



## **Development and Application of the Sustainability Skills and Dispositions Scale to the Wicked Problems in Sustainability Initiative**

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## Abstract

Throughout engineering curriculum there has been a growing focus on sustainability-related learning objectives, oftentimes with the ultimate learning goals being instilling dispositions such as the awareness of the environmental impact of engineering outcomes or concern towards social justice issues. Within this paper, we first provide an overview of an instrument we have developed to evaluate students' attainment of analogous learning objectives. This instrument, the Sustainability Skills and Dispositions Scale (SSDS), was designed to measure four sustainability-related outcomes: (a) **confidence** in responding to wicked problems and awareness of (b) **global**, (c) **social**, and (d) **environmental** responsibilities as a designer. The SSDS was implemented pre-post within a course context as part of a multi-university initiative called the Wicked Problems in Sustainability Initiative (WPSI) during the Fall of 2014.

The primary objective of this paper was to provide an overview of the reliability of the SSDS and to consider where the SSDS may still be improved for optimal alignment with WPSI objectives and outcomes. Our secondary goal was to consider where WPSI may be improved in the future in light of the survey results, which included the survey items and written reflections. To accomplish this second goal, we first used the SSDS items to compare pre- and post-course responses overall and on a course-by-course basis. To corroborate findings from this quantitative component, and to elucidate how both WPSI and the SSDS may be refined and improved, our secondary goal was pursued through content analysis of students' post-course written reflections. Participating instructors' experiences within WPSI were juxtaposed against these qualitative and quantitative findings to discuss broader implications for engineering education curriculum and to consider future recommendations for WPSI.

## Introduction

During the 2014 ASEE conference, we presented an overview of the instructional design guiding the Wicked Problems in Sustainability Initiative (WPSI). The acronym was changed from "WPSE" to WPSI. We dropped the "E" as our intent was never to be exclusive to non-engineering students or faculty members. At ASEE 2014, we presented preliminary results from the first WPSI iteration. Following the 2014 conference, we identified the need for a valid, reliable, and easily replicable assessment measure that could be used both within and outside of WPSI to measure the attainment of a series of sustainability-related learning objectives throughout the engineering education research community.<sup>1</sup> In this paper, we present the ongoing development and refinement of this measure, the Sustainability Skills and Dispositions Scale (SSDS). This instrument evaluates students' attainment of learning objectives along four scales: (a) self-reported **confidence** in responding to wicked problems and self-reported awareness of professional responsibilities in (b) **global**, (c) **social**, and (d) **environmental** contexts.

WPSI exposes students to wicked problems through problem-based or project-based learning approaches<sup>2</sup> where we characterize wicked problems as social, political, and environmental challenges that have no definitive formulation and no clear victory condition. This nomenclature was first used by Rittel and Weber who identified 10 aspects of wickedness.<sup>3</sup> Norton later

condensed this 10-item list to 4 themes: (a) uncertainty in problem formulation, (b) inapplicability of straightforward calculations, (c) non-repeatability of responses, and (d) open-endedness of the response space.<sup>4</sup> Due to the ill-structured nature and complexity of wicked problems, these are by definition never solvable. Therefore, we use the terminology of responses rather than solutions when discussing project outcomes within the WPSI courses.

Students who participated in WPSI during the Fall of 2014 were tasked to generate responses to the wicked problem *sustainable housing for the next 1 billion*, a broad social problem which has many elements of wickedness. For example, the root of the problem is unclear, where what needs fixing is subjective. Likewise, there is no “one-size-fits-all” solution, meaning a solution for one block or neighborhood is not directly replicable at another. Sustainable housing is tied with many other wicked problems such as issues of poverty, equitable education, resource conservation, and climate change. As a result, any response to this wicked problem will impact the others. Within the participating WPSI courses, student teams were tasked to develop viable responses to this wicked problem through staged design reviews, while being exposed to its overall complexity and interconnectedness of sustainable housing with other wicked problems.

## **Our Motivation**

WPSI is organized through Engineers for a Sustainable World (ESW). As an organization, our vision is for a world of environmental, social, and economic prosperity created and sustained by local and global collective action. We recognize that the next generation of leaders will be tasked to develop responses to a wide set of wicked problems in a socially and environmentally appropriate manner. Some of the most prominent wicked problems in the immediate future will include sustainable urban planning, alleviating climate change, and feeding the world, to name a few. Emergent leaders, many of whom are currently students within and outside of engineering, will be central to realizing a more sustainable world for future generations. Our goal as authors is to inspire these future leaders (our students) to become motivated to and confident in responding to these wicked problems in a manner that is socially appropriate and environmentally viable. For us, this starts with developing a community of support to give faculty the confidence to effectively introduce wicked problems into their existing courses. Through this community, faculty may leverage one another’s expertise in order to expose students to real-world wicked problems. In the spirit of holistic engineering education, our hope is to enable instructors to confidently develop their students’ non-technical skills which are integral for generating sustainability-minded leaders of the future.<sup>5,6</sup>

## **Research Methods**

In this paper, our primary research objective was to develop a valid and reliable psychometric instrument that measures a series of sustainability-related learning objectives that are central to WPSI. Our second objective was to implement the SSDS and illustrate the findings when using this survey pre- and post- course with students who participated in WPSI across three universities during the Fall of 2014. Results from these components are triangulated with students’ end-of-semester written reflections and participating instructors’ course experiences. This qualitative component allowed us to consider how WPSI might be improved in future iterations, as well as broader implications of the SSDS and WPSI for engineering education courses and curriculum.

For anonymity, throughout this paper we will refer to course offerings as Course 1, 2, and 3. This framing puts the focal point on the courses themselves rather than on the university in which the course was embedded. In Table 1, we refer to these Courses as 1, 2, and 3 to represent when the course began participating in WPSI. During Fall of 2014, Courses 1 and 2 were in their second offering of WPSI, whereas Course 3 was in its first iteration.

**Table 1:** Course descriptions of WPSI offerings during the Fall 2014 academic semester

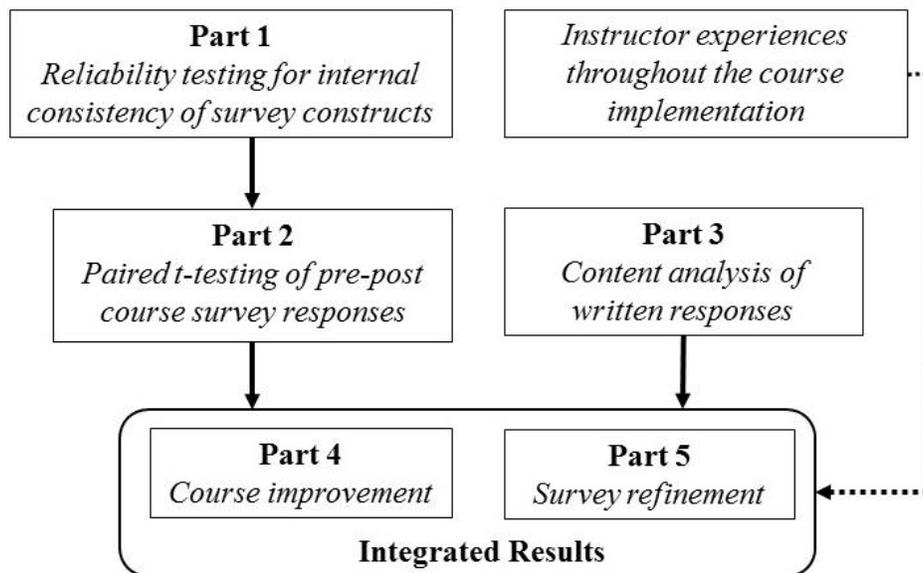
Course #	Course Title	Department	Required?	# of Students
1	Social Entrepreneurship: Engineering for Humanity	General Engineering	No	14
2	Wicked Problems	Multidisciplinary Studies	No	10
3	Technical and Professional Communication	General Studies	Yes	44

This mixed method research study, based around these course offerings from the Fall of 2014, is divided into five parts. Our theoretical approach is grounded in pragmatism, meaning our focus is on the “what” and “how” of the research topic rather than relying on any single philosophical system.<sup>7,8</sup> In other words, the pragmatic approach allows us to move beyond the contradictions between different research approaches, and instead to focus on empirical data while maintaining flexibility in our research methods.<sup>9</sup>

In the first part of this study, we provide a descriptive framing of the instrument we have developed, namely, how the Sustainability Skills and Dispositions Scale (SSDS) was informed by existing and tested quantitative instruments that have been published throughout engineering education scholarly literature. This initial portion of the study ends with a description of the survey items and reports the level of reliability ascertained from the pre- and post- course responses. The second section of this study provides an overview of the paired t-test results using this survey. The third part examines students’ responses along the three open-ended response questions at the end of the post-course survey. Taken together, results from these sections are integrated in part four of this study, where we provide a reflective discourse in light of the results to highlight WPSI’s successes, to consider possible changes for future WPSI offerings, and to explore broader implications for sustainability education. In the fifth and final part, we provide recommendations for improving the survey in light of the quantitative, qualitative, and reflective results.

Figure 1 depicts our research phases in relation to one another. The framework is described as a convergent parallel design<sup>8</sup> where the distinct research phases run in parallel and these results are integrated to inform a final data interpretation.<sup>10</sup> Here, the quantitative research components (Parts 1 and 2) run in parallel to the qualitative component (Part 3), suggesting that the results from one component do not inform the other directly. Rather, these results are integrated in the final components (Parts 4 and 5). Despite the parallel nature of these methods, it should be noted that each part is of similar weight. In addition to these qualitative and quantitative research

components, we rely on the course instructors' reflections of their course offerings in the integrative stages.



**Figure 1:** Convergent Parallel Research Design

### Part 1. Learning Objectives and Scale Development

One of the primary goals for the wicked problems courses is to expose students to the overall complexity of wicked problems<sup>3,11</sup>, while giving students the tools and cognitive awareness to effectively and confidently respond to these wicked problems in their future work as professionals, designers, and engineers (see Hess, Brownell, & Dale 2014 for the instructional design<sup>1</sup>). The survey we have designed corresponds to the following learning objectives:

*As a result of participating in the course, students will...*

- 1) Develop confidence in responding to wicked, sustainability-related problems
- 2) Become conscious of the ethical and professional responsibilities within their field in a (a) global, (b) social, and (c) environmental context

In the first WPSI iteration, we created and distributed 15 loosely related items measuring students' confidence and professional dispositions. Our focus in this second iteration was to expand these survey items so that each item would relate to a group of items that theoretically mapped onto one of the above learning objectives as a scale. As such, one of the initial steps in this round of survey iteration was the decision to retain, remove, or refine the questions from the previous survey. In this step, we decided whether the existing item fit within one of the envisioned survey constructs as written, if the items should be rewritten to fit beneath a theoretical construct, or removed altogether.

The second step involved a thorough re-examination of existing tested survey measures published within engineering education scholarly literature. We borrowed and adapted items

from a number of existing measures, which included the following (for an item-by-item description, see Appendix A):

- Zhai and Scheer's (2004) Global Perspective Scale<sup>12</sup>
- Downey et al.'s (2006) global competency questions<sup>13</sup>
- Braskamp, Braskamp, & Merrill's (2008) Global Perspective Inventory, and in particular their Interpersonal Social Responsibility Scale<sup>14</sup>
- Hilpert, Stump, Husman, and Kim's (2008) Engineering Attitudes Survey<sup>15</sup>

Throughout the survey development process, the authors were in dialogue with one another, providing feedback for item clarity, framing, and refinement. Along with evaluating the fit between survey items and constructs, each author offered suggestions for improving the survey for better alignment to each instructor's course participants. As an example of one key shift in the survey's language, because all participants were not required to be engineering students, all references to "engineering" were replaced with "my profession", and all references to "engineer" were either removed or replaced with "designer". Throughout this dialogue between the authors, we were striving for construct validity<sup>16</sup>, seeking to ensure the survey items would be a true evaluation of their corresponding learning objective. After the survey draft was complete, the survey was tested against members of the National Team of Engineers for a Sustainable World before final implementation into WPSI courses in the Fall of 2014.

The final survey consisted of 28-items along the 4 constructs corresponding to the learning objectives. For simplicity, we will refer to these constructs as (1) confidence, (2a) global, (2b) social, and (2c) environmental. Table 2 shows an overview of the 28 items, along with which construct each item theoretically maps onto. Negative signs indicate that an item was designed to negatively correlate with the other items along that scale.

During August 2014, the survey was administered pre-course to 67 students across the 3 participating universities: a large public university in the mid-western USA, a large private university in the Northeastern US, and a private engineering college also in the mid-west. At the end of the semester, the survey was re-administered to these same participants, 52 of whom completed the survey. At the start of the survey, students were notified that their responses would be kept anonymous. Each student used a unique identifier created and known only by the course instructor, and another member of the research team who was not leading any course de-identified the survey results prior to sharing descriptive statistics with the course instructors.

The last portion of this first part of the study is intended to ascertain the internal consistency reliability of the developed survey items by examining the relationships between survey items as they correspond to the theoretical constructs we have developed. Through calculating Cronbach's alpha ( $\alpha$ ) for pre-course responses, the internal consistency reliability of subscales 1, 2a, and 2b was found to be acceptable as measured using  $\alpha$  and a 0.7 threshold, whereas subscale 2d was minimally acceptable with an  $\alpha$  of 0.656.<sup>17</sup> Despite having a smaller sample size, post-course responses showed higher internal consistency, with the minimum  $\alpha$  found to be 0.748, and the highest found to be 0.844.

**Table 2:** The Sustainability Scales and Dispositions Scale (SSDS) survey items

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1. I feel prepared to work with people who define a problem differently than I do. (1)
2. I feel prepared to develop sustainable solutions in future projects. (1)
3. Designers must consider the environmental implications of their designs. (2c)
4. The present distribution of the world's wealth and resources should be maintained because it promotes survival of the fittest. (2a, -)
5. My opinions about national policies include consideration of how those policies might affect the rest of the world. (2a)
6. It is a designer's responsibility to maximize the economic profit of their solutions, even at the expense of increased environmental consequences. (2c, -)
7. Design solutions must have a positive impact in the local community. (2b)
8. Generally, an individual's actions are too small to have a significant effect on the ecosystem. (2c, -)
9. I measure success in my life by how much I contribute to society. (2b)
10. All design decisions will have an effect on the planet. (2c)
11. I am able to affect what happens on a global level by what I do in my own community. (2a)
12. I am prepared to meet and work with individuals from different backgrounds. (1)
13. I care about the effect that my professional decisions will have on the planet. (2c)
14. Designers must consider the needs of all stakeholders before coming to a decision. (2b)
11. Designers must develop solutions that promote equity between people. (2b)
12. I think my personal choices can impact people in other countries. (2a)
17. Designers must ensure that their designs are environmentally sustainable. (2c)
18. Really, there is nothing I can do about the problems of the world. (1, -)
19. I put the needs of others above my own personal wants. (2b)
20. Designers should only consider local constraints when creating a solution. (2a, -)
21. I feel confident in my understanding of metrics for measuring the sustainability of a project or solution. (1)
22. Designers must consider the effect of their decisions both locally and internationally. (2a)
23. I am confident in my ability to create environmentally sustainable solutions in my field. (1)
24. Design decisions will always have social implications. (2b)
21. I feel confident in my ability to create socially just solutions in my career. (1)
22. Designers must think about the kind of world we are creating for future generations. (2b)
27. It is not really important to me to consider myself as a member of the global community. (2a, -)
28. I often reflect on how my work and actions give back to society. (2b)

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\*LG1 corresponds to **confidence**, LG2a to **global**, LG2b to **social**, and LG2c to **environmental**

\*\*Responses were reported along a 6-point Likert scale where 1 = "Strongly Disagree" and 6 = "Strongly Agree"

**Table 3:** Internal consistency reliability of SSDS scales pre- and post- course

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Learning Objective	Pre-Course $\alpha$ statistic	Items that reduced $\alpha$ ( $\alpha$ if removed)	Post-Course $\alpha$ statistic	Items that reduced $\alpha$ ( $\alpha$ if removed)
1. Confidence	0.797	-	0.748	18 (0.760)
2a. Global	0.707	4 (0.721)	0.762	-
2b. Social	0.735	9 (0.749)	0.844	9 (0.846)
2c. Environmental	0.656	6 (0.700), 8 (0.681)	0.772	-

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Table 3 provides an overview of the internal consistency reliability for each survey construct as measured pre- and post-course. While in Table 3 we display any items that reduced the alpha score, we did not remove any survey items for our analysis in Part 2 of this study. Rather, these findings inform Part 5, where we explore possibilities for future survey improvements.

## Part 2. WPSI Pre-Post Results from the Fall 2014 Academic Semester

In this section, we only analyzed responses from participants who completed both pre- and post-course surveys. While a total of 67 students participated across the 3 universities in the WPSI course offerings, only 51 of these students completed *both* surveys. It should be noted that despite our overview of the demographic data not including 16 individuals who participated in the course, their backgrounds were similar in proportion to the numbers presented here.

11 respondents were from Course 1, 7 from Course 2, and 33 of the respondents were from Course 3. Of the 51 respondents, there were 3 sophomores, 29 juniors, 3 students who were in their 4<sup>th</sup> of 5 years, 11 seniors, 3 Masters, 1 PhD, and 1 “transfer” student. 41 of the 51 students were in some type of engineering program, which included biomedical, chemical, civil, electrical, environmental, industrial, mechanical, and optical engineering. 16 of the 51 respondents were female, whereas 35 were male. The gender and academic status of students on a course-by-course basis is presented in Table 4. Likewise, the disciplines of students who completed both surveys is presented in Table 5 according to the course they participated in.

**Table 4:** Demographic overview of individual course offerings

Course #	Gender		Academic Status						
	Male	Female	Soph.	Junior	Jr/Sr.	Senior	Masters	PhD	Other
1	4	7	2	2	1	2	3	1	-
2	6	2	-	1	2	4	-	-	1
3	25	7	1	26	-	5	-	-	-

\*Only information from students who completed the pre- and post- assessment measures is presented

**Table 5:** Discipline of participants by course

#	Engineering Participants	Non-Engineering Participants
1	Biological, Chemical (2), Electrical (3), Industrial (3), Mechanical	Urban studies
2	Civil, Electrical/Mechanical Engineering Technology	Applied Arts & Science, Business, Environmental Sustainability, Photographic Sciences (2)
3	Biomedical (8), Civil (3), Chemical (3), Computer, Electrical (3), Mechanical (11), Optical	Mathematics/Computer Science

Table 6 provides an overview of the average scores along each learning goal for all 51 students who completed the pre- and post- test surveys. In addition to these pre-post scores, Table 6 presents the mean difference scores, along with the paired t-test results. For all SSDS scales

except Learning Goal 2c, the distribution of difference scores met the normality assumption, allowing us to perform a paired t-test using this data. Using a one-tailed t-test, and testing the hypothesis that students had significant positive changes along each learning objective, it appears that the only significant change in students' responses were along Learning Objective 1, representing students' confidence in responding to wicked problems. Nonetheless, it should be noted that the learning goals corresponding to students' awareness of their professional responsibilities in a global and social context were also promising. Interestingly, the results showed a slight reduction in Learning Goal 2c. Part of the explanation for this may be that this scale had the highest pre-course mean score of all scales.

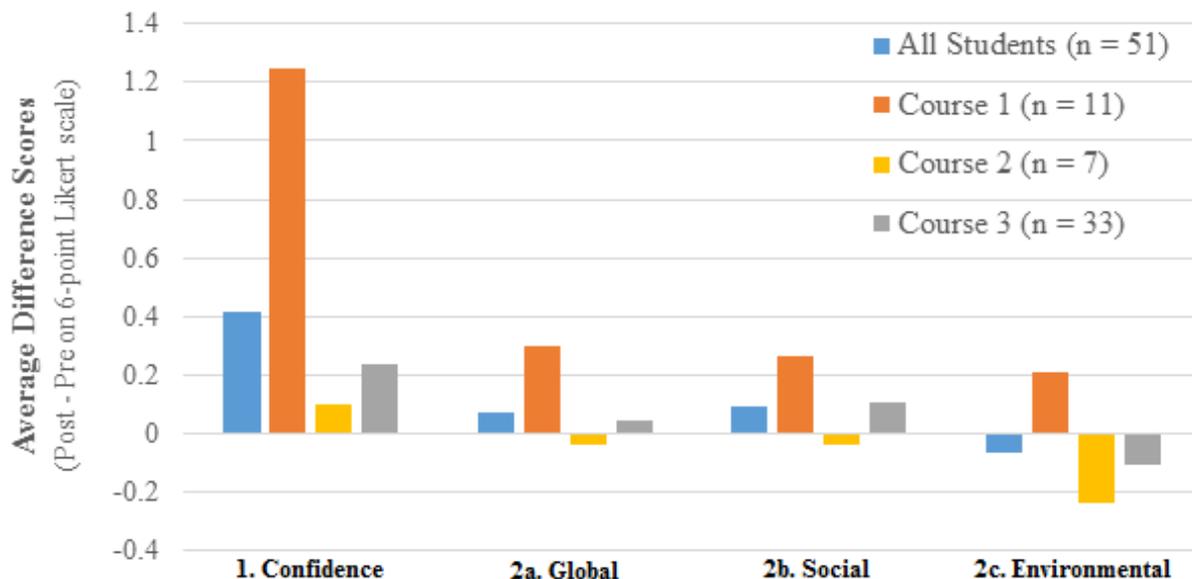
**Table 6:** Descriptive statistics and paired t-test results for pre-post scores along SSDS

Learning Goal	Pre-Course Mean (Std. Dev)	Post-Course Mean (Std. Dev)	Difference Score Mean (Std. Dev.)	t-stat
1. Confidence	4.325 (.74)	4.762 (.69)	0.437 (.83)	3.757*
2a. Global	4.305 (.71)	4.392 (.82)	0.087 (.62)	.997
2b. Social	4.299 (.71)	4.419 (.86)	0.120 (.67)	1.285
2c. Environmental	4.735 (.67)	4.680 (.83)	-0.056 (.65)	n/a**

\*Indicates there was a significant difference at  $p < .001$

\*\*Slight decrease; Survey construct did not meet normality assumptions (Shapiro-Wilk coefficient = 0.945,  $df = 51$ )

What if we compare results by each separate course offering? Figure 2 provides a comparative visualization showing the mean difference scores along each learning goal by Courses 1, 2, and 3. To provide a more in-depth picture of students' changes by Course, along with where students started and ended along each learning goal, Table 7 provides an overview of the 51 students' pre- and post- course responses.



**Figure 2:** Mean Difference Scores along Each Learning Objective by University

**Table 7:** Pre- and post-course mean and standard deviation per learning goal by course

Course #	1. Confidence		2a. Global		2b. Social		2c. Environmental	
	<i>Pre</i>	<i>Post</i>	<i>Pre</i>	<i>Post</i>	<i>Pre</i>	<i>Post</i>	<i>Pre</i>	<i>Post</i>
1 ( <i>n</i> =11)	4.08 (.62)	5.33 (.42)	4.66 (.55)	4.96 (.60)	4.72 (.63)	4.98 (.69)	4.89 (.59)	5.11 (.59)
2 ( <i>n</i> =7)	4.59 (1.01)	4.69 (.76)	4.39 (.87)	4.35 (.62)	4.30 (.64)	4.27 (.92)	4.79 (.70)	4.55 (.77)
3 ( <i>n</i> =33)	4.35 (.71)	4.59 (.64)	4.17 (.68)	4.21 (.84)	4.16 (.63)	4.27 (.85)	4.67 (.67)	4.57 (.89)

Figure 2 and Table 7 show that by far the most significant change was Course 1's students' reported confidence in responding to wicked problems. As Table 7 shows, students at Course 1 scored the lowest along this learning goal at the start of the course, and the highest at the end of the course, whereas students at both other universities started at a higher mean score and showed slight improvements in this category from start to finish. With the exception of the confidence category, the 7 students at Course 2 had slight decreases along each of the professional responsibility categories (2a, 2b, & 2c).

Implications of these findings are further explored in sections 4 and 5. For now, we turn our attention to data collection and analysis methods pertaining to the open-ended responses asked of students upon completion of the post-course survey.

### Part 3. Content Analysis of Qualitative Responses

The intent of this section is to explore qualitatively where students felt they achieved the primary gains as a result of participating in the course. Here we use content analysis as a guiding methodological framework. Content analysis involves a series of steps that, when implemented appropriately, allows the researcher to make valid inferences from some form of text.<sup>18</sup> This form of analysis seeks to make meaning of data from the perspective of a specific group in relation to some phenomenon.<sup>19</sup> In our approach, we use a conventional form of content analysis, where we allow “the categories and names for categories to flow from the data,”<sup>20, p. 1279</sup> meaning the codes and patterns are generated inductively rather than deductively. Importantly, this means the quantitative results should not inform the codes generated within this section.

While this method is often used with mass communication sources, in our case the text we collected and analyzed included 51 open-ended written responses from a small group of the students who participated in WPSI during the Fall of 2014. In total, three open-ended survey response questions were presented to students at the end of the survey. Students were not required to answer these questions, and therefore some either did not answer or only offered one or two words in response. More than 80% of respondents, however, offered at least one sentence

for each question. A number of students wrote approximately 100 words in response to each question, and a few nearly double that amount.

The questions we presented to respondents included the following:

1. As a result of participating in this course, how did your confidence in responding to wicked problems change?
2. As a result of participating in this course, how has your perception of your professional responsibilities as a designer changed?
3. Was there anything particularly insightful, challenging, or inspirational that you experienced during this course that you would like to share with anyone who is considering taking this course in the future?

As a result of the framing of these questions, students' responses were guided to be relatable to the learning objectives. Our hope was students would provide insight, whether positive or negative, on critical experiences or components of the course. Perhaps due to this framing, students' responses tended to focus on their individual *outcomes* rather than the course components, activities, or processes that led to those outcomes.

Several responses were as short as this Course 3 student's reply to Question 1, "I feel more confident in responding to wicked problems." For responses of this nature, at a slightly greater than a 2:1 ratio students self-reported having increased confidence in responding to wicked problems, in comparison to students explicitly reporting no changes in confidence (e.g. another Course 3 student's reply, "It hasn't changed.").

For our analysis, we generated codes and themes by analyzing responses across the three questions as a whole, rather than on a question-by-question basis. Table 8 provides a brief overview of the 6 themes inductively generated from this analysis, whereas the following subsections provide a more in-depth description of these themes alongside direct written excerpts.

**Table 8:** Themes generated from content analysis of students' written reflections

<b>Theme Name</b>	<b>Theme Description</b>
Holistic Complexity	Students' consciousness of the overall complexity of wicked problems became more holistic and inter-connected
Designer Responsibilities	Students felt a heightened sense of social and environmental responsibility when performing design work
Solution Realization Process	Students altered or refined their process for working through any design problem, within and outside of the course
Interpersonal Development	Students developed interpersonal skills, particularly those skills related to teamwork and communication
Heightened Uncertainty	Students held an increased uncertainty surrounding any solution implemented in response to a wicked problem
Reinforcement of Values	Students felt the course reinforced their pre-held values and, as such, encouraged their motivation to pursue their career

In the following sections, we provide a rich description of these themes alongside exemplary passages taken from students' written responses. In this process we are seeking pragmatic validation, meaning the attainment of "theories and concepts [which] are compatible with the empirical reality" of the course participants.<sup>21,p. 641</sup> By providing written responses alongside our interpretations we are seeking communicative validation, allowing the broader research community (e.g. you, the reader) to consider the alignment between our descriptive terminology and the direct wording of our participants.<sup>21</sup>

### 3.1 Holistic Complexity

This initial theme suggests that as a result of participating in the course, participants became conscious of the overall complexity of wicked problems. These students began to develop a holistic picture of wicked problems, including the surrounding constraints of the problems, the inter-connections between one wicked problem with another, and the stakeholders affected by any implemented solution to a wicked problem. Even beyond the course, students suggested they held a heightened understanding of surrounding societal wicked problems.

**Senior Bioengineering Student from Course 1:** This course helped me understand the depth and complexity of wicked problems on a level that I hadn't previously thought about. I appreciate that we actually focused on these types of problems, and framed all interventions and discussions in a way that recognized the complexity of such problems.

**Senior Mechanical Engineering Student from Course 3:** After participating in this class, I feel I understand the constraints and the limitations of wicked problems better than I did before. I also understand the need to look in depth at the criteria that are involved in coming [up] with a solution.

**Sophomore Electrical Engineering Student from Course 1:** I definitely have a better understanding of wicked problems and all of the aspects that tie into them. They are so in depth and involve so many people and this class has opened my eyes to that. I never really thought about how many stakeholders there are for one problem until this class. In addition, I now consider all stages of production in determining problem.

### 3.2 Designer Responsibilities

Many students noted they felt it was their responsibility to ensure their designs were as sustainable as possible, although several students noted that sustainability is not always possible to achieve within a design project. While a few students noted changes in their sense of environmental responsibility, many more explicitly noted that they felt obligations towards people affected by their designs, be these designs local or global. Throughout the responses, there were numerous references to changes in students' tendencies to identify the stakeholders involved in the outcome of a design solution.

**Junior Mechanical Engineering Student from Course 3:** I certainly feel more responsible to the people the design will impact indirectly. I think it is important to consider that an improvement to some people could be a detriment to others.

**Senior Chemical Engineering Student from Course 1:** I definitely understand why it is important to consider all stakeholders affected by the problem I'm trying to find a solution for. It has also been stressed why metrics for my design solution are so important for both evaluating its [it is] effective and communicating to others what I did.

**Junior Mechanical Engineering Student from Course 3:** I have found that I have to be responsible not only on a local level, but also on a national or global level. Figuring out who the stakeholders are and how they are affected is important in the design process.

**Junior Biomedical Engineering Student from Course 3:** I feel like my professional responsibilities as a designer have shifted to include more pathos because we spent a lot of time considering the impact on stakeholders. In general I now believe a lot of my professional responsibilities revolves around having a minimal environmental impact and a strictly positive social impact.

**Industrial Engineering Masters Student from Course 1:** After participating this course, I put more emphasis on what I can do to the global society rather than my career. Sustainability is a profound topic and every one of us should have responsibility to take care of it. There are social problems along with environment problems, and neither of them should be ignored. As a designer, it gets more meaning to me to improve the world of humanitarian issues.

### 3.3 Solution Realization Process

After completing the course, students felt they had learned techniques for doing design work they could use outside of the course. As a result, students internalized a novel process for responding to design problems, be those problems wicked or not. Several students noted specific tools and techniques they implemented during the course were helpful in considering social and environmental impacts of their design solutions. Some students noted that the techniques they developed in this course could be transferred to other contexts and courses and even their future careers.

**Junior Industrial Design Student from Course 2:** I learned very quickly that ideation needs to happen as soon as possible in the process, and no progress can be made until some ideas are generated. I feel we waited far too long to develop solutions and therefore could have done so much more in the time allotted.

**Senior Environmental Sustainability, Health, and Safety Student from Course 2:** I really didn't have much design experience in the beginning, but this course exposed me to a lot of the principles that one should consider when designing a solution. Designers have a responsibility to ensure their solution meets the triple bottom line as best as it can, and I think this course did a good job of giving us ways to check this constraint.

**Junior Biomedical Engineering Student from Course 3:** I understood that consideration of environmental and social factors were something to be considered, but quantifying these things in a decision matrix made them much more tangible parameters.

### 3.4 Interpersonal Development

Throughout each course, students worked in teams, and presented their work in several different forms. Many students made references to the impact of their experiences working within a design team and presenting their results. Students considered these experiences to have bolstered their confidence, abilities, or processes for working within interpersonal environments.

**Junior Computer Engineering Student from Course 3:** Working with a team to develop a proposal document is difficult and requires several rounds of revision and editing. However, you learn to communicate ideas more effectively and grow as a writer throughout the process.

**Industrial Engineering Masters student from Course 1:** I gained my confidence greatly when working in an international team and [to] express my own opinion without fear others' disagreement.

**Junior from Course 3:** I found this class very useful. The spirit of team work in harmony, I love it so much. Once every team member reach to the same frequency, the working efficiency goes to the maximum immediately.

**Junior/Senior Electrical Engineering Student from Course 1:** Presenting is another skill developed through taking this class; prior to this class, I had only done about 2-3 presentations – I have doubled that in this class alone.

### 3.5 Heightened Uncertainty

While many students recognized they developed an appreciation for the overall complexity of wicked problems, several students extended this notion one step further, suggesting that their increased awareness of the complexity of wicked problems has led them to become uncertain of the overall appropriateness of *any* solution to a wicked problem. As a result of this uncertainty, some of these students suggested they felt wicked problems were more cumbersome and difficult to approach than traditional engineering problems, and as a result, some students reported feeling *less* confident in responding to these wicked problems.

**Junior Mechanical Engineering Student from Course 3:** Before this class, I was aware of problems in the world but I didn't realize how difficult they were to fix. For example, when most people think about homeless people, they often think of them as unmotivated. In reality, there are many other factors beyond their control that makes homeless. There really isn't an easy fix to a wicked problem but in order to solve them, we must be aware of all of the factors that makes them so wicked. There isn't an easy solution but once people become aware, steps toward helping the problem can be taken.

**Junior Biomedical Engineering Student from Course 3:** I believe that knowing more about it [the complexity of wicked problems] leads me to think that they're harder to solve. It increased my knowledge of it and at the same time it made me feel insufficient to solve it.

**Junior Biomedical Engineering Student from Course 3:** I feel more confident in trying to solve the problem, even though there is little hope in actually fixing the issue completely.

**Junior/Senior Electrical Engineering Student from Course 1:** Before this course, I did not know what a wicked problems was; after completing this course, I understand that wicked problems require much thought and a proposed solution must be carefully thought. No one approach will fix everything, but there is really no way in knowing the effects this one approach will have until it is implemented.

**Sophomore Electrical Engineering Student from Course 1:** I definitely feel like I have a much better grasp as to what wicked problems are, and it also exposed me to the reality of life, there is no right answer.

### 3.6 Reinforcement of Values

Many students noted that their professional responsibilities did not change as a result of participating in the course (n=14), and roughly half of these respondents suggested their professional orientations were reinforced. For some students, this reinforcement came in the form of encouragement to continue on their chosen career path (be it engineering or some other). When this was coded, the students' reinforced values or career vision tended to be of humanitarian-orientation.

**Sophomore Electrical Engineering Student from Course 1:** For me, this class reaffirmed my thoughts of entering either the social entrepreneurship or nonprofit space after graduation. It is something that I have been juggling for a while, but I have never been able to take a class focused in this interest area because of my busy engineering/premed schedule. Without the conceptualization of the possibilities within this field, I don't think I would be so certain that it is the field I want to move into.

## **Part 4. WPSI Reflections and Broader Implications**

The objective of this portion of this study was (a) to provide a merged data interpretation by combining results from the SSDS and content analysis of students' reflections, (b) to use the authors' reflections on their respective course offerings from the Fall of 2014 as a guide for providing recommendations for future WPSI course offerings, and (c) consider implications of this study's findings for teaching towards sustainability in higher education. This discussion proceeds through a series of sections that are distinct but related to one another. Specifically, we explore which specific factors seemed to have been most critical in enabling (or disabling) students to meet the learning objectives evaluated using the SSDS. This discussion first takes the form of (a) describing the attainment of learning goals, followed by (b) course-level refinement suggestions, and ending with (c) broader implications for sustainability higher education.

#### 4.1 Learning Goal Attainment

Overall, WPSI students showed a significant increase in their **confidence** in responding to wicked problems as a result of participating in the courses. Students also saw some increases in the **social responsibility** and **global responsibility** categories of the SSDS, whereas students' environmental responsibility awareness did not change significantly. Nonetheless, as the content analysis results indicated, some students did realize changes in awareness of their **designer responsibilities**. Furthermore, several students indicated the course **reinforced** rather than changed preexisting environmental dispositions or values. This seems to indicate that the WPSI course should not be considered to have been unsuccessful along the SSDS *awareness* measures despite non-significant changes visible from the pre-post testing.

The content analysis indicated that a number of the WPSI students realized changes that were not evaluated directly by the SSDS. For example, students reported significant increases in **interpersonal development**, a more **holistic process** for approaching design problems, and the development of expertise with a number of tools and techniques applicable to their **solution realization process** that could be transferred outside of the course. Perhaps the most interesting finding from the content analysis was the **heightened uncertainty** theme. Although students felt an increased uncertainty regarding the attainability of any ultimate solution to any wicked problem, students simultaneously felt more confident in responding to wicked problems. Taken together, these results seem to indicate that the course was a success, particularly in the confidence category.

An indication of students' changes along these Learning Goals in the WPSI courses appeared to be predicted by whether or not students had backgrounds in engineering. A focus on non-engineering students' changes along the SSDS measures is shown in Table 9, which compares mean difference scores (post – pre) in learning goals between engineering students (n = 41) and non-engineering students (n = 9). These results indicate that WPSI was more impactful for engineering students along every category measured by the SSDS, although due to the limited sample size of non-engineering students, there was insufficient statistical power to conduct a reliable comparison between these groups. Nonetheless, based off the trends shown, engineering students improved nearly 5 times more than non-engineering students in the confidence category. Further, engineering students show improvements in the social and global learning goals, whereas non-engineering students' scores did not change in these categories. Lastly, while engineering students' environmental responsibility scores did not change from pre to post, non-engineering students' scores *decreased*.

**Table 9:** Comparing engineering and non-engineering students' difference scores

	1. Confidence		2a. Global		2b. Social		2c. Environmental	
	Yes	No	Yes	No	Yes	No	Yes	No
Mean	.498	.127	.112	-.06	.152	-.01	-.04	-.28
$\sigma$	.87	.62	.60	.76	.73	.30	.67	.37

\*There were 41 engineering students, 9 non-engineering students, and 1 student who did not specify

A future challenge for WPSI offerings, especially for courses with a wide mix of students who do not have backgrounds in engineering, is how we can alleviate this potential bias and make the course equally impactful for engineering and non-engineering students. Perhaps Table 9 is not an indication that all WPSI students need to be engineers, but the relative number of engineering students within a course may be key. At Course 2, only 2 of the 7 students who completed both surveys (and 2 of the 9 students who participated in the course) were engineering students. For us, in response to the question, “How might non-engineering WPSI students become ready to handle the complexity of wicked problems, move through the design process, and generate ideas that are feasible in a short time frame?” We think it is possible that having a minimum number of upper-level engineering students within a team may supply each group with a source of expertise, alleviating (to some extent) the findings between groups shown in Table 9.

Engineering students may be representative of a broader class of students who are comfortable and familiar with doing design work, especially client-based design, as the engineering students who participated in WPSI tended to bring previous design experiences into the course. Yet, while engineering curricula tend to include exposure to design, this focus is not exclusive to engineers. For example, we lack comparative information from industrial or graphic design students who might have prior exposure or experiences in this domain. Prior exposure to the design process may have enabled engineering students to augment or modify their a priori dispositions and confidence, whereas non-engineering students needed more scaffolding. This may be an indication that future wicked problems courses should begin by evaluating not only SSDS measures, but also students’ prior experiences with a design process. This brings to the fore a more direct question that avoids an engineering/non-engineering dichotomy, “What prerequisite skills or experiences should WPSI students have?”

#### 4.2 Course-Level Refinement

At the course-level, we believe there were several key factors that were impactful on student outcomes. For example, the differences by course were complex, as although faculty operated within the same guiding pedagogical framework<sup>1</sup>, each course’s topical focus, number of participants, the background of their participants, and the problems targeted by groups’ projects were variable. In this section, we consider some of these factors along with how they may be alleviated in future WPSI course offerings.

One key difference between Course 1 and Courses 2 and 3 was that groups spent more time in the solution realization phase of the design process, thereby gathering more rounds of constructive feedback regarding their proposed responses. In comparison, groups in Course 2 initially seemed overwhelmed by the openness of the complexity of the wicked problem (sustainable housing) and spent more time in the problem scoping phase, firstly with student groups striving to come to a consensus regarding which aspect of the wicked problem to address and secondly with the instructor trying to ensure students had effectively defined their problem statements. The instructor in Course 2 was rightfully concerned with students (and designers, in general) moving forward in the design process without a problem statement that addresses a real need. Conversely, although groups in Course 3 quickly formed around project topics (generally championed by a single individual within the group), this course was part of a quarter term. The relative time spent within certain design phases may be key to realizing gains in the SSDS

measures. This would suggest that when implementing a project-based or problem-based pedagogical strategy within a wicked problems course, instructors should help students specify a topical area or project focus quickly, but not too quickly. In other words, groups must spend ample time within the problem scoping phase to accurately and holistically define a need before proceeding forward, but still move forward within the term's time frame.

Enabling students to reach the design phases where they can gather critical feedback and realize the potential social impact of their response (even in the form of a proposal) may be equally important for retaining students' motivation and engagement. Groups in Course 2 had difficulty scoping the problem and received feedback on their problem statements as opposed to their proposed responses. Furthermore, students in Course 1 had more exposure to practitioners compared to the other courses. These practitioners' provided a unique perspective from that of the instructors and aligned with the real-world context of industry. While introducing feedback from practitioners may be key for individual attainment of the SSDS measures in future WPSI offerings, we need to identify the ideal means for leveraging this expertise across the course offerings. Sharing an in-class lecture may be less impactful than students actually meeting with experts face to face or students gathering direct feedback from practitioners in response to their individual responses. As WPSI grows, a key consideration will be how to leverage inter-institutional and inter-group feedback mechanisms.

In regards to mentoring of students in their groups by the leading instructor, there is a fine line between student empowerment and faculty interference. Jones et al. (2013) explored the impact of instructional strategies, student-instructor relationships, and group dynamics on student motivation within a problem-based capstone design course.<sup>22</sup> One key component Jones et al. indicated is that students need to realize how the project itself may be useful in their future careers. The communication stream between instructors and students must be strong in order for instructors to enable students to come to this realization for themselves, and to ensure that students within a group all are interested in the project focus. This may be achieved by allowing students to self-select into their project groups, and this may be monitored by a specific question within the staged individual written reflections. However, some students may become overwhelmed by the openness of the problem, and instructor intervention may become integral to the student's success (this goes back to the level of scaffolding needed being student-dependent).

Throughout the monitoring and mentoring process, one issue seems to be alleviating students' over-distress so they can focus on the tangible aspects of a design response amidst the complexity of the wicked problem. Students who are prone to becoming distressed tend to be less innovative, where too much distress inhibits key design behaviors such as questioning, observation, and idea networking.<sup>23</sup> Within course offerings where students largely lack prior exposure to design work, instructors will need to be flexible in their implementation of WPSI framework and mindful of individual written reflections from each stage of design reviews. Formative assessment measures should also be implemented regularly to engage students' stress levels overall and their engagement levels within their project groups.

### 4.3 Broader Implications for Sustainability Education

In this section we first consider the benefits of the WPSI model, specifically, how the community of educators participating in WPSI partner as a community for teaching towards sustainability. We then explore a distinction that permeates the discourse on sustainability education: teaching towards sustainability as a skill versus as a value.

#### *4.3.1 Benefits of a community for teaching towards sustainability*

Throughout the engineering education curriculum, translation of research to practice has been slow, partly due to the uncertain outcomes of applying novel pedagogical strategies to courses that have existed for generations.<sup>24</sup> WPSI provides a framework and supportive community of instructors to introduce problem- and project-based pedagogy into their current offerings. Participating within a supportive community has been indicated by faculty as key for venturing into the space of novel pedagogical strategies.<sup>25</sup> Through their reflections, the WPSI instructors (and authors) indicated this community was helpful for sharing ideas and content, and the staged pedagogical framework allowed them to focus their effort on course content and student feedback as opposed to instructional design. Nonetheless, as with any course offering, the implementation of the WPSI framework to a specific course ought to improve with practice. WPSI as a program is only in its second iteration, and each subsequent semester of iteration will improve the framework overall, and each year of instructor involvement in WPSI ought to lead to increased confidence and expertise in applying the framework at the individual instructor level.

As more course types and instructors begin to participate in WPSI, it is hopeful that the magnitude of this learning curve will decrease thanks to the benefits of accumulated knowledge within the community. However, it will take numerous instances of faculty champions willing to take a risk for the first year before this information stabilizes. This is not to suggest that any of the course offerings presented within this study failed. Indeed, while students did not show significant changes along the *awareness* learning goals measured using the SSDS, qualitative responses indicated that these students showed dispositional reinforcement or changes alongside the development of specific skills. Nearly all students left the course with increased confidence in responding to wicked problems despite their heightened uncertainty given the complexity of wicked problems.

#### *4.3.2 Teaching to sustainability as a skill*

While the SSDS was intended to measure self-reported awareness and confidence, the thematic nuances from the content analysis indicated that many students left the course with tangible tools and procedures they could use outside of the course context. This notion of teaching sustainability “as a skill” is currently prominent.<sup>26</sup> Tool-specific expertise was not directly measured by the SSDS, nor was it the direct focus of the WPSI courses. In fact, due to the large variation between course foci (e.g. social entrepreneurship, technical communication, and wicked problems) WPSI is not designed to suggest which tools should be included within a course.

Given the problem-based scoping of WPSI courses, the model is about empowering learners to choose a topic they find engaging as it relates the annually selected wicked problem. Specific group approaches to addressing the wicked problem, such as life-cycle analysis or systems modelling, are not specified a priori. Instead, as students begin to define their topical area, the instructors and participating engineering experts provide input to the specific techniques that students may apply if they so choose insofar as it makes sense for their project. Nonetheless, as one of the qualitative themes indicated, students felt like they could take the tools they learned within the course and transfer those to other design projects outside of the course. Unlike many courses, what those tools are will vary on a semester-by-semester basis.

#### 4.3.3 *Teaching to sustainability as a value*

The primary learning goals assessed by the SSDS were not tools or techniques, but evaluating students' confidence alongside their self-reported considerations of their environmental, social, and global responsibilities as designers. In this sense, the SSDS is more aligned with the notion of teaching towards sustainability as a value. This focus is less common throughout engineering education when compared to teaching sustainability as a set of tools or techniques.<sup>26</sup> However, in order to inspire students to become future leaders who are conscious of the environmental, social, and global impact of their decisions, a focus on dispositional elements of students worldviews seems as important as a learning objective as instilling techniques. In order to inspire students to design towards a more sustainable future once they leave academia, sustainability-related values must become core components of the worldview of these future leaders.<sup>27</sup>

Still, dispositions and habits of mind held by students are complex, and strongly-held worldviews tend to be rigid and resistant to change.<sup>27</sup> The timeline for each of the courses may have been insufficient for many students to internalize key changes. Whereas Courses 1 and 2 ranged from August to December of 2014 (between 4-5 months), Course 3 was on a quarter schedule (September to November, with 7 of 10 weeks spent on the WPSI project). The short-semester curricular model may have additional challenges when learning goals strive to change emotive or dispositional components. It may even indicate that a design course such as WPSI should be extended over multiple semesters, or that subsequent courses should be offered with WPSI as a pre-requisite.

On the other hand, perhaps what students were lacking was a critical experience to challenge their previous convictions along some of the dispositional target learning categories. Zoltowski, Oakes, and Cardella (2012) depicted critical instances, or experiences where students saw that their design would not work for reasons previously unfathomed, as one avenue for students to reach the highest levels of human-centered design (the highest of which they called empathic design).<sup>28</sup> Due to students' generally broad responses to the wicked problem of sustainable housing (as opposed to implementation of a specific response), students may have not this type of experience. One potential model (which is similar to capstone design models) would be to extend WPSI into a second semester with a solely project-based focus, where students take what they developed in the initial semester and create something tangible for a real client. Another possibility suggested for future WPSI courses is participation in a *Pitch Night* through partnership with related classes (perhaps cross-institutionally) where students could receive intense but constructive criticism on their ideas from students, faculty, and professionals whose

interest or perspective is within a largely distinct domain. While this type of experience would not be the same as implementing a solution and realizing it may not be optimal, this approach may provide a similar critical pathway for instilling dispositional changes while leveraging partnerships within (and potentially outside) of the growing WPSI community.

## **Part 5. Sustainability Scales and Dispositions Scale Refinement**

The objective of this final part of the study was to consider where the Sustainability Skills and Dispositions Scale needs adjustments based on the internal consistency of items and paired t-test results, students' qualitative responses, and the faculty reflections. The factor analytic structure of the survey will be explored in the future when there are a sufficient number of respondents.

### 5.1 The Responsibility Subscales

A primary question for future validation studies of this instrument is whether, theoretically, the separate professional responsibility subscales (social, environmental, global) should conform to a single responsibility scale. Reliability statistics for the majority of these subscales looked to be acceptable, but not excellent, as most were below 0.8. The only subscale that was minimally acceptable was pre-course responses along the environmental scale. This scale also had the fewest items theoretically underlying it, with 6. Based off this and the wide diversity among respondents, we feel the need to refine this subscale to a greater extent than all others, specifically by adding at least one item, (re)-examining existing surveys focused solely on this learning goal, and by gathering feedback from fellow Liberal Education/Engineering & Society division members at the 2015 ASEE annual conference.

### 5.2 The Confidence Scale

While the confidence scale proved internally consistent, it seems from the content analysis that despite enhanced confidence, many students felt a heightened sense of uncertainty. Further, we did not quantitatively measure students' self-reported confidence in terms of interpersonal development. In the future, it seems that the confidence scale could be built upon three subscales: (a) measuring interpersonal confidence, (b) measuring individual skills in responding to wicked problems, and (c) measuring awareness of uncertainty or the complexity of the wicked problems. Specifically, the relationship between awareness of complexity and confidence in responding would be of primary interest to explore.

### 5.3 Designer Language

For the majority of questions along these scales, we referred to "designer" responsibilities. The environmental subscale contained the most pervasive usage of this vocabulary, using the word design in some form for all but one question. In the qualitative responses, one student explicitly noted, "I am not a designer." If we assume that this student was not alone in this mentality, then it seems either that the language should be made even more universal across all of the subscales, or that perhaps the instrument should only be deemed reliable for students who can relate to *being* a designer. Perhaps this could be gleaned from a carefully articulated demographic question. Defining designer as "anyone who designs a solution to a problem" at the top of the survey could also help students think of the term more broadly.

## **Conclusion & Future Work**

The Sustainability Skills and Dispositions Scale (SSDS) described in this study provides a basis for evaluating the attainment of sustainability-related learning objectives that may be replicated at universities participating in the Wicked Problems in Sustainability Initiative (WPSI) in the future, as well as anyone hoping to measure similar learning objectives. As a next step in this survey development process, the authors will revise and reassess this SSDS's validity and reliability with students who participate in WPSI's third iteration during the Fall of 2015. If the sample size is adequate, we will seek to perform factor analysis to see if the theoretical structure of the instrument matches the factor analytic structure.

As evidenced by the reflective discussion in this study, implementation of the SSDS can also be used as a guide for improving educational interventions intended to develop students' confidence in responding to and awareness of sustainability issues. While our focus was on pre-post comparisons, it should be re-emphasized that if students were to come into a course scoring highly along a given learning goal (e.g. awareness of their environmental responsibility), an instructor should not necessarily expect significant changes in that category, especially in a short duration. Yet, as shown by these results, the wicked problems course did provide students with the tools and abilities they needed to feel significantly more confident in responding to wicked problems in their future courses careers despite these respondents' developed awareness of the complexity of wicked problems. The content analysis provided a more in-depth focus on these nuances that may have sparked such shifts.

As a parting note, the authors' motivation for developing WPSI and conducting this study was to develop a framework that may be replicated in a variety of course contexts to instill dispositional-related elements of sustainability. Our ultimate and ongoing goal is to develop a community of shared expertise to lower the barriers for incorporating sustainability-related elements into existing (and brand new) courses and curriculum. For instructors interested in becoming part of a community of scholars engaging in wicked problems, we invite and encourage you to join us, and share with us your own experiences in this domain.

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## Appendix A: Borrowed (and Adapted) Survey Items

### Zhai and Scheer (2004) - Global Perspective Scale

- Generally, an individual's actions are too small to have a significant effect on the ecosystem.\*
- I feel an obligation to speak out when I see our government doing something I consider wrong.
- Professionals must think about the kind of world we are creating for future generations.
- The present distribution of the world's wealth and resources should be maintained because it promotes survival of the fittest. (-)
- I think my behavior can impact people in other countries.
- I am able to affect what happens on a global level by what I do in my own community.
- My opinions about national policies are based on how those policies might affect the rest of the world as well as the United States.
- It is not really important to me to consider myself as a member of the global community.\*

### Downey and others (2006) – Global Competence Questions

- I am better prepared to work with engineers from other countries
- I now have a better understanding of how my perspective as an engineer is different from those of engineers from other countries.
- I will now be better at working with people who define problems differently than I do.

### Braskamp, Braskamp, & Merrill (2008) – Global Perspective Inventory

- I think of my life in terms of giving back to society
- I consciously behave in terms of making a difference
- Volunteering is not an important priority in my life (-)
- I put the needs of others above my own personal wants
- I work for the rights of others

### Hilpert, Stump, Husman, and Kim (2008) – Engineering Attitudes Survey

- Engineers contribute more to making the world a better place
- Engineering is more concerned with improving the welfare of others