinary teams (Wiek et al. 2011; Barth & Michelsen 2013, p.104).

Given the nature of these complex problems and the goals of sustainability science, traditional models of education focused on granting degrees in specialized fields are ill-adapted to supplying the necessary resources. Biologists are rarely conversant in economics, and philosophers are rarely up to speed on chemical engineering. Thus, ESD means marshaling different programs, courses, and instructors under a common standard. The standard educational methodologies that compartmentalize students and knowledge areas will not provide adequate training for this outcome. In fact, some argue that these systems create a barrier to developing the holistic skill set need for sustainability scientists to address complex problems (Jones et al. 2010).

Achieving the goals of sustainability science will require rethinking the curriculum and new educational approaches (Ryan et al. 2010; Niu et al. 2010). While not without critics, a competencies approach has been central to thinking about how to implement effective ESD (Mochizuki & Fadeeva 2010; Yarime et al. 2012, pp.104-105; Dobson & Tomkinson 2012, pp.268-269). In this paper, we will understand competency to mean the capacity for “successful task performance” or more precisely as the complex of knowledge, skills, and attitudes that then enable its possessor to engage in sustainability science and solve real-world sustainability problems (Wiek et al. 2011, p.204). Competencies are skill outcomes, a distinction meant to contrast with knowledge-focus outcomes such as knowing the periodic table, a set of equations, or a list of countries.

As Wiek et al. point out, there is still much work to be done in identifying the competencies most necessary to ESD:

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 (Wiek et al. 2011, p.212).

All of these efforts are motivated and directed towards finding those “competencies” (virtues of sustainability scientists) that can enable sustainability scientists to effect solutions to complex sustainability problems and model sustainable patterns in their own lives and research (Barth & Michelsen 2013, p.104).

Again, this does not replace expertise in particular fields like environmental engineering. The goal is not to create super scientists who do everything. Instead, this approach supplements domain expertise by providing a common foundation to produce sustainability scientists who are “multi-lingual,” possessing several competencies and conversant beyond their specializations. To make this possible, sustainability science education must train students for the competencies they need to solve real world problems alongside the underlying conceptions of specializations, which students have acquired in their respective schools in higher education.

Current efforts to implement sustainability science education have generally focused on the graduate and post-graduate level. This has taken several different forms: graduate courses open to students from many disciplines (e.g., Tsinghua University, China), sustainability science majors and “sub-majors” (Ibaraki University, Japan), multi-disciplinary graduate programs (The University of Tokyo, Japan), short term interdisciplinary research projects (Wageningen University, the Netherlands), and post-graduate and post-doctoral research consortiums (Lund University, Sweden). Diversity has abounded, and progress has been slow in normalizing expectations for sustainability science in universities

(Fortuin & Bush 2010; Tamura & Uegaki 2012; Yarime et al. 2012, p.104).

While no longer operating, Hokkaido University (Japan), like several other universities in Japan started a ESD training program called the Center for Sustainability Science (CENSUS). This was an inter-departmental instructional center designed to provide sustainability education opportunities as optional graduate certificates to interested graduate students regardless of their program of study. CENSUS offered two programs: the Special coordinated training program for Sustainability Leaders (StraSS) and the Hokkaido University Inter-department Graduate study in Sustainability (HUIGS). StraSS sought to help graduate students achieve competencies for resolving local and global sustainability issues and offered a certificate upon completion. HUIGS, in turn, allowed students from any discipline in the university to take courses in sustainability science.

CENSUS worked to make StraSS a mark of distinction which would signify that the certificate holder has the relevant competencies to meaningfully contribute to solving sustainability problems. To earn the StraSS certificate, an *Environmental Ethics* course was required wherein students were supposed to cultivate competency in critical thinking and normative moral thinking. Our paper looks at our pedagogical goals for this class, our implementation, our effectiveness, and finally our recommendations for future attempts to teach these competencies. Our study looked at how classroom training could help in competency formation and presents novel insights into ways to think about critical thinking and normative dialogue as competencies and how these relate to the core of the needs of sustainability science in addressing wickedly-complex problems. We continue our work in different environments now, but CENSUS, StraSS, and the *Environmental Ethics* class disappeared with the closing of the center in March 2016.

3. Critical Thinking should be a Core Competency for ESD

In this section, we argue that critical thinking functions a core competency in ESD. We first supply a definition of critical thinking. We then explain how this makes it the necessary core competency for successful ESD. Finally, we explain what it does within sustainability science.

While the Bonn Declaration (2014) declares “critical thinking” to be an emphasis of ESD (p.1), “critical thinking” faces a problem of definition, having been defined in so many ways that it sometimes becomes “newsspeak” (Wals & Jickling 2002, p.223). Wals & Jickling (2002) themselves call for “focus on competencies and higher thinking skills” (p.228). Thomas (2009) maintains that critical thinking is central to sustainability education (p.258). The Japanese Government’s National Institute for Educational Policy Research also mentions “critical thinking” within its framework for ESD as the first example of “abilities and attitudes emphasized by learning instructions from ESD viewpoints” (Kadoya & Goto 2013, p.50). Later in their article, Kadoya and Goto (2013) explain this as the “ability to see the essence based on reasonable and objective information and fair judgment, and to think and judge things in constructive, cooperative and alternative ways” (p.54).

These declarations point out the importance of critical thinking but they do not show us what it would look like as a competency. To arrive at a working definition, we start with the key finding of the Delphi report compiled for the American Philosophical Association: “We understand critical thinking to be purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based” (Falcione 1990). The core skills associated with this competency are cognitive skills for “(1) interpretation, (2) analysis, (3) evaluation, (4) inference, (5) explanation and (6) self-regulation” (Falcione 1990).

Building on the Delphi report, we understand critical thinking as the analytic skill of knowing how to define a problem, what resources are needed to address it, and how to monitor how well the problem is being solved. Critical thinking, on this definition, can occur at several levels of reflective consideration. We give two examples here to make this clearer that distinguish between performing an activity directly and reflecting critically on the activity. First, if we think about chess, then each player's action is to make a legal move (advance a pawn, move a bishop along a diagonal, etc.). As a first level of critical thinking, a player can think about how their move will cause their opponent to move. At a deeper level, the player can rethink chess in terms of attacking chances and center control, which are ideas that help the player better understand how to win but are not specifically playing the game. Instead, they help the player to play the game well. Critical thinking is what discovers both the second layer of playing smarter and the third layer of rethinking play altogether.

A second example brings us to environmental science and the problems of ESD. One task in fisheries is a fish stock assessment. In other words, we apply some method for calculating the number of fish in the sea whether this is using data from live catches or commissioning a boat for this purpose. This level is pure measurement. We then extrapolate that to estimate the stocks of certain species of fish. Critical thinking is needed to think about the validity of our assessment methods and to interpret these methods. Moreover, critical thinking about the assessment helps us to understand both how to do assessments better (even to the point of helping us to define the "better") and to understand what our assessment really can tell us. In short, critical thinking as we are using it here is the set of skills that reflect on our use of reason in other arenas.

Viewed in this way, every academic field involves some critical thinking when it reflects on the nature of its problems and its methods. For instance, agriculture is not merely husbandry, planting, and harvesting; it also involves thinking critically about field management and sustainable practice. This is a field-specific application of

critical thinking. Critical extends beyond field-specific applications when its goals cease to be linked to the practices of a specific field and become more general in much the same way as sustainability science itself has the task of integrating disparate fields.

With this concept of critical thinking in mind, we maintain that this is a core competency that should be taught in ESD. We distinguish it as a core competency by contrasting it with the OECD's definition of "key competency" as a competency, which meets three conditions:

- (1) It should have measurable economic and societal benefits.
- (2) It should function in a wide spectrum of context
- (3) It should be important for all individuals (as opposed to a specialized trade) (OECD 2005, p. 7).

OECD (2005) further identifies three areas of key competency: "Using Tools Interactively," "Interacting in Heterogeneous Groups" and "Acting Autonomously" (pp.10, 12, 14). The glue that holds these together is what the report calls "Reflectiveness — the heart of the key competencies" which "allows individuals to then think about this technique, assimilate it, relate it to other aspects of their experiences, and to change or adapt it." (OECD 2005, p.9)

We agree in general with this finding, but we maintain that "reflectiveness" could be better defined and would be better understood in terms of critical thinking. First off, there are several distinct terms that have been used for what is effectively the same thing. Mochizuki & Fadeeva (2010) point to "reflexive competency" as the core competency and unifying feature in ESD (p.397). Thomas (2009) speaks of "problem-solving skills in a nonreductionist manner for highly complex real-life problems" within the context of education for sustainability (p.254).

All of these ideas point to a competency that functions at a more fundamental level than the key competencies and can enable them to function. We will call this a "core competency," drawing an analogy to how core muscles supporting and enabling the function-

ing of the whole human body. The term “critical thinking” as defined above captures the idea of reflecting on our activity with the use of reason.

As OECD (2005) notes, key (and core) competencies are those which are not discipline-specific. Critical thinking understood as this reflective engagement with one’s work that goes beyond the specific field functions as a core competency that invigorates the key competencies and informs the individual scientist of how to balance and use their entire skill set. Thus, it is precisely the skill that enables us to face wickedly difficult problems. It engages the scientific method of creating testable articulations of the problem — and then revising these as they get defeated or enhancing them as new complexity arises.

Since critical thinking is transdisciplinary rather than discipline specific, it applies to both to sustainability problems themselves, stakeholder claims, and potential solutions. Without critical thinking as a foundation, it is impossible to coherently implement the multi-actor governance in which we balance the interests of stakeholders (Shiroyama et al. 2012). In order to balance claims at all, we must be able to understand each party’s claims in objectively comprehensible terms, and this is precisely what critical thinking enables. Through this, we can avoid circumstances where stakeholders’ respective dreams are other stakeholder’s nightmares (Shiroyama et al. 2012, p.48).

We can restate the point in the vocabulary of Aristotle’s philosophy. Critical thinking as we are defining it is synonymous with *phronesis* or practical wisdom. Practical wisdom is the excellence (competence) in knowing how to practice other excellences (competencies) well (Aristotle, “Nicomachean Ethics”; Ryan 2013). In other words, critical thinking takes the long list of possible competencies, which identify and list the particular competencies needed by individual sustainability scientists, and it figures out how best to use these by reflecting on their value and effect. As such, the core competency of critical thinking is necessary to yield real-world solutions to human and ethical problems. In what follows, we sustain this argument and show how critical

thinking is necessary to realize normative dialogue, which is an aspect of interacting with disparate groups (See “Core Competencies” 2005, p.12).

While some claim that critical thinking skills can be sufficiently acquired indirectly in the ESD curriculum, there are strong reasons to doubt that this occurs to a sufficient degree. First off, most other disciplines focus on solving problems pertinent to their disciplines. A mycology class is about understanding mushrooms — not about critiquing the methods of investigation we use in the study of mushrooms. While good pedagogy would include reflective moments about the meanings of methods, there is no reason why it would then move to deeper critical thinking outside of the field-specific context.

Second, when critical thinking occurs in field-specific contexts, it remains linked to the discipline’s goals and focuses on improving outcomes for these goals by rethinking methods. In other words, it fails to be a key or core competency if it remains too tightly about improving a single discipline. Effective ESD requires critical thinking that extends beyond reflectively thinking about method. So while students may improve their reflective abilities by understanding the significance of an ecological survey, this may not translate into the ability to step back and reframe the ecology problem as a human sustainability problem or to recognize that ecological concerns may be secondary to other non-field specific concerns. In other words, if we want the deep critical thinking necessary for sustainability, we need to teach this core competency directly.

Finally, it should be noted that the OECD draws a similar recommendation, noting the importance of critical thinking for education specifically adding the evaluation of critical thinking through conceptual problem-solving to its framework for education (PISA 2015, 2013; Froese-Germain 2010). While the needs of sustainability science and the needs of the OECD are not perfectly identical, both are facing similar problems and noting that competency in critical thinking is integral to overcoming complex problems.

Several recent articles point out the need for new

skills and approaches to address the problems of global sustainability. Fortuin & Bush (2010) note that one of the largest needs to make progress in sustainability education is “boundary crossing skills” (p.20). The boundaries in question here are those that separate diverse stakeholders and put their interests at odds.

In the ESD literature on competencies, critical thinking is absent from the list of Tamura & Uegaki (2012). Wiek et al. (2011) mention it and classify it as a basic competency, a term that they do not thoroughly explain, and which stands in contrast to what they called key competencies for sustainability science. Onuki & Mino (2009) suggest an idea of “detachment” meaning the ability to take a step back from the problem. More promisingly, Lang identifies critical thinking as the core skill for problem-framing (Lang et al. 2012, p.35), and Niu et al. (2010) state that “To reorient current curricula in higher education, educators will be required to address critical issues and to promote integrative and analytical thinking with problem-solving approaches.” (p.156). In this paper, we make clear what these resources are hinting at.

4. Normative Dialogue as a Key Competency

In this section, we propose that normative dialogue should also be a key competency in ESD. We define normative dialogue as the ability to articulate one’s moral thinking in objective terms and to be able to understand the value concerns and interests of others. Here, this stands in contrast to merely making declarations of right and wrong. In other words, this is not a skill of having moral values. Instead, it is a competency in both receiving and communicating value judgments in neutral manners.

The background for this is that sustainability is premised on a widely shared value claim: to value the earth for present and future generations of human and non-human inhabitants. Thus, sustainability development is inherently normative and value-laden. This insight

inspires most (all?) ESD programs reflect this in part by including a course on environmental ethics and see it as a core course (e.g., Niu et al. 2010, p.156). The most basic value behind ESD, i.e., that we should take care of our planet, is not controversial: “However, it is a choice that is as such almost universally accepted: I personally never met anybody that seriously argued to give up this planet, and just let various sustainability catastrophes happen.” (Mulder 2010, p.74).

The problem arises when we turn to details and the wicked complexity of sustainability problems brings these to the fore (Jerneck et al. 2011, pp.75-76). Beneath the surface level agreement about sustainability lurks conflict about how the value of sustainability should interact with other values, such as national survival, poverty reduction, economic claims, religious claims, and justice claims. In other words, sustainability science’s normative thinking becomes more complicated as it involves tradeoffs between values like the equity of wellbeing between developing and developed countries in our generation (i.e., the North — South issues), poverty, population, resource utilization, food distribution, land distribution, aquatic resource distribution, current and future human wellbeing, and other areas of moral conflict (e.g., World Commission on Environment and Development, 1987; Sadowski, et al. 2013, p.1324).

Consequently, it is an important task for sustainability scientists to be equipped to deal with diverse groups that have disparate reasons for valuing sustainability science. Our goal in this section is not to dictate answers to these value conflicts. Instead, we recognize the need to accept diversity in the global project of sustainability and seek to limit the values we impose on the project to those required by sustainability itself, viz., a commitment to interacting with the earth in such a way that it can provide for current and future generations. In the process, we must ourselves achieve competency in normative dialogue and ask what values we may appropriately require of our students and which values we must realize are personal matters inappropriate for manipulation (Dobson & Tomkinson 2012, p.275).

We believe that normative dialogue can work in

tandem with critical thinking. Thus, we seek here to outline the normative dialogue competency to which builds on the core competency in critical thinking and enables sustainability scientists to think and converse about moral issues with the self-awareness that the norms, values, attitudes, beliefs and assumptions that are guiding our perception, thinking, decisions and actions and that these values and weightings of values reflect our values and may not be shared by all stakeholders. Sadowski et al. (2013) explain that, “For sustainability ethics, students must possess moral reasoning capabilities that are adaptive to the unfamiliar and unexpected situations characteristic of wicked problems” (p.1326). In other words, competency in normative dialogue is about navigating normative conflict for sustainability outcomes to problems we are currently facing.

In making this suggestion, we are not alone. First, OECD (2005) identifies “Interacting in Heterogeneous Groups” as a key competency and explains that this is the competency in relating well with others who are different from ourselves while managing our emotions and engaging in empathy (p.12). Wiek et al. (2011) identify “normative competence” as a key competency for doing sustainability science (p.204). Competency in normative dialogue is awareness of different perspectives (Fortuin & Bush 2010, p.21) and the ability to navigate these differences and find solutions that have “culturally appropriate” expression (Mochizuki & Fadeeva 2010, p. 393). Moreover, it is the ability to work within multiple normative frameworks (Lemons 2011, p.385).

Implementing the normative dialogue competency in ESD means enabling future sustainability scientists to understand the moral underpinnings of the decisions they make (Biedenweg et al. 2013, p. 7). Finding a good method for developing normative competency has proven elusive. Two previous articles have treated on this issue.

Muijen (2004) implemented a dilemma oriented learning model whereby students faced a fictionalized case regarding food and sustainability. They were then asked to evaluate which of eight options they thought would be best from an ethical perspective (p.25). As Muijen rightly notes, every choice involves values and

must relate back to how that community “conceptualises and values human beings in relation to each other, to the cultural and natural surroundings, and to a spiritual or religious dimension” (p.25). One of the first phases is for students to realize that they come with values and norms related to values that may not be as universal as they imagine. As a consequence of her research, Muijen argues that more direct attention should be given to integrating philosophical ethics into ESD. Such measures can clearly raise awareness of the degree to which students are already engaged in normative thinking but not necessarily lead to productive dialogue.

Biedenweg et al. (2013), for instance, define ethics as that which “defines good and bad ... [,] ... helps people decide how to live and what to buy ..., [and what] allows groups to determine fair and appropriate procedures” (p. 7). Wiek et al. (2011) similarly mention normative thinking as crucial for sustainability science but seems to mean by this objective thinking rather than normative moral thinking and reduces all moral concerns to a utilitarian calculus (p.213). Biedenweg et al. 2013) notes the poverty of the current discussion in the method they used for their ethics course: “First, [the students] gained more detailed understanding of diverse ethical principles that are normally glossed over, or often left out of discussions of technology and decision-making” (p.10).

Biedenweg et al. (2013) allude to a second challenge: the highly philosophical nature of many discussions of normative moral thought. Sustainability science must address differences between natural and human-made systems and thus involves “basic ontological and epistemological questions” which have often been unaddressed (Jerneck et al. 2011, p.72). Jerneck et. al (2011) further explain:

Differences in ontology and epistemology constitute one of the main obstacles to the integration of knowledge across scientific disciplines (Feyerabend 1991), especially when values, conflicting goals and difficult choices are involved. Methodology is, therefore, no trivial issue in sustainability science. Methods are rooted in (some) methodology and are, therefore, not neutral, whereas techniques are often

more neutral in the sense that they are less associated with a particular methodology (Jerneck et al. 2011, p.78).

These philosophical arguments impact what it means to be doing sustainability science and this in turn impacts how we should do sustainability science education.

Without developing competency in normative dialogue, sustainability projects can become mired in needless disagreements. The main goal of this competency is to avoid those disagreements or rather to make it so that only substantive disagreements between stakeholders wind up becoming part of the discussion. The key to this, in our view, is to learn how to articulate vested ethical claims in neutral mutually comprehensible ways.

5. Pedagogy for Critical Thinking and Normative Dialogue Competencies

In the preceding sections, we defined the competencies we want to foster. Here we look at what we take to be ideal methods for teaching these competencies. As Yarime et al. (2012) point out, a major hurdle for sustainability science is figuring out “effective pedagogical approaches” that integrate different disciplines (pp. 101-102). In other words, even if we are correct in saying that critical thinking should be a core competency and normative dialogue a key competency, this does not explain how to teach these in ESD. The pedagogy question is what sort of lectures, tasks, or projects would help students to grow in these skills.

In our view, critical thinking competency would be ideally fostered by the combination of (1) emphasis on basic thinking skills for informal logic, (2) consideration of model problems that mirror real-world sustainability issues, and (3) ultimately involvement with other stakeholders in the resolution of these problems. Several existing pedagogies at Arizona State (Wiek & Kay 2015) and the University of Tokyo and Kashiwa (Trencher et al. 2015) also emphasize real stakeholder interaction, and the European Workshop considers model problems to foster critical thinking by having faculty mentors guide

students mostly “by asking questions to trigger and enhance critical thinking and alternative views” (Fortuin & Bush 2010, pp.27, 31).

We believe it is admirable as a goal to have students do real-world sustainability and practice critical thinking on the job, but we also think it is important to foster the a toolkit of critical thinking skills before throwing students into the deep end. While there are some considerations about identifying “critical thinking” with Western critical thinking (Kubota 1999; Atkinson 1999), the reality is that sustainability science is conducted on the model of Western problem-solving and requires making claims and arguments in the model of Western thought. Consequently, we believe that pedagogy should include basic informal logic, including both simple sentential logic and basic induction. The primary goal was to help students understand how to formulate claims and arguments and to recognize the patterns of argumentation in which they are engaged. In the process, they could gain a grasp of logical structure and common fallacies so that they can be avoided in trickier real-world contexts.

After students have basic ability using these tools, students should then be fostered to apply this skill in increasingly real contexts. Thus, this should involve working through practical problems that mirror real-world sustainability issues with sufficient detail and involve role-playing different stakeholders. Finally, a critical thinking pedagogy would culminate in work on real sustainability problems with faculty, industry, government, and the community. Developing these skills would provide them with critical thinking competency that would help them articulate their positions more clearly and give them more flexibility in facing the often ill-defined and complex problems of sustainability

Turning to normative dialogue, we believe the goal is to foster competency in articulating one’s own views in neutral objective terms and to learn to understand and articulate the views of other stakeholders coming from disparate backgrounds. Little work has been doing in establishing a solid pedagogy for this. Along with Mujien (2004), we maintain that this should involve a basic familiarity with philosophical ethics. Here, a challenge,

highlighted above by Biedenweg (2013) et al. is that we are not asking students to become ethicists. Instead, we are asking them to develop an appreciation for the work of ethicists both through rights-talk and ethical theories, and to help them cultivate a very basic ability to communicate about values with people with whom they disagree. There is more to normative thought that could be helpful such as familiarity with the major claims of the religions that dominate world cultures or an anthropology of common folk beliefs.

6. Implementing our Teaching Pedagogy

Given our understandings of the competencies and our educational goals, we now turn to what we taught in our *Environmental Ethics* course to help foster these competencies. StraSS students are passionate about sustainability problems, and we wanted to channel that into rigorous competency to enable them to present these claims to others and to publish them. The majority of StraSS students were international students with a minority being Japanese students, all of whom were relatively strong English users.

For the first section, we designed a brief critical thinking curriculum focused on the concepts of “argument,” “statement,” “premise,” “conclusion,” “inductive” and “deductive.” We begin here, because we cannot assume our students have familiarity with the mode of thinking built around constructing arguments along classical Western lines. (The term “deductive” posed a challenge for several students who possibly for reasons of language took it to have a meaning somewhat similar to subtraction). By focusing directly on these concepts, we avoid the problematic approaches of “covering as much content as possible” and “one of many” (Nosich 2005). We addressed briefly what makes an inductive argument strong or weak by emphasizing the similarities between inductive arguments and statistical methods. We also explained the concept of a deductive argument and its key beneficial feature: truth-preservation and through this the distinction between inductive arguments as strong or

weak and deductive arguments as valid or invalid.

The critical concept of the first section is that arguments are built on claims, i.e., statements that can be either true or false, rather than on convictions. This feature should resonate with their experience in hard sciences. Moreover, this provides students with an objective basis for analyzing their own arguments and reasoning. This point was difficult for many of our students whose background included hard science classes but whose education systems did not emphasize critical thinking specifically. In particular, this was an issue faced by Japanese students since critical thinking is not generally a part of the Japanese school curriculum. For cultures and students not trained in this mode of argument, learning to grasp arguments in terms of defeasible premises proved more difficult than anticipated.

In the second part, we started training students to work with moral and legal normative frameworks to make simple claim-based ethical arguments. Since our students primarily came from the sciences, we sought to train was how to use normative frameworks to ethical arguments by using moral claims to increase their competency for normative dialogue. While we avoided teaching ethical theories in detail, we briefly included the concepts of deontology and consequentialism as we expect students to encounter these sorts of arguments in multi-stakeholder sustainability projects. We also taught students about the moral thought behind international frameworks such as the United Nations Declaration on Human Rights and the Geneva Convention. The key conceptual thought was to help students learn to understand and articulate moral terms objectively so that those with different assumptions can agree to the outcome without arguing about the justification.

The third required component was for students to use the competencies of normative moral thinking and critical thinking by working in groups to build moral arguments on the foundation of normative framework. Student presentations both give students a chance to practice and instructors a chance to see whether or not students are demonstrating competency for the required

Table 1. Student Critical Thinking Abilities Assessment Results

Item	Pre-Test Correct		Post-Test Correct	
	Correct Answers	Percent of Answer Correct	Correct Answers	Percent of Answers Correct
Claim: “In logical and critical thinking, an argument is a way to communicate in objective terms.”	33	97%	22	100%
Performance task: Able to identify a statement in logic	22	65%	21	95%
Claim: “in logic, validity means that an argument’s conclusion would be true if all of its premises are true.”	15	44%	15	68%
Claim: “a deductive argument is valid if its conclusion would be true if all of its premises were true.”	29	85%	20	90%
Total	34	100%	22	100%

material. For this component, we used the movie *Darwin’s Nightmare*, an award-winning but controversial film that raises questions about the fishing of the Nile Perch in Lake Victoria to generate an “embedded case study” (Scholz & Tietje 2002; Yarime et al. 2012, p.110) or problem-based learning scenario (Dobson & Tomkinson 2012, p.264). Each student group selected a problem from the movie, presented evidence of how this was a problem, and used these in conjunction with a legal moral framework to construct a moral argument for why what they saw was wrong.

We also provided an optional session where we explained the basics of sentential logic and laid out standard forms like *modus ponens* which was well-attended. In this context, we explained the basic symbolization of arguments and the standard operators used in deductive logic. The students who attended were readily able to grasp the benefits of this training. In addition to the general concepts, we also introduced students to standard forms of argument like *modus ponens*, *modus tollens*, hypothetical syllogism, disjunctive syllogism, and dilemma, which they can use as the basis for their policy papers. Based on feedback from that course, we would like to make it a requirement for all of our students to help them develop further competency in argumentation.

If additional resources had been available, we would have liked to also help students learn more about the psychology of disagreement. Our goal was to help students move from nebulous generic claims to defeasible claims founded on frameworks and science, i.e. from “I

think polluting the river is wrong” to more thorough articulations that express why on objective grounds we should consider dumping a particular chemical into the river is wrong or to being able to address the degrees of risk involved in different judgments about to what degree it is acceptable to pollute or to risk pollution.

7. Evaluating our Pedagogy (Teaching Outcomes)

We tested the effectiveness of our pedagogy using both surveys and by evaluating student presentations. We found the four weeks to be insufficient to achieve competency on our qualitative measure, and the quantitative measure to have insufficient data to draw a strong conclusion.

For the surveys, we had students fill out before and after surveys using Survey Monkey (an online survey tool) before and after this module of *Environmental Ethics*. While surveys have limitations, our students had little to no prior familiarity (50%) or only some familiarity (31%) with critical thinking (See Table 1 above). Despite this lack of formal training, students were already understood several of the key terms in critical thinking, but they were unprepared for more technical skills involving informal logic. Moreover, results tabulated from a free-form question about the relationship between critical thinking and sustainability indicated students were largely unaware of any relationship between critical thinking and sustainability (summarized

Table 2. Student Perceptions of Critical Thinking for Sustainability Science

Category	Pre-Class Evaluation	Post-Class Evaluation
Did not know	1	0
Resource policy + Morality	2	4
Resource policy	3	0
Objective thinking	4	3
Convincing others of what we think	4	2
Morality	2	1
Ethics (personal behavior change)	1	0
Could not be categorized	0	3
Total	17	13

Answers are number of students providing each response.

Table 3. Student Critical Thinking Abilities Assessment Results

Item	Pre-Test Correct		Post-Test Correct	
	Correct Answers	Percent of Answer Correct	Correct Answers	Percent of Answers Correct
Claim: “normative thinking is used to express views on moral issues in objective terms.”	25	89%	15	71% ¹
Claim: “a consequentialist approach seeks to maximize some good or commodity.”	5	18%	10	48%
Claim: “a deontological framework looks moral duties and their fulfillment.”	17	61%	18	90%
TOTAL	28	100%	21	100%

¹ [We theorize the decline occurred when students misunderstood the incorrect answer “to decide what is right and wrong” and interpreting that to mean that normative thinking can help us to identify whether something is right or wrong within a framework.]

in Table 2 below). Students’ answers were not normally distributed but generally reflected a lack of awareness of the relationship between sustainability science and critical thinking. From this, we maintain that our students lacked this core competency.

In our post-test, we saw little improvement in raw terms, and the differences in percentages are subject to multiple explanations. Students continued to perform strongly with definitions, correctly identifying that “In logical and critical thinking, an argument is a way to communicate in objective terms” (97% and 100% respectively). Similarly, there were percentage gains in core critical thinking concepts, such as identifying a statement from 65% (22 of 34 respondents) to 95% (21 of 22 respondents) and in understanding the validity (a technical term in logic), moving from 44% (15 of 34 respondents) to 68% (15 of 22 respondents). Moreover, students gained in their ability to grasp the ideas behind deductive arguments. These results are marred, however,

by a decrease in response rate, which makes it unclear how successful we were in our pedagogical objectives.

Our quantitative results also indicate that StraSS students also recognize the need for critical thinking as a core competency. 71% of our students indicate they believe sustainability science students at Hokkaido University would benefit from “a full course on critical and logical thinking.” In addition to see this course as valuable for others, 80% of students indicated they were extremely interested in taking such a course themselves if it were offered.

The same pre-test and post-test tested their ability to grasp the basics of normative dialogue. In terms of normative dialogue, 50% of the students we taught indicated they had little or no prior competency; 32% some competency; and 18% claimed to be knowledgeable. Here, we found gains in understanding the core terms in this competency (see Table 3 above). Specifically, we saw that students better grasped the core

theories of ethics. For example, performance rose in understanding “a deontological framework looks moral duties and their fulfillment” from 61% (17 of 28 respondents) to 90% (18 of 18 respondents). Similarly, correct understandings of “a consequentialist approach seeks to maximize some good or commodity” rose from 18% (5 of 28 respondents) to 48% (10 of 28 respondents).

Results for a question about the definition of “normative thinking” seem to contradict this, but we believe this can be explained. The correct answer is “to express views on moral issues in objective terms.” Several students incorrectly selected “to decide what is right and wrong.” As worded, this answer is fundamentally incorrect, because normative thinking builds on critical thinking to distance our ability to think about moral problems from our own moral thoughts, feelings, and frameworks. There are two possible explanations. First, students could have misunderstood the answer. Since normative thinking does enable us to *hypothetically* decide right and wrong within a given framework, they could mistakenly believe it is about deciding right and wrong. Second, it is possible that there were mistakes in the form of instruction, which left students confused as to the relationship between right and wrong and normative frameworks. Unfortunately, due to the dissolution of CENSUS, we have not been able to test this again.

In our post-test, we also asked students what they see as the relationship between normative frameworks and environmental ethics in response to a prompt that allowed for free answers. Table 4 tabulates information about student awareness of key concepts for normative dialogue competency by looking at student answers in

response to a free-writing question about the relationship between normative frameworks and environmental ethics. Through this, students gained a better appreciation of the complex ways that normative moral thinking relates to other competencies in sustainability science.

Turning to the students’ presentations, eight groups of four or five students made presentations focused on sustainability topics raised in *Darwin’s Nightmare*. We evaluated these presentations on two bases: (1) did the groups grasp the nature of critical thinking and articulate their views as objective arguments? And (2) did they understand how to integrate normative moral and legal frameworks into their presentation of arguments? Most groups in our *Environmental Ethics* class mentioned the sort of frameworks commonly referenced in policy agreements. Two groups demonstrated basic competency with only minor hiccups that could be expected in using a skill for the first time, but several other groups were not yet prepared to use this skill, making either purely economic arguments without explaining why that matters to morality, raw appeals to emotions about right and wrong, or failures to build an argument on the framework they selected.

We found their performance inadequate in general on the key integrative task. Based on our results in testing the competencies in action, we believe that students need more practice making arguments and having theses critiqued and more familiarity with the sorts of normative legal and philosophical frameworks that would enable them to make objective normative moral arguments.

We interpret the data to show that four class sessions did not sufficiently develop these valuable skills and that

Table 4. Student Perceptions of Ethics for Sustainability Science

Category of Response	Pre-Class Evaluation	Post-Class Evaluation
Norm for action and method of objective thinking	2	2
Method of objective thinking	0	1
Could not be categorized	1	1
Norm for action	5	2
Useful for convincing others	0	2
Did not Know	2	0
Total Responses Scored	12	8

Answers are number of students providing each response.

more needs to be done before students achieve competency in critical thinking or normative dialogue. Our immediate suggestion for improvement is that both the amount of homework and the number of course sessions should be increased. At the same time, it is possible that other approaches may be more efficient at fostering these competencies than the pedagogy we supplied above. While we had hoped to continue refining our approach, due to the changing interests of the times, the CENSUS program did not receive sufficient funding from either the government or Hokkaido University to continue offering the certificate or the course.

8. Conclusion

In our paper, we began by looking at how sustainability science seeks to answer wickedly-difficult problems. We then turned to the competencies framework central to ESD (Wiek et al. 2011). We argued and continue to maintain that critical thinking is a core competency for ESD and normative dialogue is a key competency crucial to the success of multi-stakeholder sustainability projects. Moreover, we believe that these competencies will not be achieved incidentally in other coursework.

What we took away from our experience teaching this material in the *Environment Ethics* class for CENSUS/StraSS at Hokkaido University is three-fold. First, when exposed to it, students realize the importance of critical thinking for sustainability science (90% found the sessions valuable or extremely valuable). In other words, brief introductions to critical thinking and normative dialogue can spark further interests from students who want to be sustainability scientists. Thus, we would encourage the inclusion of these ideas in introductory sustainability science materials and coursework.

Second, more work needs to be done on defining what skills are involved in each of these competencies for the purpose of sustainability science. We think the above definitions make the goals sufficiently clear. For critical

thinking, the goal is to interpret, reflect on, and rethink problems in order to find sustainability solutions that go beyond our current methods and discipline-specific approaches. Above, we articulated three different critical thinking tasks that could enable students to grow in this competency: (1) skill in informal logic, (2) consideration of model sustainability problems, and (3) involvement in real-world problems that require critical thinking. In conjunction with other researchers, we have proposed a more robust model for involving students with real world problems that we hope to implement soon (Fukushima et al. 2017). It is quite possible more work needs to be done in relating informal logic to sustainability science or that certain features or elements of informal logic are not necessary to the competency. Hopefully future research can address this question.

For the normative dialogue, the end goal is clear: to communicate moral claims in neutral terms, but the tasks that will help foster this skill are less clear. It is possible that emphasis on philosophical ethics does not contribute to this, and it would be better achieved through studying anthropology, psychology, or religion. To better test this hypothesis, we would need to compare how effective different forms of training are at accomplish this goal.

Third, regardless of the definitional problems we believe remain, we are confident that four weeks is not enough time to foster these competencies in any deep or meaningful way. While we have limited data, our analysis is that students were able to receive some knowledge about critical thinking and normative dialogue but nothing that rises to the level of competency. For one thing, we were not able to have students practice and receive feedback on several integrative scenarios that required critical thinking. Moreover, in a four-week period, there was no time to have students partner with and participate in real-world multi stakeholder projects.

References

Aristotle. (2000), *Nicomachean ethics*, Trans. by Terence Irwin, Indianapolis: Hackett Publishing

- Atkinson, D. (1999), Comments on Ryuko Kubota's "Japanese culture constructed by discourses: Implications for applied linguistics research and ELT": Postmodern applied linguistics: Problems and contradictions' another reader reacts, *TESOL Quarterly* 33(4), 745-749, doi: 10.2307/3587887
- Barth, M. & Michelsen, G. (2013), Learning for change: an educational contribution to sustainability science, *Sustainability Science* 8, 103-119, doi: 10.1007/s11625-012-0181-5
- Biedenweg, K., Monroe, M.C. and Oxarart, A. (2013), The importance of teaching ethics of sustainability, *International Journal of Sustainability in Higher Education* 14 (1), 6-14, doi: 10.1108/14676371311288912
- Bonn Declaration 2014 (2014), National Conference to Reflect on the UN Decade, 1-5
- Clark, W.C. (2007), Sustainability science: a room of its own, *Proceedings of the National Academy of Science* 104(6), 1737-1738
- Dobson, H. and Tomkinson, C. (2012), Creating sustainable development change agents through problem-based learning: Designing appropriate student PBL projects, *International Journal of Sustainability in Higher Education* 13(3), 263-278, doi: 10.1108/14676371211242571
- Falcione, P. (1990), *Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction*, California Academic Press
- Feyerabend, P. (1991), *Three dialogues on knowledge*, London: Basil Blackwell
- Fortuin, I. and Bush, S. (2010), Educating students to cross boundaries between disciplines and cultures and between theory and practice, *International Journal of Sustainability in Higher Education* 11(1), 19-35
- Froese-Germain, B. (2010), *The OECD, PISA and the impacts on educational policy*, Canadian Teachers Foundation
- Fukushima Y., Ishimura G., Komasinski A., Omoto R. and Managi S. (2017), Education and Capacity Building with Research: a possible case for Future Earth, *International Journal of Sustainability in Higher Education*, forthcoming
- Itoh, M., Suemoto, M., Matsuoka, K., Ito, A., Yui, K., Matsuda, T. and Ishikawa, M. (2008), Contribution of Kobe University to the regional centre of expertise (RCE) on education for sustainable development (ESD) Hyogo-Kobe, *International Journal of Sustainability in Higher Education* 9(4), 479-486
- Jerneck, A., Olsson, L., Ness B., Anderberg S., Baier M., Clark E., Hickler T, Hornborg A, Kronsell A, Lövbrand E. and Persson J. (2011), Structuring sustainability science, *Sustainability Science* 6(1), 69-82, doi: 10.1007/s11625-010-0117-x
- Jones P., Selby D. and Sterling S.R. (2010), More than the sum of their parts? Interdisciplinary and Sustainability" In Paula Jones, D Selby, & SR Sterling (Ed.) *Sustainability Education: Perspectives and Practice across Higher Education* (pp. 17-37), UK: Earthscan, London
- Kadoya, S. and Goto, M. (2013), The past, present, and future of ESD in Japan, *Kokuritsu Kyouiku Seisaku Kenkyuujo Kiyou* [National Institute for Educational Policy Research Journal] 142, 47-58
- Kajikawa Y., Ohno J., Takeda Y., Matsushima K. and Komiyama H. (2007), Creating an academic landscape of sustainability science: An analysis of the citation network, *Sustainability Science* 2, 221-231
- Kates, R., Clark, W., Corell, R., Hall, M., Jaeger, C., Lowe, I. and Svedin, U. (2001), Sustainability science, *Science* 292, 641-642
- Kitamura, Y. and Hoshii, N. (2009), Education for sustainable development at universities in Japan, *International Journal of Sustainability in Higher Education* 11(3), 202-216
- Kubota, R. (1999), Japanese culture constructed by discourses: Implications for applied linguistics research and ELT, *TESOL Quarterly* 33(1), 9-35, doi: 10.2307/3588189
- Lang, D.J., Wiek A., Bergmann M., Stauffacher M.,

- Martens, P., Moll P., Swilling M. and Thomas C. (2012), Transdisciplinary research in sustainability science — practice, principles and challenges, *Sustainability Science* 7 (Suppl), doi: 10.1007/s11625-011-0149-x
- Lemons, J. (2011), The urgent need for universities to comprehensively address global climate change across disciplines and programs, *Environmental Management* 48, 379-391, doi: 10.1007/s00267-011-9699-z
- Mochizuki, Y. and Fadeeva, Z. (2010), Competences for sustainable development and sustainability: Significance and challenges for ESD, *International Journal of Sustainability in Higher Education* 11(4), 391-403
- Mulder, K. (2010), Don't preach. Practice! Value laden statements in academic sustainability education, *International Journal of Sustainability in Higher Education* 11(1), 74-85
- Muijen, H. (2004), Integrating value education and sustainable development into a Dutch university curriculum, *International Journal of Sustainability in Higher Education* 5(1), 21-32
- Niu, D., Jiang D. and Li, F. (2010), Higher education for sustainable development in China, *International Journal of Sustainability in Higher Education* 11(2), 153-162
- Nomura, K. and Abe, O. (2010), "Higher education for sustainable development in Japan: policy and progress," *International Journal of Sustainability in Higher Education* 11(2), 120-129
- Nosich, G. (2005), Problems with two standard models for teaching critical thinking, In *New Directions for Community Colleges* 130, 59-67
- OECD (2005), *The Definition and selection of key competencies*, Viewed at <http://www.oecd.org/pisa/35070367.pdf> (Accessed December 2015)
- Onuki, M. and Mino T. (2009), Sustainability education and a new master's degree, the master of sustainability science: The graduate program in sustainability science (GPSS) at the University of Tokyo, *Sustainability Science* 4 (1), 55-59, doi: 10.1007/s11625-009-0073-5
- PISA 2015 (2013), *Draft collaborative problem solving framework*, Viewed at <http://www.oecd.org/pisa/pisaproducts/Draft%20PISA%202015%20Collaborative%20Problem%20Solving%20Framework%20.pdf> (Accessed December 2015)
- Ryan, A., Tilbury, D., Blaze, P., Abe O. and Nomura, K. (2010), Sustainability in higher education in the Asia-Pacific: developments, challenges, and prospects, *International Journal of Sustainability in Higher Education* 11(2), 106-119
- Ryan, S. (2013), "Wisdom" in *Stanford Encyclopedia of Philosophy*, Viewed at <http://plato.stanford.edu/entries/wisdom/> (Accessed December 2015)
- Sadowski, J., Seager, T., Selinger E., Spierre S. and Whyte, P. (2013), An experiential, game-theoretic pedagogy for sustainability ethics, *Science Engineering Ethics* 19, 1323-1339, doi: 10.1007/s11948-012-9385-4
- Scholz R.W. and Tietje, O. (2002), *Embedded case study methods: integrating quantitative and qualitative knowledge*. Sage, Thousand Oaks
- Shiroyama H., Yarime M., Matsuo M., Schroeder H., Scholz, R. and Ulrich, A. (2012), Governance for sustainability: Knowledge integration and multi-actor dimensions in risk management," *Sustainability Science* 7 (1), 45-55, doi: 10.1007/s11625-011-0155-z
- Tamura, M. and Uegaki, T. (2012), Development of an educational model for sustainability science: challenges in the mind-skills-knowledge education at Ibaraki University, *Sustainability Science* 7, 253-265, doi: 10.1007/s11625-011-0156-y
- Trencher, G., Terada, T. and Yarime, M. (2015), "Student participation in the co-creation of knowledge and social experiments for advancing sustainability: Experiences from the University of Tokyo," *Current Opinion in Environmental Sustainability* 16, 56-63
- Thomas, I. (2009), Critical thinking, transformative learning, sustainable education, and problem-based learning in universities, *Journal of Transformative*

Education 7(3), 245-264

Wals, A. and Jickling, B. (2002), “Sustainability” in higher education: From doublethink and newspeak to critical thinking and meaningful learning, *International Journal for Sustainability in Higher Education* 3(3), 221-232

Wiek, A. and Kay, B., (2015), “Learning while transforming: Solution-oriented learning for urban sustainability in Phoenix, Arizona,” *Current Opinion in Environmental Sustainability* 16, 29-36

Wiek, A., Withycombe, L. and Redman, C.L. (2011), Key competencies in sustainability: a reference

framework for academic program development, *Sustainability Science* 6(2), 203-218

World Commission on the Environment and Development (1987), *Our common future*, Oxford: Oxford University Press

Yarime, M., Trencher, G., Mino, T., Schloz, R., Olsson, L., Ness B., Frantzeskaki, N. and Rotmas, J. (2012), Establishing sustainability science in higher education institutions: towards an integration of academic development, institutionalization, and stakeholder collaborations, *Sustainability Science* 7(Suppl), doi: 10.1007/s11625-012-0157-5