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Assessing sustainability education in a transdisciplinary undergraduate course focused on real-world problem solving: a case for disciplinary grounding

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Abstract

Purpose: University sustainability programs intend to provide an integrated education that fosters the key competencies that students need to solve real-world sustainability problems. Translating these key competencies into pedagogical practice in integrated academic programs is not straightforward and the effectiveness of certain teaching methods in fostering sustainability competencies is largely unknown. The purpose of this paper is to present the results of a classroom assessment aimed at determining the extent to which key sustainability competencies develop in students during an introductory transdisciplinary sustainability course.

Design/methodology/approach: The paper summarizes three previously identified key sustainability competencies and describes teaching methodologies used in the introductory course described here to foster these competencies in students. The development of these competencies over the course of one semester are assessed using a pre-/post-test based on case analyses. The implications of these finding for academic sustainability programs are discussed.

Findings: Based on the assessment used here, the sustainability competencies developed differently in students with different disciplinary affiliations as a result of the introductory sustainability course. Business majors did not improve any of the key competencies, Sustainability majors improved systems thinking competence only, and Sustainability minors who were majoring in another traditional discipline improved all competencies.

Practical implications: Universities incorporate sustainability into their undergraduate curricula in many ways, ranging from infusing sustainability into courses based in traditional disciplines to creating academic programs focused entirely on sustainability that offer stand-alone sustainability courses. The results of this assessment suggest that universities should pay attention to the different preconceptions and disciplinary affiliations of students, as well as the overall structure of their undergraduate curriculum, as they figure out how to make sustainability part of undergraduate education.

Originality/value: The paper contributes to undergraduate sustainability education by shedding light on how sustainability might best be incorporated into specific academic programs. This information may help create more effective sustainability courses and academic programs, which may maintain the viability of current sustainability programs and promote the institutionalization of sustainability in higher education in general.

Keywords: sustainability education, transdisciplinary, sustainability competencies, assessment

Running Heads: Assessing sustainability education in an introductory course

1. Introduction
The UN has challenged higher education to reorient towards education for sustainability (UNESCO, 2003). In response, institutions of higher education worldwide have begun offering undergraduate degrees in Sustainability (AASHE, 2011). Many of these degree programs are transdisciplinary in nature, rather than being firmly grounded in a traditional academic discipline. This has led to much discussion in the educational literature pertaining to what should be included in the curricula of these programs, specifically what knowledge, skills, and attitudes students will need to tackle real-world sustainability challenges. Several key competencies for sustainability education that have consistently emerged from the educational literature over the past two decades were recently identified and synthesized by Wiek *et al.* (2011). The translation of abstract competencies into a functional university curriculum is not straightforward, yet it is critical for the effectiveness, credibility, and long-term viability of undergraduate sustainability programs. Thus, evaluating acquisition of these competencies through assessments of student learning and teaching effectiveness is an important phase in implementing and ultimately institutionalizing sustainability curricula. The purpose of this study is to assess the development of three of the general key competencies established by Wiek *et al.* (2011) among undergraduate students in a trans-disciplinary introductory sustainability course. Following a brief overview of what is meant by a transdisciplinary sustainability education and the issues surrounding this type of integrative program at an institution of higher education, these three key competencies – systems thinking, normative, and strategic – are summarized.

1.1 Transdisciplinarity and the Sustainability Curriculum
Throughout history, universities have adapted their curricula to meet the changing demands of society and this has largely played out by altering the degree of knowledge integration in academic programs (Klein, 1990). Universities of the 19th and early 20th centuries trended towards knowledge specialization, reductionist thinking, and the creation of disciplinary silos, which provided a platform for many technological advances that have improved human and societal well-being. A sustainable future would maintain these benefits, but at the same time preserve natural capital and eliminate the unintended harms to people that have resulted from some of these technologies. Thus, the sustainability challenges and opportunities that our societies face in the 21st century call for integration of knowledge about natural and human systems, holistic thinking, and collaboration across disciplinary and institutional boundaries. Further, the demands of industry and employers in other sectors are shifting from graduates that are disciplinary specialists capable of solving routine technical problems to graduates armed with competencies necessary for tackling complex real-world problems (Steiner and Laws, 2006). Institutions of higher education have responded by implementing integrative programs, ranging from individual courses to certificates to entire curricula.

The integration of disciplinary knowledge in these programs is variously referred to as multidisciplinarity, interdisciplinarity, and transdisciplinarity, and many scholars view these designations as a progression of the degree of knowledge integration (Brown *et al.* 2010; Marinova and McGrath, 2004). Brown *et al.* (2010, p. 4) describe multidisciplinarity as "a combination of specializations for a particular purpose, such as in a public health initiative," interdisciplinarity as "the common ground between two specializations that may develop into a discipline of its own, as it has in biochemistry," and transdisciplinarity as "the collective understanding of an issue … created by including the personal, the local, and the strategic." Similarly, Marinova and McGrath (2004) explain transdisciplinarity as arising from earlier multidisciplinary and interdisciplinarity research efforts:

> Multidisciplinarity is defined as research that studies a topic not only in one discipline but in several at the same time. Interdisciplinarity concerns the links and the transfer of knowledge, methods, concepts and models from one discipline to another. Transdisciplinarity instead involves what is between the disciplines, across the disciplines and beyond the disciplines. (Marinova and McGrath, 2004, p. 3).

Thus, from this perspective of increasing knowledge integration, multidisciplinarity does not explicitly involve the

sharing of methods, perspectives, and ways of knowing among different disciplines. Instead, it involves several disciplinary experts coming together to collaboratively solve a particular problem using his or her distinct disciplinary approach. Interdisciplinarity and transdisciplinarity, on the other hand, involve the dissolution of disciplinary boundaries and there is controversy associated with this type of program development within colleges and universities. It is important to note that these programs do not do away with traditional disciplines, which are essential to higher education and just as important to a sustainable future as holistic perspectives (Cairns, 2004).

In the literature, there are three general avenues of focus on interdisciplinarity in research and education. First, in academic research surrounding postmodernist thought, which occurs largely in the humanities, scholars question the disciplinary construction of knowledge and how this has led to the control, dissemination, and regulation of knowledge by certain disciplines (Messer-Davidow, 1993). They argue that disciplines are essentially political entities whose followers act to safeguard their own turf at the cost of advancing knowledge. Second, in K – 12 educational settings concerns about interdisciplinarity are practical rather than intellectual, as teachers are more concerned with administrative mandates for this type of education and with student motivation for learning that is enhanced through a focus on interdisciplinary real-world problems (Grossman *et al.* 2000). Third, interdisciplinarity in higher education often focuses on preparing students to solve real-world problems and it is this aspect that we are primarily interested in here. Along these lines, we use the following definition of *interdisciplinary understanding* by Boix Mansilla (2005) of Harvard's Project Zero (Project Zero, 2010):

> [T]he capacity to integrate knowledge and modes of thinking from two or more disciplines or established areas of expertise to produce a cognitive advancement – such as explaining a phenomenon, solving a problem, or creating a product – in ways that would have been impossible or unlikely through single disciplinary means (Boix Mansilla, 2005, p. 15).

Transdisciplinarity builds upon and goes further than interdisciplinarity by moving education into the world outside of the university. In sustainability education and research, transdisciplinarity involves disciplinary integration to solve real-world problems within a university setting but then moves beyond a university's institutional boundaries into a wider community of stakeholders (Scholz *et al.*, 2006; Stauffacher *et al.*, 2006; Brundiers *et al.*, 2010; Brown *et al.*, 2010) and has been termed 'external interdisciplinarity' (Klein, 1990). This type of collaborative tackling of real-world sustainability problems is aimed at integrating expert or academic knowledge with the practical or traditional knowledge of actors and stakeholders from outside of academia. Thus, *transdisciplinary understanding* adds to the meaning of *interdisciplinary understanding* in that knowledge and modes of thinking of stakeholders outside of academia are added to the knowledge integration. The push towards this type of education is based on the premise that academic knowledge alone has failed to solve society's most pressing problems, often calling for the democratization of science (Fischer, 2000). In sustainability, this type of collaboration between academics and non-academic stakeholders is referred to as co-production of knowledge (Carolan, 2006).

Despite the apparent benefits and widespread advocacy for interdisciplinary and transdisciplinary programs, the success of these programs in fostering students' capacities for real-world problem solving remains unsubstantiated. The fact that promotion of these programs has overtaken a thorough assessment of the outcomes of a new curriculum put into practice is characterised by Grossman *et al.* (2000) in the following way:

> Despite the popularity of interdisciplinary curricula across the nation, there is no body of evidence that attests to greater learning in high-quality interdisciplinary versus high-quality disciplinary classrooms. The problem goes well beyond the lack of data on student achievement. The existing literature on this topic (cf., Adler and Flihan, 1997) is almost entirely comprised of idealized descriptions of programs and how to put them in place, and almost entirely devoid of descriptions of what actually happens when theory meets school practice. We know nearly nothing about what occurs when teachers from different walks of life and different academic backgrounds join together to thrash out programs for student learning (Grossman *et al.*, 2000, p. 9).

Although Grossman's assessment of the situation speaks to K – 12 programs, the issues surrounding evidence of effectiveness are the same for higher education. Unlike K – 12 programs, disciplinary affiliations in higher education are strong and resistance to integrative curricular approaches abound for reasons including territoriality, academic tenure reward structures, and external funding opportunities (Becher, 1989; Cairns, 2004). Also, there are good arguments for strong disciplinary grounding prior to attempts at interdisciplinary integration (Klein, 2008, 1990; Boix Mansilla and Duraising, 2007; Brandes and Seixas, 2000; Messer-Davidow, 1993). Reasons for this include concerns for education that is "a mile wide and an inch deep" (p. 222), students' inability to "draw the links"(p. 223) if they don't have basic disciplinary understanding, and the "danger of students going 'meta' too quickly by focusing on epistemology and methodology at the expense of more substantive disciplinary understanding" (Boix Mansilla and Duraising, 2007, p. 224). If *interdisciplinary understanding* is the "capacity to integrate knowledge and modes of thinking from two or more disciplines" (Boix Mansilla, 2005, p. 15), then students must understand the methods, tools, and perspectives of different disciplines before using them in an integrated way to solve a real-world problem. On the other hand, this concern for strong disciplinary grounding is not an issue in all fields of study. The humanities, where connections are regularly made across seemingly permeable disciplinary boundaries, are not as uneasy as more vertical disciplines (such as chemistry and physics) where learning is more structured and sequential (Li, 1997).

Nonetheless, both the resistance to integrative curricula within some institutions of higher education and concerns about the need for a strong disciplinary grounding adds to the suspicion surrounding the effectiveness of interdisciplinarity and transdisciplinarity programs.

In summary, there are apparent benefits of a transdisciplinary curriculum to sustainability education. However, the resistance to implementing these programs for the reasons discussed above calls into question what is actually being learned in these programs and the quality of that learning. We must cease to simply advocate for these programs without producing evidence of student learning and teaching effectiveness. With this research, we attempt to assess key sustainability competencies through analysis of student work. These key competencies, drawn from Wiek *et al.* (2011), are described next.

1.2 *Systems Thinking Competence*

Systems thinking arose from the natural sciences, such as ecology, where integration during problem solving is a fundamental concept. From a systems perspective, the goal is to understand the whole and the many levels of interrelationship that characterize the system. Systems thinking evolved to counter reductionist or mechanistic thinking, which claims the possibility of explaining a whole system through an analysis of its component parts in isolation. Almost anything consisting of two or more component parts can constitute a system (e.g. a tree, an economy, a digestive system). The emergent property of systems thinking is the ability to perceive the system as a functional whole (e.g. a tree carries out photosynthesis; an economy fosters the production, distribution, and consumption of goods and services; a digestive system digests food) and appreciate its dynamic nature (Capra, 1996). Although it originated in the natural sciences and has often been used for quantitative predictive modeling applications in these disciplines, systems thinking is equally applicable to social and cultural systems (Checkland, 1981; Marten, 2001; Meadows, 2008). When applied to these systems, the approach is often different in that the problem or question of interest may be more dependent on subjective judgment and perception. In this case, systems thinking becomes an epistemological tool to support qualitative understanding. Both approaches to systems thinking are relevant to sustainability.

Systems thinking has long been recognized as a central component to achieving sustainability literacy (ACPA, 2008; Forum for the Future, 2004; Hulbert *et al.*, 1997; McKeown, 2006; Svanström *et al.*, 2008) and, most recently, was identified as a widely-recognized key competency in sustainability education (Wiek *et al.*, 2011). Specifically, understanding the interrelationship between human systems and the ecological system is particularly salient in solving problems related to sustainability (Dale and Newman, 2005; Marten, 2001). Challenges that manifest within these systems are inherently complex and interdisciplinary in nature, can exhibit counterintuitive behaviour, and often defy linear, cause-and-effect correlations; making problem solving complicated (Holling, 2001). The specific types of systems that we deal with in sustainability, known as a complex adaptive systems, are subject to legacy effects that generate path dependencies; spontaneously self-organize and self-regulate; involve feedbacks and chaotic behaviour; and constantly move through long-term cycles of adaptive change (North, 1990; Gunderson and Holling, 2002; Chapin *et al.*, 2009). A systems thinking approach to sustainability education is not only necessary to prepare graduates for understanding the dynamics of coupled natural and human systems, but it is a skill that is currently at a premium in professional practice (Martin, 2008).

According to the recent literature review and synthesis by Wiek *et al.* (2011), systems-thinking competence is composed of a suite of core concepts and research methodologies aimed at understanding complex socio-ecological systems. For the purpose of this assessment, we focused on a subset of these concepts and methodologies. One primary element of systems thinking, as associated with sustainability literacy, is the ability to integrate multiple perspectives into one's viewpoints (Dale & Newman, 2005; Ellis & Weekes, 2008; Forum for the Future, 2004; Porter and Córdoba, 2008; Svanström *et al.*, 2008; UNESCO, 2003; Warburton, 2003). This requires the ability to holistically analyse complex systems across the different sustainability domains of environment, society, and economy that span a variety of temporal and spatial scales (Turner *et al.*, 2003). In our research, we specifically focused on assessing students' skills and understanding necessary to identify and prioritize challenges across these three domains, with sensitivity to sustainability principles.

Another important element of systems thinking in sustainability is the capacity to recognize the values underlying the actions of individuals and the structure of social systems (Wiek *et al.*, 2011). The three sustainability domains encompass a diversity of perspectives borne from different value and belief systems, which creates conflict in reaching solutions to sustainability challenges. As such, learners must be able to discern and critically reflect on the values that punctuate these perspectives (Forum for the Future, 2004; Herremans and Reid, 2002; Schlottman, 2008; Warburton, 2003), which is a key component to contextualizing problems (Martin, 2008). For this assessment, we evaluated students' ability to identify and critically reflect on the values pertinent to a specific sustainability challenge.

1.3 *Normative and Strategic Competencies*

Although the term normative has different connotations in different academic disciplines, normative ways of thinking generally stipulate an ideal standard or model (Baron, 2000). It was 18th century philosopher David Hume's recognition of this type of thinking, in his 1739 classic work *A Treatise of Human Nature*, which brought explicit awareness to this idea. In philosophy, and in many other academic disciplines, normative statements or knowledge

regarding *what ought to be* are often contrasted with positive (i.e. descriptive) knowledge aimed at affirming *what is*. In sustainability, normative knowledge is often associated with an assertion of values and ideas of what the world should look like, whereas positive knowledge is associated with factual statements meant to explain reality. Thus, the normative competence goes beyond having the ability to describe a current system's sustainability and how that system might continue to develop into the future under business-as-usual or other conditions (Wiek *et al.*, 2011). It involves thinking about how the current system *should be* developed into the future so that the sustainability of environmental, social, and economic systems will be enhanced.

Sustainability itself is a value-laden concept which says: *When a human activity preserves the Earth's natural capital and does not diminish the well-being of people living today or in the future, then it is sustainable.* An abundance of sustainability declarations expressing this ideal have been written (e.g. Brundtland Report: WCED, 1987; Millenium Declaration: UN, 2000). However, these ambiguous affirmations intentionally leave the specifics open to interpretation, and there is not widespread agreement on the goals or the means of achieving sustainability (Beatley, 1995; du Pisani, 2006; Hopwood *et al.*, 2005; Bell and Morse, 2008; Rees, 1995). Ultimately, it is the values, preferences, and beliefs of individuals and societies that influence decisions made and actions taken regarding sustainability. Thus, in order to navigate our current systems towards future sustainability, students must possess the ability to recognize and resolve the conflicts among the diverse values, preferences, and beliefs associated with social, environmental, and economic systems and reconcile them with those of sustainability. Resolving these conflicts involves developing trade-offs using sustainability as a compass (Colucci-Gray, Camino, Barbiero, & Gray *et al.*, 2006; Keough, 1998; Herremans & Reid, 2002; Schlottman, 2008; Svanström, 2008). Schlottman (2008) argues that complete resolution of conflicts among various perspectives is unlikely, but learners should be encouraged to design innovative trade-offs among them. He posits, "How do we choose between sustainability and appreciation, political majorities and deeply held values, fairness of resource distribution and irreversible loss of species?" (p. 211). Arguably, these are just a few of the complicated challenges future generations must be equipped to face. For this assessment, we evaluated the ability of students to identify conflicts among preferences of the three sustainability domains and the tradeoff in values that may be necessary to achieve a sustainable system.

Closely linked with normative competence is strategic competence. As a result of competing values, different stakeholders with different preferences and beliefs will propose disparate strategies or courses of action when confronted with a sustainability challenge. Thus, students must develop the action-guiding or strategic knowledge that is required to motivate stakeholders towards sustainability by engaging and working with their specific values, preferences, and beliefs (Grunwald, 2007). The strategic competence means that students have the ability to collectively design and implement "interventions, transitions, and transformative strategies" to redirect current systems towards a sustainable future state (Wiek *et al.*, 2011). This involves recognizing barriers to change, how to overcome those barriers, and anticipating unintended consequences. In simple terms, this competence is about being able to "get things done" (Wiek *et al.*, 2011, p. 8) and, subsequently, involves familiarity with real world situations. For this assessment, we evaluate students' ability to devise multiple realistic strategies for resolving the conflicts between sustainability priorities that reflect consideration of economic needs, ecosystem health, and human well-being. Not only are the normative and strategic competencies important for solving sustainability challenges, university graduates are now expected by future employers to possess these skills (Steiner and Laws, 2006). None of the key competencies described here are mutually exclusive and, for the purposes of this paper, the normative and strategic competencies are grouped together.

1.4 Sustainability Competencies and Pedagogy

Unlike other types of cognitive activity, systems thinking is not intuitive or innate. When thinking about a problem, we do not naturally think about all things connected to it and their interrelationships. There is evidence suggesting that humans do not have the natural mental capacities to understand and manage complex socio-ecological and technological systems, especially those that are highly interactive and tightly coupled (Perrow, 1984; Forrester, 1971; Forrester, 1987). Thus, it is necessary to cultivate this skill explicitly (Hung, 2008). A variety of pedagogical strategies used in the context of higher education related to sustainability content have been proposed, including future-focused visioning projects (Goekler, 2003; Martin, 2008), back casting (Martin, 2008), word games (Goekler, 2003), concept mapping (Warburton, 2003), models and queries (Wang and Wang, 2011) as well as modelling via software applications (Hung, 2008). Porter and Córdoba (2008) introduce multiple approaches which may be taken to achieve different levels of systems thinking: a functionalist perspective in which learners must identify and quantify what is knowable in the system (like inputs and outputs), an interpretive approach in which students are encouraged to better understand the more subjective perspectives in a system (like ethics), and a complex adaptive approach where learners gradually widen their worldview to understand the more complex, non-linear phenomena in a system (like entrenched social systems). Warburton (2003) suggests even broader strategies which may guide the integration of systems thinking at the curriculum level: 1) using a wide range of conceptual and material content, 2) explicitly demonstrating the interconnections and interdependence of that material, and 3) emphasizing the dynamics rather than static nature of material.

Pedagogical approaches to developing the normative and strategic competencies are not as formally developed as those for the systems thinking competence. To address these competencies, learning through

experiences focused on solving actual, real-world sustainability problems has been proposed (Brundiers *et al.*, 2010) and there is wide recognition of the value of this type of learning experience in sustainability education in general (Cortese, 2003; Rowe, 2007; Sipos *et al.*, 2008; Stauffacher *et al.*, 2006). However, in an introductory course at a large university where hundreds of students are enrolled during any given semester, these types of learning experiences can be tricky for a variety of reasons including students' lack of basic knowledge, skills, and understanding of sustainability concepts and methodologies and a dearth of instructor capacity for coordination, supervision, and facilitation of a large number of real-world projects each semester. An alternative to an actual real-world problem-solving experience for developing these competencies in this educational setting is the use of case studies and group projects in the classroom.

Beginning with use by the Harvard Law School in the late 19th century, the case study method has become a popular pedagogical approach for connecting theory with practice in the classroom and has been used across diverse disciplines including medicine, business management, and engineering (Wassermann, 1994; Barnes *et al.*, 1994). The goal of the case study method is to increase students' problem solving skills through engagement with practical real-world challenges where an interdisciplinary perspective is required, understanding stakeholder interests and relationships is key, and students are forced to make decisions under uncertainty. According to an analysis of the case study method based on the cognitive and affective domains of Bloom's taxonomy of instructional objectives (Bloom *et al.*, 1956), Romm and Mahler (1986) define the means for achieving this goal as honing students' abilities for: logical analysis of a problem, coping with the emotional aspects of a problem, and choosing among a variety of solution options. Further, the case study method may be an effective mechanism for increasing students' capacity for tackling "wicked" sustainability problems, where the problem definition and solution is dependent on the values, preferences, and beliefs of stakeholders (Skaburskis, 2008, p. 1):

> [T]here are no 'right' or 'wrong' solutions for any case. …[S]tudents realize that a case always has many problems, and the definition of one of these problems as 'the main' one is often subjective and arbitrary. They also realize that once a problem has been defined, it can have different reasons and be solved in different ways, depending on whose interests are being served or being given priority. [S]tudents eventually realize that even when two cases look the same, subtle differences in their details or the personality of their characters can highly affect their analysis and the choice of the appropriate solution (Romm and Mahler, 1986, p. 695).

The case study method has been used in both sustainability education and research (Stauffacher *et al.*, 2006; Scholz *et al.*, 2006). As a pedagogical tool in sustainability, it has typically been used in upper division undergraduate courses and in graduate programs, and has involved students going out into the real-world to work with stakeholders to solve problems (Stauffacher *et al.*, 2006; Brundiers and Wiek, 2011). At the introductory level, where real-world experiences are often not feasible, analysis of sustainability problems through case studies in the classroom can be used to "bring the world in" (Brundiers *et al.*, 2010, p. 314). In this setting, case studies provide a limited form of interaction between students and the societal context on which a case study is based, as students usually have no direct contact with stakeholders outside of the university. Nonetheless, classroom case analysis can serve as a first step in building students' competencies for solving complex real-world sustainability problems by bridging the gap between academia and the outside world (Steiner and Laws, 2006).

Assignments and projects that require students to work in groups have become more common in higher education in general (Johnson *et al.*, 1998; Mills and Cottell, 1998; Bruffee, 1993) and increasingly called for in sustainability education in particular (Stauffacher *et al.*, 2006; Moore, 2005; Cortese, 2003). However, group work in higher education is wrought with controversy. On the one hand, group work can be challenging as "…group processes are difficult, delicate, complex, sometimes thrilling, exhausting, and, last but not least, they do need time and attention" (Stauffacher *et al.*, 2006, pp. 265). Students often become frustrated with group work due to poor guidance by faculty and dependence on other group members for their grade (Feichtner and Davis, 1984). On the other hand, group work fosters many skills important in collaborative work on real-world problems including interpersonal communication, organization, planning, and delegation. Not surprisingly, students attribute their success during upper division group project-based courses to experience with group work in lower division classes, prior work experience, and summer internships (Colbeck *et al.*, 2000). Thus, despite its challenges, in sustainability programs with curricula structured to engage students in real-world problem solving during upper division courses, such as described by Brundiers *et al.* (2010), it is wise to engage students beginning in their first year in well-supported and structured group projects (Hendry *et al.*, 2005). This is important to do during introductory courses so that they will learn the collaboration skills necessary for working with stakeholders outside of academia in upper division courses.

The purpose of this project is to assess development of the systems thinking, normative, and strategic competencies among a diverse group of undergraduate students before and after a semester-long introductory transdisciplinary sustainability course. The course was designed to increase these key competencies in students. To answer the research questions, data were collected at two points in time: pre- and post-semester. The aim of the study was to answer the following general research questions:

1. Prior to the sustainability course designed to increase key competencies, what are the levels of competence

among students?
2. Is there a significant change in students' competencies following the sustainability course?
3. Was the transdisciplinary sustainability course more effective in improving competencies among sub-groups of the class with different disciplinary affiliations?

2. Methods

Institutional Setting: Student and Course Characteristics
The sample for the study was composed of undergraduate students from Arizona State University (ASU). Specifically, the study utilized students completing an introductory sustainability course (SOS 110: Sustainable World) in the School of Sustainability (SOS), which offers undergraduate (B.A. or B.S.) or graduate (M.A., M.S., or Ph.D.) degrees in Sustainability. All of the SOS's courses are designed to build and deepen understanding of several overarching concepts, including complex adaptive system dynamics and evaluation of trade-offs. Students learn to be sustainability problem solvers through real-world learning experiences. The SOS 110 course is the beginning of this experience and the world is brought into the classroom through case study analysis throughout the semester and a final group project based on analysing and proposing solutions to a real-world sustainability problem. The course was the first sustainability course taken by most of the students in this study. The 103 students enrolled in the course who participated in the study were from different academic programs: 58 were Sustainability majors in SOS, 25 were Business majors concentrating in Sustainability from ASU's W.P. Carey School of Business, and 20 were pursuing a minor in Sustainability but enrolled in other academic departments to major in other disciplines. Table I provides a complete demographic summary of the participants. After completing SOS 110, and its companion course focused on urban sustainability (SOS 111: Sustainable Cities), Sustainability majors go on to take upper division courses to pursue one of seven possible specialization areas or "tracks" to earn either a B.A. (Society and Sustainability, Policy and Governance in Sustainable Systems, International Development and Sustainability, or Sustainable Urban Dynamics) or a B.S. (Economics of Sustainability, Sustainable Ecosystems, or Sustainable Energy, Materials, and Technology) in Sustainability. Of the 20 students majoring in a discipline other than Sustainability or Business, the breakdown of disciplinary majors is as follows: Anthropology (1), Biological Sciences (2), Design Studies (3), Earth and Environmental Sciences (1), Earth and Space Exploration (1), Economics (1), English Literature (2), General Studies (1), Landscape Architecture (2), Mathematics (1), Performance/Guitar (1), Political Science (1), Sociology (1), Interdisciplinary Studies (1), and Exploratory Humanities for Fine Arts and Design (1).

		Sustainability Majors	Business Majors	Other Majors
Sex				
	Males	33	20	13
	Females	25	5	7
Age				
	18	22	0	1
	19	22	2	6
	20	3	15	3
	21	0	4	2
	22	0	1	3
	23 – 34	11	3	5
Year in School				
	Freshman	20	0	2
	Sophomore	26	11	8
	Junior	9	11	4
	Senior	3	3	4
	Post-Baccalaureate	0	0	2

Table I. Demographic overview of sample as grouped by declared major

The overall goal of the course was to prepare students to become sustainability problem solvers. To understand sustainability, one must understand the functioning of complex systems in general and the details of natural and socio-economic systems in particular (Clayton and Radcliffe, 1996). Thus, students were presented with knowledge of key principles related to natural and socio-economic processes and also some aspects of complex adaptive systems theory. The course involved weekly lectures, with accompanying readings, during which these

fundamental concepts were explained. Concept presentation was always problem-based and revolved around sustainability challenges. For example, the laws of thermodynamics were used to explain why a meat-based diet is more resource-intensive than a vegetarian diet, and plate tectonics and the global carbon cycling were used to explain why fossil fuels result in more net carbon emissions to the atmosphere than biofuels. For social science concepts, the tragedy of the commons was used to explain why open ocean fisheries are rapidly being depleted, and informal social norms, beliefs, and values were used to explain why homeowners living in the middle of the desert have lush green lawns. Students were also qualitatively exposed to concepts in complex adaptive systems theory, such as feedbacks, causal chains, cascading effects and unintended consequences, and thresholds. Parallel to the lectures, the students attended weekly breakout sessions during which they participated in small group discussions and classroom activities. Through the use of case studies, the breakouts were designed to deepen students' understanding of knowledge acquired during lecture and also to introduce the sustainability science problem solving methodologies (Kajikawa, 2008) used specifically to solve sustainability problems (e.g. visioning, future scenario development, indicator setting, intervention points, transition strategies). For their final project, students were asked to choose a real-world sustainability problem and, using the sustainability science problem solving methodologies learned over the course of the semester, propose a solution to their problem.

Assessment Materials and Procedure
Assessing internal cognitive processes is inherently problematic, but in the assessment of systems thinking skills in higher education, an examination of writing samples or case studies seems to be the most viable approach (Wang and Wang, 2011; Zulauf, 2007), utilizing a structured rubric for analysis (Hung, 2008; Wang and Wang, 2011; Zulauf, 2007). To our knowledge, there are no well-established methods for most effectively assessing normative and strategic competencies. As a result, we incorporated questions into the case studies and criteria into the rubric for assessment of these competencies (see below). To assess the students' key sustainability competencies, two case studies (for pre- and post-semester assignments) were developed. Each case study, written by one of the authors, presented a typical sustainability challenge, a potential solution being promoted by a non-profit organization, and the major stakeholders (consumers, governments, businesses, non-profit organizations). Climate change was the sustainability challenge that served as the basis for the pre-semester case study. Students were presented with the fact that gasoline used in transportation contributes about 20 % of total CO_2 emissions to the atmosphere through human activities (IPCC, 2007). The solution presented in this case study was to transition to the electric car as a way to reduce CO_2 emissions from current gasoline-powered vehicles. The impact of excessive nitrogen input to ecosystems (toxic algae blooms, ocean dead zones, human health, biodiversity loss) was the focus of the post-semester case study. More than half of all synthetic nitrogen fertilizer ever used by humans for agriculture has been applied since 1985 (MEA, 2005). Thus, the sustainable farming practice of polyculture that includes nitrogen-fixing species was the proposed solution. The specific, written case studies used in this assessment can be obtained from the authors upon request.

At the beginning (pre-semester) and end (post-semester) of one semester, all students read the same case study and responded to the same set of questions. For each case study, the instructions to the students were to:

Q1. Identify all possible social, environmental, and economic challenges presented in the case study.
Q2. Prioritize the challenges in terms of the ones they believe most important to achieving sustainability.
Q3. Identify and critique the values that underline the non-profit's strategies.
Q4. Identify the conflicts between the social, environmental, and economic priorities.
Q5. Identify where the non-profit might have to compromise on values, making a trade-off to achieve their goal.
Q6. Make recommendations for the non-profit about how the conflicts between the social, environmental, and economic priorities could be resolved while still supporting sustainability.

The questions are aimed at assessing systems thinking (1, 2, and 3), normative (4 and 5), and strategic (6) competencies. These questions, along with the answer key, rubric, and case study scoring procedures described below, where used in a similar sustainability assessment by Hiller Connell *et al.* (in review). The purpose of that assessment was to determine the relative effectiveness of two different instructional methods on sustainability competencies development among undergraduate students at two undergraduate institutions.

Prior to beginning data analysis, the authors developed an answer key for both the pre- and post-semester case studies. Independently, each author read the two case studies and generated answers to the questions. The authors then compiled their responses and developed an initial answer key. Further refining of the answer key occurred as the researchers read through the students' responses and identified additional, legitimate answers to the questions. Once the authors were satisfied that they had a complete answer key, they used it to analyse all of responses to the case studies.

To guide the analysis of the participants' responses to the case studies' questions and the assessment of key competencies, the researchers developed a rubric. Utilizing the previously discussed key competencies, they identified two primary thrusts: holistic thinking (HT) and conflict resolution (CR). The holistic thinking elements of the rubric were intended to analyse systems thinking skills, whereas the conflict resolution elements were to analyse the closely related normative and strategic competencies. The four elements of HT were defined as: 1) the ability to

identify social, environmental, and economic perspectives/issues embedded in the case study scenario, 2) the ability to prioritize those perspectives/issues with sustainability in mind, 3) the ability to identify and critically reflect on the values which underpin the scenario, and 4) the ability to communicate ideas descriptively and with reflection. Likewise, three elements for CR were defined as: 1) the ability to identify conflicts between the interrelated sustainability priorities (social, environmental, and economic), 2) the ability to identify possible trade-offs among these priorities, and 3) the ability to formulate realistic strategies for resolving the conflict with sustainability in mind. On a scale of zero to five (0=No skill; 5=Exceptional skill), levels of quality in responses for each element of HT and CR were then designed. The scoring rubric used in this study is included in Table II.

	Exceptional (5)	*Above Average (4)*	*Average (3 2)*	*Below Average (1)*	*No Skill (0)*
HT 1 (Q1)	Student identifies all of the social, environmental, & economic challenges represented in the scenario	Student identifies most of the social, environmental, & economic challenges represented in the scenario	Student identifies some of the social, environmental, & economic challenges represented in the scenario	Student struggles to understand the tenets of sustainability, and therefore, is able to identify challenges but not necessarily pertaining to sustainability	Student *cannot* identify social, environmental, or economic challenges in scenario
HT 2 (Q2)	Student is able to prioritize issues represented in the scenario with sensitivity to sustainability principles	Student prioritizes challenges, but is not necessarily completely focused on sustainability principles	Student prioritizes challenges, but is not considering sustainability	Student struggles to prioritize challenges	Student *cannot* prioritize challenges
HT 3 (Q3)	Student can identify & reflect critically on all of the values that underpin of the scenario	Student can identify most of the values that underpin the scenario, and *reflect on them critically*	Student can identify some of the values that underpin the scenario, but struggles to *reflect on them critically*	Student struggles to identify the values that underpin the scenario; therefore, *critical reflection is implausible*	Student *cannot* identify the values or reflect critically on the values that underpin the scenario
HT 4 (Q1 – Q3)	Conceptions communicated are detailed & reflect depth in thought	Conceptions reflect depth of thought, but thought process is incomplete without more detail	Conceptions are simplistic, lacking both depth of thought and detail	Student struggles to think deeply about concepts; therefore, detail is lacking	Conceptions do not exhibit detail or depth in thought
CR 1 (Q4)	Student identifies many conflicts between the interrelating sustainability priorities (social, environmental, & economic)	Student identifies most of the conflicts between the interrelating sustainability priorities	Student identifies some of the conflicts between the interrelating sustainability priorities	Student struggles to identify conflicts between the interrelating sustainability priorities	Student *cannot* identify conflicts between the interrelating sustainability priorities
CR 2 (Q5)	Student can identify several possible trade-offs in values that may be necessary for the non-profit to reach its goals	Student can identify at least *two* possible trade-offs in values that may be necessary	Student can only identify *one* possible trade-off in values	Student struggles to identify where trade-offs in values and can give only a partial or simplistic example	Student *cannot* identify where trade-offs in values may be necessary
CR 3 (Q6)	Student makes multiple realistic strategies for resolving the conflicts between sustainability priorities. Recommendations reflect consideration & incorporation of the economic needs of the business, the health of the ecosystem, and the safety, health, and human rights of people that may be affected	Student's recommendations are realistic but reflect a lopsided focus on one of the three sustainability tenets. Nevertheless, *recommendations evidence an effort to support* more than one tenet of sustainability	Recommendations reflect a lopsided focus on one the three sustainability tenets. *Recommendations are singular and lack an effort to support* more than one tenet of sustainability	Student *struggles to* make recommendations reflective of the tenets of sustainability	Student *cannot* make recommendations reflective of the sustainability tenets

Table II. Assessment scoring rubric used to analyse pre- and post-semester case studies. Q1 through Q6 correspond to the questions in the text to which students were asked to respond.

Upon finalizing the answer keys and the scoring rubric, two researchers (Researcher A and B) independently analysed the students' responses to the pre- and post-semester case studies. Using the rubric, they scored the students' responses to the case study questions and assigned scores corresponding to the four elements measuring HT and the three elements measuring CR. Then, for each participant, Researcher A's scores for the four items measuring holistic thinking were summed and averaged into a single score. Similarly, Researcher A's scores

for the three items measuring conflict resolution were also summed and averaged into a single score, as were the scores assigned by Researcher B. Data analysis continued by averaging Researcher A and B's scores, for each participant (for both HT and CR) leaving one summed score, for each participant, representing the individual's total competency score. The researchers repeated this process of data analysis for the participants' post-semester case study responses.

Statistical Analyses
SPSS Version 15.0 statistic software was used for all analyses. The Kolmogorov-Smirnov test for normality was applied to all data before using parametric techniques to assess the differences between groups. When comparing groups, Levene's test for homogeneity of variances was used to ensure that the assumption of similar variance in scores among groups of different sizes was not violated.

For all students, t-tests were used to evaluate differences between holistic thinking and conflict resolution scores at a single time point (pre-semester or post-semester) and also changes in these scores over the course of the semester. An independent-samples t-test was conducted to compare all participants' pre-semester holistic thinking with their pre-semester conflict resolution. A paired-sample t-test was conducted to evaluate the impact of the sustainability course on students' holistic thinking and conflict resolution scores by comparing pre-semester and post-semester scores for all participants as a whole.

Analysis of variance was used to explore differences among disciplinary affiliation sub-groups as defined by declared major. A one-way between-groups ANOVA was used to determine if there was a difference among declared major groups in pre-semester holistic thinking and conflict resolution scores. A mixed between-within subjects ANOVA was used to determine if the sustainability course affected participants' holistic thinking and conflict resolution scores differently among sub-groups of the class as defined by declared major. When appropriate, this was followed by a paired-sample t-test to evaluate the impact of the sustainability course on participants' holistic thinking and conflict resolution scores within each declared major group by comparing pre-semester and post-semester scores.

3. Results
Descriptive statistics of the pre-semester competencies of all students reveal low mean scores for holistic thinking, conflict resolution, and overall competence (Table III). The independent samples t-test showed that there was a significant difference between pre-semester holistic thinking and pre-semester conflict resolution [t(103)=4.611, p=.05], with students having a greater ability for holistic thinking (2.99 ± 0.81) compared to conflict resolution (2.48 ± 0.77) at the beginning of the semester. A paired-sample t-test was conducted to evaluate the impact of the sustainability course on participants' holistic thinking and conflict resolution by comparing pre-semester and post-semester scores. There was a statistically significant [t(103) = -3.374, p = 0.05 (two-tailed)] increase in holistic thinking from the beginning of the semester (2.99 ± 0.81) to the end of the semester (3.31 ± 0.81). The mean increase in holistic thinking scores was 0.31 with a confidence interval ranging from 0.13 to 0.50. The eta squared statistic (0.10) indicated a moderate to large effect size (Cohen, 1988). There was not a statistically significant difference in conflict resolution from the beginning of the semester (2.48 ± 0.77) to the end of the semester (2.62 ± 0.67) for the class as a whole.

	Pre-semester (mean ± standard deviation)	Post-semester (mean ± standard deviation)
Holistic thinking	2.99 ± 0.81	3.31 ± 0.81
Conflict resolution	2.48 ± 0.77	2.62 ± 0.67
Overall competence	5.47 ± 1.45	5.93 ± 1.31

Table III. Descriptive Statistics of Pre-Semester Competencies for All Participants

The one-way between-groups ANOVA , which was used to compare pre-semester holistic thinking and conflict resolution among different sub-groups based on declared major, revealed the there was no significant difference in either set of competencies among these groups at the beginning of the semester. However, the mixed between-within subjects ANOVA revealed that these competencies developed differently among the different groups. For holistic thinking, there was no significant interaction between declared major and time [Wilks Lambda = 0.98, F (1, 9) = 1.30, p = 0.28, partial eta squared = 0.03], and there was a substantial main effect for time [Wilks Lamdba = 0.92, F (1, 9) = 9.22, p = 0.003, partial eta squared = 0.08] (Table IV). The main effect comparing the three declared majors groups was significant and suggests a moderate between-subjects effect [F (1, 100) = 3.99, p = 0.02, partial eta squared = 0.074]. For conflict resolution, there was no significant interaction between declared major and time

[Wilks Lambda = 0.98, $F(1, 4) = 1.05$, $p = 0.36$, partial eta squared = 0.02] and there was a substantial main effect for time [Wilks Lamdba = 0.96, $F(1, 4) = 4.029$, $p = 0.047$, partial eta squared = 0.04] (Table 3). The main effect comparing the three declared majors groups was significant and suggests a moderate between-subjects effect [$F(1, 100) = 3.38$, $p = 0.038$, partial eta squared = 0.063].

	Sustainability Majors (n = 58)	Business Majors (n = 25)	Other Majors (n = 20)
Pre-semester holistic thinking	3.08 ± 0.90	2.80 ± 0.66	2.97 ± 0.71
Post-semester holistic thinking	3.43 ± 0.75	2.90 ± 0.87	3.48 ± 0.75
Difference	0.35 ± 1.65[†]	0.10 ± 1.53	0.51 ± 1.46[†]
Pre-semester conflict resolution	2.57 ± 0.83	2.25 ± 0.47	2.51 ± 0.82
Post-semester conflict resolution	2.64 ± 0.66	2.35 ± 0.66	2.89 ± 0.61
Difference	0.07 ± 1.49	0.10 ± 1.13	0.38 ± 1.43[†]

Table IV. Competencies development among three declared major groups. A † symbol indicates that there is a statistically significant difference between pre-semester and post-semester scores.

Because there was a difference in competencies development among sub-groups based on declared major, a paired-sample t-test was conducted to evaluate the impact of the sustainability course on participants' holistic thinking and conflict resolution by comparing pre-semester and post-semester scores. For Sustainability majors, there was a statistically significant [$t(58) = -2.726$, p = 0.05 (two-tailed)] increase in holistic thinking from the beginning of the semester (3.08 ± 0.90) to the end of the semester (3.43 ± 0.75). The mean increase in holistic thinking scores was 0.35 with a confidence interval ranging from 0.09 to 0.61. The eta squared statistic (0.12) indicated a moderate to large effect size. There was not a statistically significant difference in conflict resolution from the beginning of the semester (2.57 ± 0.83) to the end of the semester (2.64 ± 0.66) for Sustainability majors. For Business majors, there was not a statistically significant difference in holistic thinking from the beginning of the semester (2.80 ± 0.66) to the end of the semester (2.90 ± 0.87) nor was there a difference in conflict resolution (pre-semester: 2.25 ± 0.47; post-semester: 2.35 ± 0.66).

Students who were neither Sustainability nor Business majors experience statistically significant changes in both competencies over the course of the semester. There was a statistically significant [$t(20) = -2.694$, p = 0.05 (two-tailed)] increase in holistic thinking from the beginning of the semester (2.97 ± 0.71) to the end of the semester (3.48 ± 0.75). The mean increase in holistic thinking scores was 0.51 with a confidence interval ranging from 0.11 to 0.91. The eta squared statistic (0.28) indicated a large effect size (Cohen, 1988). There was also a statistically significant [$t(20) = -2.191$, p = 0.05 (two-tailed)] increase in conflict resolution from the beginning of the semester (2.51 ± 0.82) to the end of the semester (2.89 ± 0.61). The mean increase in conflict resolution scores was 0.38 with a confidence interval ranging from 0.02 to 0.75. The eta squared statistic (0.20) indicated a large effect size (Cohen, 1988).

4. Discussion
The study examined development of three key competencies among undergraduate students who completed a semester-long introductory, trandisciplinary sustainability course. After assessing competence development for the class as a whole, the student participants were broken into sub-groups based on disciplinary affiliation (declared major) to examine differences in improvement of these competencies among groups. The study utilized a pre-/post-semester experiment to answer the research questions.

The results of the study indicate that, at the beginning of the semester, the all students had low-level skills related to systems thinking, normative, and strategic competencies. This finding is reasonable given students' educational backgrounds and limited previous exposure to a sustainability course aimed at fostering these competencies. However, the students were more competent in thinking holistically about sustainability issues (systems thinking competence) compared to their ability to identify and resolve conflicts presented in the case studies (normative and strategic competencies). Based on age and year in school (Table I), most students in this course were young (more than 80 % were 22 years old or younger) and just beginning their college education (65 % were freshman and sophomores). Thus, we can assume that the majority of the students have spent most of their lives in K – 12 and university educational systems, rather than working in the real-world whether in a full-time career or an internship experience. This finding suggests that formal educational systems in general may be adequately emphasizing the multiple perspectives of environmental, social, and economic systems required to develop the

systems thinking sustainability competence, but not effectively developing the normative and strategic competencies required to identify conflicts, evaluate trade-offs, and develop solutions to resolve sustainability conflicts. Therefore, sustainability curricula aimed at fostering the key competencies assessed in this study should ensure that not only are students capable of identifying the interrelationships between human and ecological systems, but that they are equally competent at identifying conflicts and developing trade-offs between conflicts among social, environmental, and economic perspectives, using sustainability as a guide.

A more outstanding discovery of the study was that students with different disciplinary affiliations appear to have varying capacities for developing the three key competencies. For Business majors, neither holistic thinking (systems thinking competence) nor conflict resolution (normative and strategic competencies) increased as a result of the sustainability course. Knowledge of sustainability in the business profession is increasingly important. The Harvard Business Review has deemed sustainability as the next "business megatrend," as important as the quality movement of the 1970s and the information technologies megatrend of the 1980s and 1990s (Lubin and Esty, 2010). Despite the obvious importance of including sustainability in the business curriculum, this remains one of the biggest challenges faced by business schools (Russell, 2006). A major consideration is whether sustainability should be integrated into traditional business courses or taught as an isolated course outside of the business curriculum (Christensen, 2007; Tilbury *et al.*, 2004). An argument against teaching sustainability courses as separate from the business curriculum is based on the "pedagogical gulf" that exists between the free market focus of traditional business courses and the environmental and social externalities that are components of sustainability courses (Carrithers and Peterson, 2006). In addition, Daly and Farley (2004) point out the underlying paradigm of neoclassical economics, which envisions the environment as a subsystem of the economy from which resources are extracted and into which waste is disposed. In contrast, in sustainability courses, students are taught that the economy is a subsystem of an environment containing finite natural resources. As a result, students may conclude that business and sustainability are inherently in conflict. In the constructivist view of learning, students come to the classroom with preconceived understandings and ideas about how the world works (Bransford *et al.*, 2000). If instructors do not engage these understandings, students may fail to grasp new concepts and information. In order to avoid these educational disconnects, it may be crucial for business students to learn sustainability within a business context (Stubbs and Cocklin, 2008). This is especially true for introductory sustainability courses, where avoiding this educational disconnect may be important to the retention of business majors in a Sustainability concentration.

In addition to the basic intellectual disconnects between business and sustainability, students pursuing a business degree might bring with them certain predispositions in values, knowledge, and skills related to why they chose to major in business. Students pursue business degrees for several reasons, with the top motivations including general interest in the work, good job opportunities, a good fit with abilities, and projected earnings (Kim et al., 2002). This list does not include ensuring the well-being of the people and the planet. Thus, as observed by Armstrong (2011), the heavy concepts confronted in a sustainability class may cast a dark shadow on the reasons that business-focused students originally came to their discipline. Armstrong (2011) also observed that business-focused apparel and textile students felt concepts such as industrial ecology and biomimicry were too science-heavy. Business students may simply not have the knowledge or skills required to attain sustainability competencies, especially those related to the natural sciences. Although we did not collect specific data in this study, in informal meetings with hundreds of students as part of an extra credit office visit, students were asked why they chose their major. Anecdotal evidence from these meetings suggests that about half of the business students are in the course because they care about sustainability and see a business career as a means to effecting change. The other half give reasons such as not getting into their preferred business major (e.g. finance) or they feel that a business sustainability major will give them a competitive edge. In contrast, sustainability majors are overwhelmingly concerned about social and environmental issues with little to no interest in business sustainability.

Only the holistic thinking scores of Sustainability majors increased, whereas both holistic thinking and conflict resolution increased for students majoring in other disciplines spread across the natural sciences, social sciences, and humanities. The fact that holistic thinking increased for both of these groups suggests that this sustainability course adequately develops students' systems thinking competence, assuming that Business students' system thinking competence did not increase for the reasons cited above. However, holistic thinking increased more for students affiliated with other disciplines than it did for Sustainability majors. In addition, the students affiliated with other disciplines were the only group to develop conflict resolution (normative and strategic competencies) over the course of the semester. This suggests a greater capacity in general for these students to learn in interdisciplinary or transdisciplinary settings, and provides support for the idea that a strong disciplinary grounding is necessary for successful interdisciplinary understanding (Boix Mansilla and Duraising, 2007).

The reason for increased conflict resolution scores for students majoring in other disciplines, but not for the other two groups, might have to do with a greater capacity for students strongly affiliated with other disciplines to develop normative and strategic competencies. Boix Mansilla and Duraising (2007) suggest three interrelated criteria for assessing students' interdisciplinary understanding: (1) disciplinary grounding, (2) cognitive advancement through integration, and (3) critical awareness of the meta-cognitive coordination of different disciplinary perspectives. The third criterion evaluates students' ability to weigh the benefits of one disciplinary perspective against others and also against the overall purpose of the integrative work. Eighty percent of sustainability majors were freshman and sophomores, whereas only 50 % of students majoring in traditional disciplines were this new to higher education and

the other 50 % were juniors or beyond (Table I). In traditional disciplines, students generally begin exposure to their discipline's epistemology in introductory courses. In contrast, sustainability students in the program described here do not choose a specialization area until their sophomore or junior years and cannot even advance to more discipline-specific upper division courses until they complete two general introductory sustainability courses. Thus, it is possible that students taking this course who are majoring in other disciplines have stronger disciplinary grounding than new sustainability students.

It is possible that students without strong disciplinary grounding have a lower capacity for reflecting on and integrating different disciplinary epistemologies and methodologies to come up with novel solutions to problems because they are not firmly rooted in any discipline. One faculty member involved with assessing student interdisciplinary understanding remarked that the "…meta questions do not make a lot of sense if you are not understanding the material that they are about" (Boix Mansilla and Duraising, 2007, p. 224). Based on this information, the students in this study who are strongly rooted in other disciplines may have a greater ability for critical awareness. This ability to reflect on and integrate different disciplinary perspectives to solve a problem, if transferred to a greater capacity than other students to identify conflicts among stakeholders with different perspectives and evaluate trade-offs for developing solutions, may explain why students with a strong disciplinary grounding showed improvement in conflict resolution (normative and strategic competencies). After all, academic disciplines can be viewed as stakeholders in the collective quest for knowledge. In addition to contributing to knowledge production using particular ways of knowing and methodologies, disciplines provide a "social matrix for people with common interests, joint commitments, and certain commonalities in viewing the world" (Grossman *et al.*, 2000, p. 3) and academic departments provide the context for developing certain attitudes and beliefs (Grossman and Stodolsky, 1995). By being strongly grounded in a way of knowing and belief system about how the world works, students who are affiliated with a discipline may be better positioned to evaluate stakeholder conflicts from a meta-level.

In this study, we focused on identifying differences in the development of three sustainability competencies among students majoring in a variety of disciplines over the course of a semester for one sustainability course. For a better understanding of why these differences exist, future studies should try to uncover students' predispositions in values, knowledge, and skills that might impact competence development. This might include a survey of world views such as the New Ecological Paradigm (Dunlap *et al.* 2000) or of political and ethical orientation such as the Political Compass Test (Pace News, 2001). Surveys asking each student why they chose their major would also add valuable information. To better understand how the overall structure of an academic program influences competence development, assessment should occur throughout each students' university sustainability education. During such a long-term assessment, courses taken alongside sustainability courses should also be noted as these courses may variously reinforce, challenge, or contradict sustainability principles. Simultaneously taking a sustainability course in conjunction with a course that reinforces these principles may impact overall competence development differently than if the sustainability course were taken alongside a contradictory course.

5. Conclusions

With the recognition that sustainability should become part of education (UNESCO, 2003; Cortese, 2003), there have been many attempts by institutions of higher education to include sustainability in their academic programs. These attempts range from infusion of sustainability into traditional disciplinary courses (for example, Remington and Owens, 2009) to the creation of entire departments offering majors in sustainability (for example, ASU's School of Sustainability). It is clear from the results of this study that there is no best way to do this across the board. For Business majors, our results suggest that sustainability education might be most effective if infused into traditional business courses. Pursuing a minor in Sustainability, while majoring in a traditional academic discipline, appears to be an effective way to advance systems thinking, normative, and strategic competencies for some students. For Sustainability majors, the course improved the systems thinking competence only. As evidenced by the greater capacity for conflict resolution by students minoring in Sustainability but with a strong disciplinary grounding, perhaps normative and strategic competencies will improve for Sustainability majors as the move into upper division course with a more disciplinary focus. With specific reference to the key competencies assessed here, the preference of one implementation mechanism over another will depend on the preconceptions and disciplinary affiliations of the students, and the overall structure of a given curriculum. Future research should focus on assessing competence development in both sustainability interventions in traditional disciplinary courses and also as students progress into upper division, disciplinary courses within transdisciplinary sustainability programs.

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