AC 2011-1292: ASSESSING ENGINEERING STUDENTS' READINESS TO COLLABORATE SUSTAINABLE DESIGN: AN OPEN ACCESS INSTRUMENT FOR EXPERIMENTATION

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Abstract
Topping the list of the National Academy of Engineering's grand challenges for engineering is the imperative for designs which meet the needs of today's society without compromising the ability of future generations to meet their own needs--sustainable design. Best practices in sustainable design have drawn on open, participatory collaboration with stakeholders--a rare procedure in most engineering disciplines. This type of collaboration requires integrated ethical and social development as well as reflexive analysis. We present here an instrument under development that has shown preliminary promise as a "quick and dirty" measure of potential readiness to collaborate for sustainable design. It is a 17-item instrument. It targets assessment of specific constructs in the context of collaboration for sustainability based on Fink's integrated taxonomy of significant learning. They are: 1) personal agency for sustainability; 2) value of self-transcendence and 3) awareness of one's limited perspective in situations. The theoretical grounding of the constructs derive from Bandura's model of agency, Schwartz's model of universal human values, and Argyris' model of inference, respectively. At the time of this writing, the instrument has been completed by roughly 200 college students. Two of the three scales have strong internal reliability with Cronbach alpha reliability measures of 0.73 for construct 1) and 0.90 for construct 2). The third is weaker with a Cronbach alpha of 0.3, clearly calling for a closer examination and alteration of the survey questions. Each of the scales accounts for 68%, 63% and 51% of the variance, respectively. We present evidence of validity for the three scales. Construct validity is illustrated through predictable performance on the scales by contrasting groups of students, consistency in the internal structure through factor analysis and expected correlations across scales. However, we recognize that these instruments can be refined and improved; we have deployed them in a web-based open-access format to encourage change. The significance of this tool and its open format is that it provides the engineering education community with a way to participate in the broader development and refinement of a tool that shows merit in assessing proxy indicators of students' readiness to collaborate for sustainability. It has the potential to raise awareness of this limited proxy indicator of students' readiness of collaborating for sustainable design. Our intent in making it transparent is to foster a deeper reflection in the engineering education community about sustainable design and the hidden meaning within engineering curricula and cultures.

Introduction: Why is this instrument needed?

In 2007, the National Academy of Engineering convened a diverse group of experts from around the world to identify the grand challenges to engineering. They organized their 14 grand challenges into four broad areas of human concern—sustainability, health, vulnerability, and the joy of living [1]. They also make clear, like other leading advocates for sustainability, that the challenge of creating sustainable ways of living necessitate collaboration across traditional disciplinary, national and socio-economic boundaries [1-3].

The present-day concept of sustainability, though perhaps practiced by indigenous people throughout the ages, was brought into the global arena through the 1992 Brundtland Report arising out of the United Nations Summit Meeting [4]. It differs from the ecology movement of the mid-20th century, which was focused on preserving the natural environment. Sustainability

practitioners recognize the need for environmental health, but they also incorporate sufficiency of well-being for all peoples in their calculus [5-7]. They recognize that economic activity is not only intertwined with the health of the environment, it is intimately interconnected to social equity and societal stability [8-10]. Sustainability is fundamentally a holistic, dynamic systems view of the interplay between economic activity, environmental health and societal well-being. As such, sustainable design represents a shift in context for engineering. The boundaries of design move from a product or process to the complexity of a larger social, political, environmental, economic, global, historical and future system. Clearly simultaneously considering all these dimensions is a tall order, underscoring the need for engineers to collaborate across traditional boundaries.

However, traditional engineering curricula focus on providing the parts of knowledge and skills believed to be required for engineering. To be sure, engineering programs provide opportunities (i.e. courses) for students to integrate these parts through application and design. Our measures of student mastery often focus on understanding and application, as can be seen in the Fundamentals of Engineering (FE) Exam. These abilities represent lower-levels of learning development in hierarchical taxonomies, such as Bloom's taxonomy of cognition [11]. It is not clear that the sum of the parts of education adds up to the higher levels of intellectual integration required in the capacity to collaborate for sustainable design.

Given the urgent international call for sustainable development by intergovernmental coalitions [1, 4, 12] and the integral role that engineers are expected to play in this transition, engineering educators would benefit from knowing if current curricula are preparing students for this complex task of collaborating for sustainable design. Certainly, an instrument to assess students' readiness does not facilitate their readiness just as "measuring the pig does not make it grow." However, without an understanding of students' readiness, we are not able to target their further development in constructive ways.

This paper describes the first known attempt to create an open-source instrument as an aid to engineering educators to measure students' readiness to collaborate for sustainable design. The instrument presented in this paper, like the FE exam, attempts to measure "parts" rather than the whole. However, we believe its value is in simply answering the question of whether the "parts" exist, with the assumption that their existence is a necessary if insufficient condition; we also believe it provides the educator with an opportunity for a deeper reflection on the engineering curriculum as a whole. We present this research with humility to the greater community with the awareness that it only provides limited, perhaps distorted insight into what we need to understand about our students' development. Our intent in presenting it at this early stage of development is to foster a deeper reflection on our role as educators in the process of preparing engineering graduates for the complex world in which they will practice.

Background: Other instruments and their relevance to designing for sustainability

Others have published their efforts to measure competence for sustainability. For example, Lourdel et al. have developed a method of having students create mind maps of the terms they associate with the concept of sustainable development [13]. To assess the students' development, the faculty map the number of connections between terms onto a graph with six dimensions: social, cultural; environmental; economic scientific, politics, multidisciplinary aspects, actors.

Their method helps illicit the breadth of students' thinking about the factors. A challenge with the assessment method is the subjective, time-intensive nature of the analysis. The method possibly confounds students' understanding of sustainable development concepts with the extent of their verbal skills. The present work was motivated by the need for a straightforward assessment of students' readiness to collaborate sustainable design.

Although we know of no such instruments to measure readiness to collaborate for sustainable design, there are instruments that measure qualities that we expect to contribute to one's readiness. One such instrument was developed by Stern, Dietz and Kalof [14]. Their 16-item instrument was designed to measure one's orientation toward political action and beliefs about the consequences of actions to mitigate environmental impact. The construct for political action, as shown in Table 1, attempts to capture peoples' self-reported behavior with respect to political and individual action regarding environmental issues. The other three constructs are beliefs in consequences for self, others and the biosphere with respect to environmental issues. Their survey instrument also includes a measure on willingness to pay. Stern et al's instrument is designed to assess environmental concerns balanced against a willingness to pay. It contains embedded assumptions about the competitive nature of costs of goods and services that serve environmental well-being. Case studies indicate that the assumptions have varying validity, depending on the situational factors. The instrument is also limited to environmental and economic concerns.

Table 1. Items used in Belief and Behavioral-Intention Scales by Stern, Dietz and Kalof [14].

Belief in consequences for self

- Protecting the environment will threaten jobs for people like me
- Laws to protect the environment limit my choices and personal freedom
- A clean environment provides me with better opportunities for recreation

Belief in consequences for others

- We don't need to worry much about the environment because future generations will be better able to deal with these problems than we are.
- The effects of pollution on public health are worse than we realize
- Pollution generated here harms people all over the earth

Belief in consequences for the biosphere

- Claims that current levels of pollution are changing the earth's climate are exaggerated
- Over the next several decades, thousands of species will be come extinct
- The balance of nature is delicate and easily upset

Political Action

- I would participate in a demonstration against companies that are harming the environment
- I would contribute money to environmental organizations
- I would sign a petition in support of tougher environmental laws
- I would take a job with a company I knew was harming the environment

Another instrument, developed by Forsyth, Nye and Kelley, measures the ethic of caring[15]. This 10-item scale is a 9-point scale ranging from completely disagree (1) to completely agree (9). Their testing of this unidimensional scale revealed a high internal consistency as measured by Cronbach alpha (α=0.85). It is intended to indicate the ethic of caring. The items are listed in Table 2.

Table 2. Items from the Ethic of Caring Scale by Forsyth, Nye and Kelley [15].

Item
Moral people strive to live in harmony with others.
Morality is based on each person's responsibility to others.
We all are morally obligated to make the world a better place to live in.
Morality offers a way of solving conflicts so that no one is hurt.
In moral solutions to conflicts, everyone benefits.
Morality is based on responsibility to people.
Moral people are unselfish.
We are morally responsible to other people.
Morality means caring for other people.
Moral actions sometimes requires self-sacrifices

Stern, Dietz and Guagnano developed a brief inventory of values [16] based on a 56-item scale on human values by Schwartz and Bilsky [17, 18]. Their 12-item inventory contains four scales that measure the major clusters of values called Self-Transcendence, Self-Enhancement, Openness to Change, and Conservation (or Traditional) values. Respondents to the survey were instructed to rate each value on a 7-point scale, "Please tell me how important each of these is as a guiding principle in YOUR life." The items are shown in Table 3. One could argue that collaboration for sustainable design draws on valuing Self-Transcendence and Openness to Change, so this instrument could potentially serve as a proxy measure for these two key values.

Table 3. Factors measured in Stern, Dietz and Guagnano brief inventory of values [16].

Factor I: Self-Transcendence	**Factor II: Conservation (Traditional)**	**Factor III: Self-Enhancement**	**Factor IV: Openness to Change**	**Other value items**
Protecting the environment	Honoring parents	Authority	A varied life	A sense of belonging
Unity with nature	Family security	Influential	An exciting life	Mature love
Respecting the earth	Self-Discipline	Wealth	Curious	Enjoying life
A world at peace	Honest	Social power		
Social justice	Obedient			
Equality	Loyal			
Preventing pollution	Forgiving			
	Helpful			
	True friendship			

All three of these instruments measure dispositions or values that would be expected to contribute to one's readiness to collaborate for sustainable design. However, as theorized in the following section, we propose that one's readiness requires a minimum of three constructs: a sense of agency about one's own actions to bring about a more sustainable world, value of the

self-transcendent goals inherent to sustainability and the awareness of the inherent subjectivity of any viewpoint.

Development Process of Survey Instrument

According to McMillan and Schumacher [19], the process of developing an instrument usually consists of an iterative process whereby a body of recognized content experts develops an exhaustive list of core constructs. This list may then be socialized among a larger body of content experts for the purpose of refining the list. This process may be repeated for the items (or questions) developed for each of the constructs that the researcher intends to assess. The process of engaging the content experts serves to establish face validity of what is being measured. The researcher would then pilot test the instrument and refine the instrument based on the behavior of the piloted versions. The technical adequacy of the instrument to measure the intended construct would then be established through various forms of evidence, such as the relationship of the results to other validated measures, predictable performance of contrasting groups on the instrument, expected relationship of items to one another or comparison to other measures that focus on tasks related to what is being measured.

The development of this instrument necessitated a different process, since sustainability as a field of expertise is not yet established; the notion of "content experts" is less valid than it would be for a discipline like physics. For this reason, the process of developing this instrument involved a survey of sustainability case studies, publicly available practitioner narratives and existing literature. From this body of information, we synthesized a set of what we believed would be key constructs. In our view, continual development or learning is the core competency for this emergent field. We therefore chose to base our test on a development model around learning.

Because sustainability derives from a holistic paradigm, we chose to use an integrated taxonomy of learning as a framework to identify the kinds of development needed for sustainable design. We chose Fink's taxonomy, which has six areas of interrelated development: *foundational knowledge, application, integration, human dimension, caring,* and *learning how to learn* [20]. We used this as a framework to consider the competencies required of the twenty first century engineer. We map these core competencies in Figure 1 within the Fink significant learning framework. Fink suggests that these areas of development are not distinct, but mutually reinforcing; Fink asserts that individual's "significant learning" is most leveraged at the center of the diagram in Figure 1, where all area overlap. This theory of interdependent learning is consistent with theories of human development, such as proposed by Alderfer [21] . Classroom-level assessment often aims to measure *foundational knowledge* and *application*, so we sought to develop an instrument that assessed readiness in Fink's other areas of development. *Integration* refers to making connections across different knowledge that is learned, *Human Dimension* concerns learning about self and others, and *Caring* signifies interests and values.

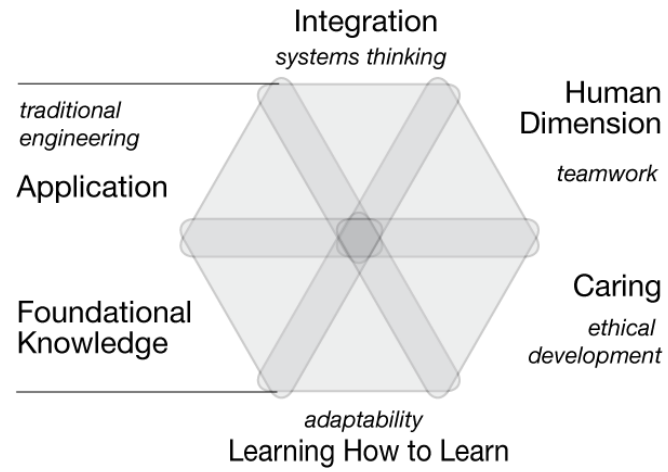

Figure 1. Our mapping of twenty-first century engineering competencies onto Fink's taxonomy.

The initial field tests involved the *caring* dimension through a values survey based on Schwartz's human values survey instrument [18]. These tests involved two sections of 40 items each and two sections of 16 items. The 16 items were derived from the Situational Intrinsic Motivation Scale by Guay, Vallerand and Blanchard [22]. Their 16-item survey is listed in Table 4. For the first 16-item section, *benevolence* was described using Schwartz's definition, and respondents were asked about their motivations for practicing benevolence. The second 16-item survey included a definition of *universalism* and asked respondents the same 16 questions with respect to their practice of universalism.

Table 4. Reproduction of the items on the Situational Intrinsic Motivation Scale by Guay, Vallerand and Blanchard [22]. Respondents were asked to choose the degree to which the statement best fits the reason why they practiced *benevolence* or *universalism*. The choices were Not at all (1), Very little(2), A little(3), Moderately (4), Enough (5), A lot (6), Exactly (7).

Item	Statement
1	Because I think that this activity is interesting
2	Because I am doing it for my own good
3	Because I am supposed to do it
4	There may be good reasons to do this activity, but personally I don't see any
5	Because I think that this activity is pleasant
6	Because I think that this activity is good for me
7	Because it is something that I have to do
8	I do this activity but I am not sure if it is worth it
9	Because this activity is fun
10	By personal decision
11	Because I don't have any choice
12	I don't know; I don't see what this activity brings me
13	Because I feel good when doing this activity
14	Because I believe that this activity is important for me

15	Because I feel that I have to do it
16	I do this activity, but I am not sure it is a good thing to pursue it

Codification key: Intrinsic motivation: Items 1, 5, 9, 13; Identified regulation: Items 2, 6, 10, 14; External regulation: Items 3,7, 11, 15; Amotivation: Items 4, 8, 12, 16.

Our initial goal was to create a brief survey instrument through demonstrating strong correlations with the results of the Schwartz value survey and the results of the two 16-item surveys. Without going into great detail, the survey of roughly 100 respondents of varying ages and majors at a research institution yielded very poor results. The reasons are varied, including poor design of the initial instrument. Many respondents did not complete the survey beyond the first 40 items.

The survey instrument was completely redesigned based on existing surveys and a wider consideration of the constructs that should be measured. The theoretical basis for the current version of the survey instrument is explained in the following section.

Theoretical Foundations for the Instrument

Sustainable design is an emergent concept and therefore its exact meaning is still unfolding. As evidenced by the focus in engineering education conference presentations on sustainable design, the engineering education community has largely conflated sustainable design with the activity of reducing the harmful environmental effects of a product or process [23]. The social equity concern within sustainability is presumably addressed through lessening environmental impacts. This narrow definition of "sustainable design" enables engineers to work solely with other engineers. In contrast, the type of collaboration reported in sustainable development case studies[24-26] indicate sustainable design will require the capacity to effectively work with individuals of very different viewpoints. By *viewpoint*, we refer broadly to the entire ecology of a "frame of reference": assumptions, values and beliefs about what constitutes valid knowledge, methods for acquiring new knowledge and decision-making processes.

As Schein points out, assumptions, values and their attendant beliefs are typically invisible to those who hold them [27]. These invisible aspects of viewpoint often have the unexamined status of "truth" those possessing the viewpoint. Consequently they become the basis of contention in collaborative efforts. Oftentimes the conflict caused by differing viewpoints is resolved through enacting a hierarchical decision process (i.e., the one in charge decides), a process of the domination (i.e., the dominant view of the majority "wins") or by compromise (i.e., someone relinquishes the attachment to their view for the sake of group progress). An alternative is advocated by Bohm [28], which is to inquire for greater understanding of the source of the conflict and allow a new solution to emerge from this shared understanding. In this "generative" mode of collaboration, the process of sustainable design requires people to either suspend their own frame of reference or to deconstruct their own. In either case, this interruption of habit represents an individual engaging in a self-regulated cognitive process.

By self-regulation, we refer to "an interaction of personal, behavioral and environmental triadic processes" [29]. According to Zimmerman, self-regulation requires not only the behavior skills of self-management, but also "the knowledge and the sense of personal agency to enact this skill in relevant contexts" [30] p. 14). Working against our habits of mind also requires one to choose

to engage in this process because of its demand for focused attention. People make choices for many reasons. However, we assert that shifting one's frame of reference, like a shift in paradigm, requires the kind of value-based judgment of the consequences inherent in adopting new paradigms [31].

Based on these considerations, we assert that the capacity to collaborate for sustainable design, independent of one's disciplinary grounding, requires at minimum three dispositions: the belief that one's actions can contribute to sustainability (Fink learning domain of *Human dimension*), a value of the self-transcendent goals of sustainability (Fink learning domain of *Caring*), and the awareness of the subjectivity of any frame of reference (Fink learning domain of *"Learning How to Learn")*. Based on our examination of case studies and emergent sustainable design efforts, we assert that these constructs enable one to believe in the power of their own actions for the "greater good" and learn through collaboration. We believe they are necessary, perhaps insufficient, conditions for one to effectively design for sustainability.

Our conception of these three constructs are pictured in Figure 1. The items we developed to serve as proxy measures for the constructs are shown in Table 5.

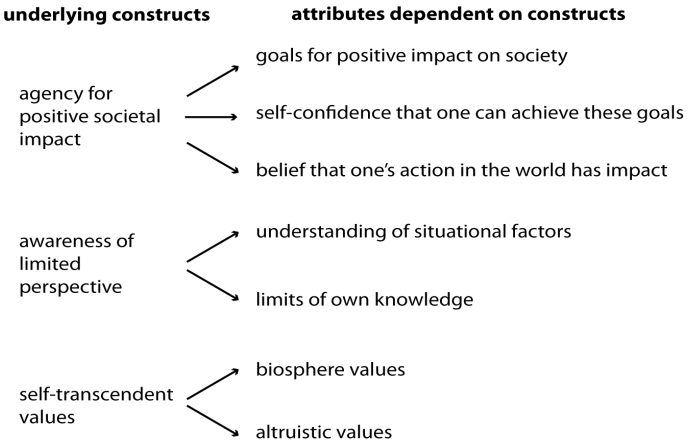

Figure 1. Construct within the readiness for collaboration for sustainable design

In the first section of the survey, respondents were asked to indicate their level of agreement with the statements that followed. The items in section I were randomized on the survey, rather that ordered as shown in Table 5. The options on the 5-point Lickert scale were *strongly disagree (1), disagree (2), neither agree nor disagree (3), agree (4)* and *strongly agree (5).* In the second section of the survey, the items were ordered as indicated in Table 5. Respondents were asked to "Please indicate how important each of these is as a guiding principle in YOUR life." The options were *opposed to my principles (1), not important (2), somewhat important (3), important (4), very important (5).*

We used Bandura's theory of personal agency [32] as the basis for the questions pertaining to the construct, *agency for positive societal impact.* We contextualized these questions by making them specific to the principles of sustainability. Argyris's theory of inference [33] was used as a basis for the questions related to *awareness of limited perspective.* The intent was to reveal habits of mind regarding drawing conclusions, testing the respondent's awareness of the role situational factors play and the ways in which one's perspective is limited. The items to assess self-

transcendent values in Section II were derived from Stern, Dietz and Guangano's brief inventory of values [16].

Table 5. Items related to the constructs scales within the instrument. Item numbers shown in [ ].

Section I: 5-point Lickert scale from strongly disagree (1) to strongly agree (5)

Agency for positive societal impact

Goals

Is it important to me that I use my talents to improve the world around me. [10]

I am personally committed to living in a way that contributes to a sustainable world. [1]

Self-Confidence

Sustainability is important, but I am not confident that I can live more sustainably. (reverse coded) [6]

I am confident that I can do what is needed to create a more sustainable world. [11]

Belief

My actions won't make much of a difference toward a sustainable world. (reverse coded) [3]

My commitment to sustainability will influence those around me to live more sustainably. [8]

Awareness of limited perspective

Understanding of situational factors

There are right and wrong ways to view every situation. (reverse code) [7]

My understanding of any situation is limited. [9]

In complex situations, it is possible for contradicting viewpoints to both have validity. [2]

Limits of own knowledge

I reach conclusions based on facts that are free of assumptions (reverse code) [5]

When I hear new information, I quickly categorize it as "true" or "untrue." (reverse coded) [4]

Section II: 5-point Lichert scale *opposed to my principles (1), not important (2), somewhat important (3), important (4), very important (5)*

Self-Transcendent Values

Biosphere values

Protecting the environment, preserving nature [13]

Unity with nature, fitting into nature [16]

Respecting the earth, harmony with other species [14]

Altruistic values

Equality, equal opportunity for all [12]

Social justice, correcting injustices, care for those who are less privileged [17]

A world at peace, free of war and conflict [15]

Methods of Instrument Administration

The instrument was administered in three parts at a private research university in the northeastern United States (E-group), a public research university in the southern United States (S-group) and a public masters university in the pacific coastal United States (P-group). Students were requested to take the survey by the faculty in their courses. The introductory text of the survey made clear that participation was optional, anonymous and without reward or penalty. All surveys were completed outside of formal class time via a web interface. Those in the E-group and S-group were requested to completed the survey at the beginning and end of a graduate-level course in engineering design for sustainability. Those in the P-group were requested to complete the course as part of a freshman-level communications course. Table 6 summarizes the general differences in the three demographics. As shown in Table 6, the S- and P-group were all engineering students, although at very different points in their curricula; S-group respondents were seniors and graduate students whereas P-group respondents were freshmen.

Table 6. General demographics of instrument respondent groups.

group	institutional setting (Carnegie Classification)	demographics
Eastern (E)	Private, not-for-profit, Arts & Science Focus/high graduate coexistence; Large 4-year, highly residential; more selective, lower transfer in	N=31: 8 male, 22 female; 5 graduate business students, remaining engineering or science majors in senior or graduate year of study
Southern (S)	Public, Balances arts & sciences/professions, high graduate coexistence; Large 4-year, primarily non-residential; selective, higher transfer in	N=90: 65 male, 24 female; all engineering majors in senior or graduate year of study
Pacific (P)	Public, Profession + arts & sciences, some graduate coexistence; Large 4-year, primarily non-residential; more selective, higher transfer in	N=79: 52 male, 17 female; 53 engineering majors, 5 or fewer liberal arts, sciences, agriculture, business, architecture or other majors

For all survey items except item 10, responses were from 1 through 5. For item 10, the responses ranged from 2 through 5.The means varied from 2.74 to 4.34 as shown in the Appendix, with standard deviations ranging from 0.6 to 1.2. Because of the reverse coding, we expect numbers closer to 5 to represent a "higher" readiness to collaborate for sustainable design.

We ran a cluster analysis of each response for E-group and S-group respondents, who represented similar levels of higher education schooling. We followed the cluster results with a Chi-square test of the proportions of responses for each cluster by group. Statistically significant differences were found for three items within the *Learning How to Learn* group of statements. In all cases the E-group scored significantly higher than the S-group in terms of their awareness of the limits of their own knowledge. These results are displayed in Table 7 below. Note that while both E- and S-groups are both dominated in their numbers by engineering students, the E-group has a much larger proportion of females than the S-group. Regardless, we would expect the E-group to exhibit a higher score in the area of *Learning How to Learn*, based on the more selective nature of the institution. That is, we expect the E-group to be more aware of the presence of assumptions, the limits of their understanding and the possibility of multiple valid viewpoints in any situation.

Table 7. Statistically-significant results of cluster analysis.

Item	cluster 1	cluster 2	Chi-square significance
5: I reach conclusions based on facts free of assumptions	*Agree* Overrepresented by S-group	*Disagree* Overrepresented by E-group	p-0.018
9: My understanding of any situation is limited	*Agree* Overrepresented by E-group	*Disagree* Overrepresented by S-group	p=0.001
7: There are right and wrong ways to view every situation	*Agree* Overrepresented by S-group	*Disagree* Overrepresented by E-group	p=0.001

Mathematical Behavior of the Instrument

Transcendent Values (Section II)

Using 188 valid responses, we ran an exploratory factor analysis with principal component analysis and Varimax rotation. The purpose of this analysis is to reduce the number of variables

and see structural relationships in the item responses. This type of extraction and matrix rotation maximizes the variance ("vari-max"), so as to create a set of principal components (or "scales") that differentiate the correlation of individual items into distinct conceptual categories. This type of rotation treats the scales as orthogonal, which means the items are assumed independent of one another. The correlation matrix for the transcendent values scale is shown in Table 8 below. All items are correlated to one another with a statistical significance of $p<0.001$. Not surprisingly from these correlations, this analysis revealed a single scale with internal reliability measured by Cronbach alpha of 0.904 using all six standardized items. It captures 63.8% of the cumulative variation in the responses, which is considered a relatively large proportion in social science research. These results indicate that the instrument shows internal consistency in response of the items. That is, respondents answered these items similarly and consistently.

We refer to this scale as the "Transcendent Values Scale." It is intended to serve as a proxy measure of an individual's self-reported values around the biosphere and altruism. This portion of the instrument is extracted from part of Stern, Dietz and Guangano's *brief inventory of values,* with the modification that we are using a 5-point Likert scale rather than their 9-point Likert. The component matrix with factor loadings are shown in Table 9. Because the rotation process extracts the solution with the maximum variation, the factor loadings are both correlation coefficients between the coded particular items and the new scale ("Transcendent Values Scale") and the weighting factors in a general linear model,

$$y = \beta_{12}x_{12} + \beta_{13}x_{13} + ...\beta_{17}x_{17}$$

where x_i is the mathematically coded response to item i in the Transcendent Values Scale and y is a numeric indicator that captures the essence of the responses to items 12 through 17. While the value of y has no absolute meaning, one could conceivably give the Transcendent Value Scale to two different groups and compare their relative y values as a means of understanding their self-reported values around the biosphere and altruism. A comparison like this has the weakness of presuming that the response levels hold the same meaning for different people. Because the scale data is categorical, a more valid treatment of comparing the results would involve a Chi square test of proportions of particular responses within the scale items rather than a t-test of scale (i.e., y) values.

Table 8. Correlation matrix for Transcendent Values Scale. All correlations are significant at $p<0.001$.

Correlation Matrix

	ITEM12	ITEM13	ITEM14	ITEM15	ITEM16	ITEM17
ITEM12		.564	.557	.504	.561	.635
ITEM13			.821	.604	.707	.652
ITEM14				.593	.795	.569
ITEM15					.545	.585
ITEM16						.574
ITEM17						

Table 9. Component matrix for Transcendent Values Scale.

Component Matrix[a]

	Component
	1
ITEM12	.763
ITEM13	.884
ITEM14	.883
ITEM15	.766
ITEM16	.850
ITEM17	.806

Extraction Method: Principal Component Analysis.
a. 1 components extracted.

Agency (Section I)

For the responses relating to agency for sustainability, we ran an exploratory factor analysis, also using principal component extraction and Varimax rotation. The exploratory factor analysis of these items created two principal components with the factor loadings shown in Table 10. What is interesting about this result is that the negatively worded items around agency (items 3 and 6) indicate an unanticipated structural relationship. These items are (3) My actions won't make much of a difference toward a sustainable world. (reverse coded) and (6) Sustainability is important, but I am not confident that I can live more sustainably. (reverse coded). By inspection, one can see that the item statements reflect a hopelessness or helplessness.

Table 10. Factor loadings for Agency. Loadings with absolute value less than 0.4 are omitted for clarity

Rotated Component Matrix[a]

	Component	
	1	**2**
ITEM1	.782	
ITEM3		.846
ITEM6		.861
ITEM8	.702	
ITEM10	.732	
ITEM11	.763	

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 3 iterations.

Reliability tests of each of the component scales yield a Cronbach alpha of 0.732 for component 1 and 0.640 for component 2. Sixty three percent of the cumulative variance is accounted for by these two component scales. The existence of two principle components indicates that two different constructs are being assessed. We had intended to assess one, but the results of the

exploratory factor analysis reveals that the negatively worded items clearly elicit similar responses, distinct from those elicited by the other items. This implies we might consider removing or replacing the negatively-worded items.

Awareness of limited perspective (Section I)
The same exploratory factor analysis was done for the items corresponding to the awareness of one's limited perspective (principle component extraction with Varimax rotation). This analysis yielded two scales (or equivalently, "components"). As shown in the factor loadings of Table 11, the items loaded onto a scale that represented a black/white world view (component 1) and awareness of their thinking process (component 2). These two scales accounted for 51% of the cumulative variation. However, this particular set of questions showed poor reliability with Cronbach alpha between 0.3 and 0.33 for both components.

By examining the statements in retrospect, one can see that several of the statements contain more than one concept. For example, (4) When I hear new information, I quickly categorize it as "true" or "untrue" potentially contains the concept of a black/white world view ("true" or "untrue"), but it also contains a statement about one's thinking process, referring to whether someone "quickly categorizes" that information. Item 2 is similar in its complexity as a statement: (2) In complex situations, it is possible for contradicting viewpoints to both have validity. If one were to consider their agreement with this statement, they would need to create a meaning for "complex situation," "contradicting viewpoints" and "validity." One might have a threshold around what "validity" means or how much contradiction one is considering. This particular set of items should be re-examined and re-worded to yield more reliable and clear results.

Table 11. Factor loadings for Awareness of limited perspective. Factor loadings with absolute values less than 0.4 are omitted for clarity.

Rotated Component Matrix[a]

	Component	
	1	**2**
ITEM4-When I hear new information, I quickly categorize it as "true" or "untrue"	.728	
ITEM7-There are right and wrong ways to view every situation	.724	
ITEM2-In complex situations, it is possible for contradicting viewpoints to both have validity		
ITEM9-My understanding of any situation is limited		.852
ITEM5-I reach conclusions based on facts that are free of assumptions		.653

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 3 iterations.

Implications for Engineering Educators

Instruments like the one presented in this paper are intended to reveal something about one's disposition. In our case, we hoped to assess students' sense of agency for societal impact, awareness of their limited perspective, and the extent to which they espouse self-transcendent values. This instrument, like others, presumes that responses accurately reflect the respondents' internal state. The next presumption is that one acts in general accordance with their internal state and espoused values. While the use of these instruments is common practice in education, it is reasonable to question the validity of these presumptions. That is, most people upon honest reflection can see the incongruence between their espoused and lived values in at least some areas of their lives. Additionally, respondents may not posses the self-awareness needed to accurately respond or they may want to report themselves in a more positive light, a phenomenon known as *social desirability*. There are methods to measure the existence of social desirability within a survey instrument [34-35]. We have chosen to forgo the use of these methods for the sake of instrument brevity. In the end, the proposed instrument provides, at best, a rough measure of what we believe are the necessary (and insufficient) constructs that enable one to effectively participate in sustainable design: personal agency for positive societal impact, awareness of one's limited perspective and self-transcendent values.

The value of seeing a rough picture of students' state with respect to these constructs is that it can foster a deeper reflection by the engineering educator on the results. For example, the S-group exhibited a low awareness of the limits of their perspective. We would presume that a higher awareness would actually lead to more learning; this presumption is supported by the fact that students at the highly-selective institution of the E-group were overrepresented in the high awareness data cluster. That is, having an awareness of the limits of one's perspective contributes to one's academic success rather than hinders it. One might consider the implications of having a *low* awareness of the limits of one's perspective: What are the consequences when an engineer has a low awareness of the limits of their perspective? Alternatively stated, what are the consequences when an engineer believes his or her perspective is all-inclusive? What are the consequences when an engineer cannot recognize the role the situational factors play in a particular outcome or pattern? What are the conditions at the personal, collective (i.e., systemic) and perceptual levels that create a low awareness of the limits of one's knowledge? What are the cultural habits within the language, artifacts, processes and practices of an engineering curriculum or an engineering educational system that create the condition of a "low awareness of one's limited perspective?"

As educators, we may engage in the same kind of reflection if we were to discover that students report a low level of agency for positive societal impact or devalue the biosphere or service to others. The question of what would *cause* such an outcome is indeed complex, but given that the purpose of the engineering profession is " the advancement and betterment of human welfare" [36] we believe it is our role as engineering educators to ask these very questions. Presumably one would also consider whether and how they would then intervene to produce an outcome that was more congruent with our stated professional purpose.

Conclusions

The rapid pace of change combined with an urgency to address issues of sustainable design have inspired us to create an assessment instrument for students' readiness to collaborate for

sustainable design. In the absence of an accepted body of knowledge for sustainable design, we drew from emergent case studies and practices to create a survey tool based on Fink's framework of integrated learning, with the bias that integrated learning is a key competency for sustainable design. We focused on assessing students' readiness in the *human dimension, caring,* and *learning how to learn* domains. The instrument attempts to quantify respondent's personal agency for sustainability (*human dimension)*, their disposition toward transcendent values (*caring*), and their awareness of the limits of their perspective (*learning how to learn*). The scales for personal agency and transcendent values show promise in their technical performance. The third scale has a low reliability, which is likely due to poor wording in the statements. Our motivation to present these as a work in progress comes from Texan A & M University Executive Vice President Karan Watson in her 2009 ASEE Main Plenary speech in which she urged engineering educators to publish our mistakes as well as our successes. By doing so, we invite the greater engineering education community into a consideration of how we are preparing students for the future, what development is critical and how we might begin to measure if students possess the readiness for the important work of collaborating for sustainable design. For those who are interested in engaging in this research, we have made the instrument and data publicly available in an open-source web format. It is our hope that the transparency and free access to the tool will enable educators to collectively accelerate our ability to prepare our students for the complex world their will inherit.

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References

1. The National Academies. *Grand Challenges for Engineering*. 2007 [cited 2009 February 13]; Available from: http://www.engineeringchallenges.org/.
2. Senge, P.M., et al., *Collaborating for Systemic Change.* MIT Sloan Management Review, 2007.
3. Clark, W.C. and N.M. Dickson, *Sustainability Science: The Emerging Research Program.* Proceedings of the National Academy of Sciences of the United States of America, 2003. **100**(14): p. 8059- 8061.
4. UNEP, Earth Summit: Agenda 21-Global Programme of Action on Sustainable Development. 1992: United Nations Environment Programme.
5. Meadows, D., *Indicators and Information Systems for Sustainable Development*. 1998, Sustainability Institute: Hartland, VT. p. 1-95.
6. Bell, S. and S. Morse, Breaking through the Glass Ceiling: who really cares about sustainability indicators? Local Environment, 2001. **6**(3): p. 291-309.
7. Yuan, W., et al., Development of sustainability indicators by communities in China: A case study of Chongming County, Shanghai. Journal of Environmental Management, 2003. **68**: p. 253-261.
8. Clark, W.C., America's National Interests in Promoting a Transition to Sustainability. Environment, 2001. **43**(1): p. 18-27.

9. Dovers, S.R. and J.W. Handmer, *Uncertainty, sustainability and change.* Global Environmental Change, 1992. **2**(4): p. 262-276.
10. Kruijf and Vuuren, Kruijf and Vuuren Following Sustainable Development in Relation to the North-South Dialogue. Ecotoxicology and Environmental Safety, 1998. **40**: p. 4-14.
11. Bloom, B.S., et al., Taxonomy of Educational Objectives: Handbook 1: Cognitive Domain. 1956, New York: Longman.
12. Change, I.P.o.C., *Climate Change 2007: Synthesis Report*. 2007, Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
13. Lourdel, N., et al., *Sustainable development cognitive map: a new method of evaluating student understanding.* International Journal of Sustainability in Higher Education, 2007. **8**(2): p. 170-182.
14. Stern, P.C., T. Dietz, and L. Kalof, *Value Orientations, Gender, and Environmental Concern.* Environment and Behavior, 1993. **25**(5): p. 322-348.
15. Forsyth, D.R., J.L. Nye, and K. Kelley, *Idealism, Relativism, and the Ethic of Caring.* The Journal of Psychology, 2001. **122**(3): p. 243-248.
16. Stern, P.C., T. Dietz, and G.A. Guagnano, *A Brief Inventory of Values.* Educational and Psychological Measurement, 1998. **58**(6): p. 984-1001.
17. Schwartz, S.H. and W. Bilsky, *Toward a psychological structure of human values.* Journal of Personality and Social Psychology, 1987. **53**: p. 550-562.
18. Schwartz, S.H. and W. Bilsky, toward a theory of the universal content and structure of values: Extensions and cross-cultural replications. Journal of Personality and Social Psychology, 1990. **58**(878-891).
19. McMillan, J.H. and S. Schumacher, *Research in Education: Evidence-Based Inquiry*. Sixth ed. 2006, Boston: Pearson.
20. Fink, L.D., Creating Significant Learning Experiences:An Integrated Approach to Designing College Courses. 2003: Jossey-Bass.
21. Alderfer, C.P., *An empirical test of a new theory of human needs.* Organizational Behavior and Human Performance, 1969. **4**: p. 142-175.
22. Guay, F., R.J. Vallerand, and C. Blanchard, On the Assessment of Situational Intrinsic and Extrinsic Motivation: The Situational Intrinsic Motivation Scale (SIMS). Motivation and Emotion, 2000. **24**(3): p. 175-213.
23. Vanasupa, L., et al., The systemic correlation between mental models and sustainable design: Implications for engineering educators. International Journal of Engineering Education, 2010. **26**(2): p. 438-450.
24. May, S., Ecological citizenship and a plan for sustainable development. City, 2008. **12**(2): p. 237-244.
25. Bell, S. and S. Morse, *Story telling in sustainable development projects.* Sustainable Development, 2007. **15**(2): p. 97-110.
26. Dumreicher, H., Chinese villages and their sustainable future: The European Union-China-Research Project "SUCCESS". Journal of Environmental Management, 2008. **87**(2): p. 204-215.
27. Schein, E.H., *Organizational culture and leadership*. Third ed. 2004, San Francisco, California: Jossey-Bass.
28. Bohm, D., *On Dialogue*, ed. L. Nichol. 1996, New York, NY: Routledge.
29. Bandura, A., Social Foundations of Thought and Action: A Social Cognitive Theory. 1986, New Jersey: Prentice Hall.

30. Zimmerman, B.J., *Attaining Self-Regulation: A Social Cognitive Perspective*, in *Handbook of Self-Regulation*, M. Boekaerts, P.R. Pintrich, and M. Zeidner, Editors. 2001, Academic: San Diego, CA. p. 13-39.
31. Kuhn, T.S., *The structure of scientific revolutions*. 2nd ed. 1970, Chicago: Chicago University Press.
32. Bandura, A., *Exercise of human agency through collective efficacy.* Current Directions in Psychological Science, 2000. **9**(3): p. 75.
33. Argyris, C., *Reasoning, Learning and Action: Individual and Organizational*. Social and Behavioral Science Series. 1982, San Francisco, CA: Jossey Bass.
34. Loo, R., & Loewen, P. (2006). Confirmatory Factor Analyses of Scores From Full and Short Versions of the Marlowe–Crowne Social Desirability Scale. 1-10.
35. Paulhus, D. L. (2003). Control of Social Desirability in Personality Inventories: Principal-Factor Deletion. *Journal of Research in Personality*, 1-6.
36. Engineer's Creed, Code of Ethics (1954), National Society of Professional Engineers.

APPENDIX

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
ITEM1	169	1	5	3.97	.862
ITEM2	170	1	5	4.19	.761
ITEM3	170	1	5	3.41	1.117
ITEM4	169	1	5	3.20	.921
ITEM5	168	1	5	2.81	.960
ITEM6	170	1	5	3.33	1.070
ITEM7	168	1	5	2.74	1.214
ITEM8	170	1	5	3.59	.887
ITEM9	169	1	5	3.17	1.209
ITEM10	168	2	5	4.34	.664
ITEM11	168	1	5	3.67	.837
ITEM12	188	1	5	4.16	.919
ITEM13	188	1	5	4.16	.887
ITEM14	188	1	5	4.07	.916
ITEM15	188	1	5	3.97	1.036
ITEM16	188	1	5	3.79	1.042
ITEM17	188	1	5	4.01	1.024
Valid N (listwise)	156				