INNOVATIVE AND SUSTAINABLE DESIGN: PERCEPTIONS OF EXPERTS

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Abstract

Innovation and creativity research assists and enables designers to break the mold of everyday, expected designs and discover the delightful, but unexpected, meaning-rich, and radical through novel approaches to engineering problems and opportunities. Sustainability is one “wicked problem” that requires innovative design thinking to change the interface between nature, society, economy and artifact. We surveyed perspectives on the innovation process from 59 design experts internationally through two separate workshops. In the first workshop, 38 experts in innovation provided perspectives on the cognitive underpinnings and design processes relevant to innovation. In the second, 21 experts provided their perspectives on the same topics in light of sustainable design objectives. These findings show the two areas of research to be linked alternatives, and that future research into analogies, creativity, open-mindedness and the application of constraints can help bridge the gap between techniques in engineering design innovation and the applications of sustainable engineering design.

Keywords: Design process, Sustainability, Ecodesign, Innovation, Design education

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1 INTRODUCTION

"Sustainability," pronounced Nidumolu et al. (2009) in the Harvard Business Review, "is a mother lode of organizational and technological innovation." Their study of the sustainability initiatives of 30 corporations revealed that sustainability is a key driver of innovation (Nidumolu et al., 2009). Similar observations by academics, businesses and consultants suggest that research in sustainable design and innovative design can learn from each other (Braungart and McDonough, 2002; Carrillo-Hermosilla et al., 2010; McAloone, 2007; Nidumolu et al., 2009). But are we treating these areas of research and practice differently or as linked initiatives? Surveying the perspectives of expert design researchers and practitioners in both the U.S. and Europe, we compared their ratings of methods, tools, education, and collaboration as they support or hinder innovative design and sustainable design. The results show that the two areas have much in common, but reveal misunderstandings and disagreements within design cognition and tools for innovation.

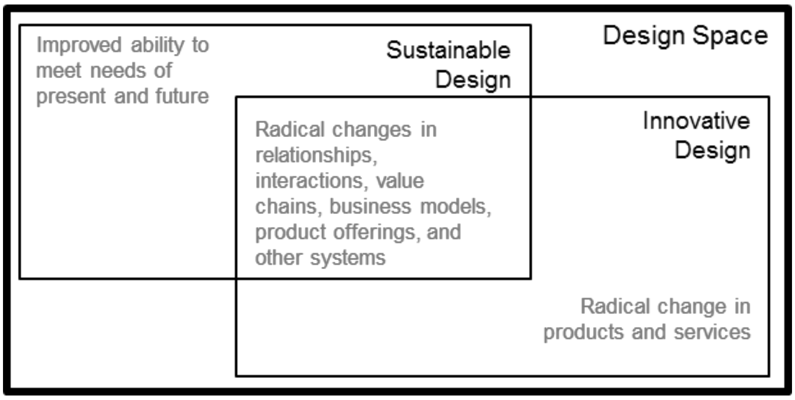

Figure 1: Significant overlap exists between sustainable and innovative design

In many ways, sustainability and innovation are inseparable, as in Figure 1.Innovation challenges us to design the unexpected, and sustainability focuses on balancing resources for economic, social, and environmental benefit (Keskin et al., 2013; Schaltegger and Wagner, 2011). While good design may satisfy customer, client, or stake-holder needs based on a systems approach, innovative design can create new needs and user experiences, and change expectations (Kano, 1984). Innovative design changes our relationship with products and systems (Saunders et al., 2011). In their study of characteristics of award-winning products, Saunders et al. (2011) found that most innovative products create novel interactions between users and environments. It is this change of expectations and relationships that seems to connect sustainability and innovation.

Design for Sustainability(Crul and Diehl, 2006) changes the design task at a more fundamental level than creating additional constraints (Skerlos et al., 2006); it reframes design to include complex, spatial and temporal systems blending social, economic, and ecological sciences (Mihelcic et al., 2003). Sustainable design is largely defined by the United Nation's Environmental Program as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). In the report, this definition is expanded to include economic, social, and environmental needs, and highlight the emphasis on understanding both needs and limitations. McDonough, Braungart Design Chemistry certifies sustainable design efforts by focusing on systems that feed both social and ecological spaces, with beneficial outputs to both society and environment (Braungart and McDonough, 2002; Braungart et al., 2007; McDonough et al., 2003).

In their 2009 article, Nidumolu et al. (2009) emphasize that a sustainable world requires defining new relationships. Their study of 30 corporations using sustainability as a driver of innovation revealed that innovative, sustainable advancement of a company typically occurs in five stages: (1) viewing compliance as opportunity, (2) making value chains sustainable, (3) designing sustainable products and services, (4) developing new business models, and (5) creating next-practice platforms. These stages proceed as a company begins to "anticipate and shape regulations", make their supply chains more environmentally conscious, redesign their offerings to be more eco-friendly, changing their business models, and then radically changing perspectives on business and products. Examples of these latter two stages include the merger of FedEx and Kinkos to allow for electronic shipment of documents to another location (stage 4), and smartgrids (stage 5) (Nidumolu et al., 2009). These later stages exemplify the interaction of sustainable design and innovation processes, and provide opportunity for synergy between the two fields of research.

To explore the research intersection of innovation and sustainable design, we expanded upon a previous research study (Krager et al., 2011) of design and innovation experts to ask: "How can innovation techniques and creativity theories be extended to the very real, wicked problem of sustainability?" Using inspiration and results from a past National Science Foundation (NSF) workshop, we conducted a sister workshop at the DESIGN 2014 conference in Cavtat, Croatia. Both workshops included pre-surveys to query perspectives on innovation practices. The NSF workshop on individual and team-based innovation revealed current perceptions of innovation and opportunities for improvement in teaching and researching innovative processes. In the second workshop, we disseminated, practiced and discussed exemplar work and research questions in the fields of sustainable and innovative design regarding tools, entrepreneurship and cognition. Both sets of participants are design researchers and innovators with a range of expertise.

The following sections use these surveys to explore perspectives at the intersection of practice and theory. Topics include teamwork, education, brainstorming, ideation, fixation, creativity, and analogies. Section 2 of this paper provides the background and foundations of the survey methodology. Section 3 provides an overview of the questions, responses and test statistics for study by the reader. In Section 4, we present a discussion of the perspectives on practice in sustainable and innovative design in conjunction with references to the literature, highlighting discrepancies and accuracies.

2 METHOD

We seek to compare perceptions of innovation and sustainability between two similar groups of experts in design research using the method shown in Figure 2. A set of demographic questions and two sets of technical questions on innovative and sustainable design are used. One set of technical questions focuses on innovative design and was asked of experts attending a NSF conference (Krager et al., 2011; Schunn et al., 2006). This first set will be referred to as the innovation set. The second set of questions repeats the technical content of the first, but is focused on sustainable design and was asked of experts attending a conference of the Design Society (The Design Society, 2014). This second set will be referred to as the sustainability set. Both groups provided the same demographic information regarding age, citizenship, and technical background. The two groups were expected to have similar technical backgrounds, a mix of commercial and theoretical experience. This theoretical experience provides both an advantage and disadvantage, as the responses may reflect a depth of understanding that a typical designer or engineer may not possess.

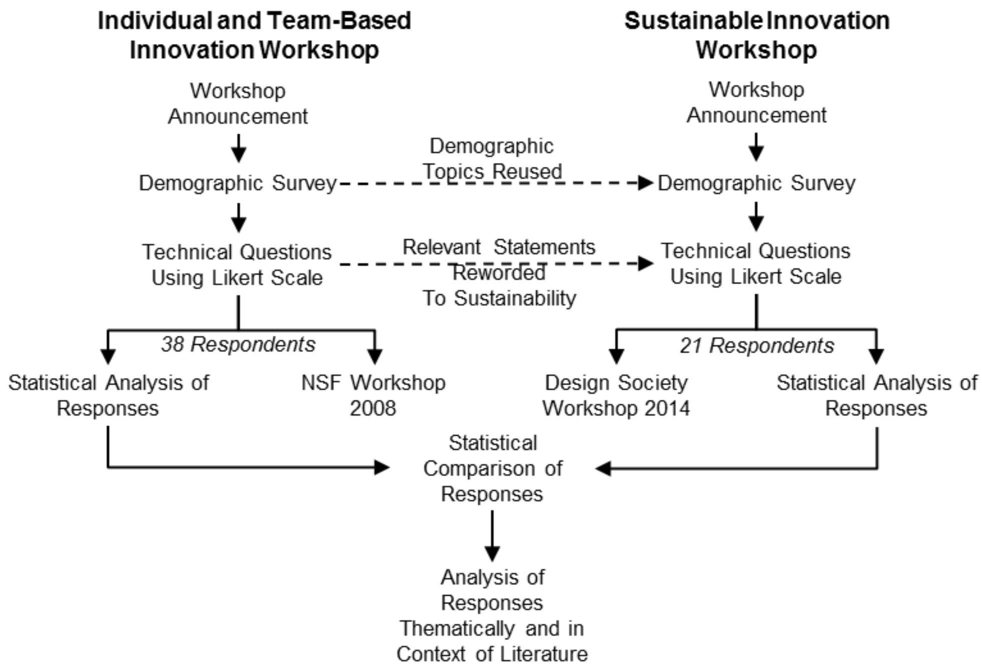

Figure 2: Perspectives on Innovation Compared from Two Sister Workshops

The technical questions were originally developed through a collaboration of experts in cognitive science, social psychology, and engineering design as part of an NSF workshop considering convergent and interfacial research between the fields of psychology and engineering (Schunn et al., 2006). Participants were asked to respond to a statement about innovation or sustainability using a Likert-scale to express agreement or disagreement. Shown in Table 2, each survey covered identical topics, but applied to either sustainability or innovation.

Table 1: The Innovation and Sustainability Questions used in the Respective Surveys

Innovation Group Statements	Sustainability Group Statements
Brainstorming is an effective technique for creating innovative ideas.	Brainstorming is an effective technique for creating sustainable ideas.
The use of analogies is a necessary part of the innovation process.	The use of analogies is a necessary part of sustainable design.
Undergraduate engineering programs inhibit creativity and innovation as the students proceed in the program.	Undergraduate engineering programs inhibit sustainable thinking as students proceed in the program.
Modeling of a design problem, i.e., generalizing or clarifying it, is a critical part of the early innovation process.	Modeling of a design problem, i.e. generalizing or clarifying it, is a critical part of the early innovation process.
Designers / people become blocked (fixated) on particular solutions depending on how a problem is stated.	Designers/people become blocked or fixated on particular solutions depending on how a sustainability problem is stated.
The presence of people from outside disciplines during ideation can hinder the ideation process.	The presence of people from outside disciplines during ideation can hinder the ideation process for sustainable design.
The physical design environment is critical to assist and empower innovation.	The working culture is critical to assist and empower sustainable design.
	The work space is critical to assist and empower sustainable design.
During idea generation, all constraints should be suspended.	During generation of sustainable ideas, all constraints should be suspended.
During idea generation, all negatives or criticisms should be avoided.	During generation of sustainable ideas, all negatives or criticisms should be avoided.
The use of analogies can cause fixation during the innovation process.	The use of analogies can cause fixation during the sustainable design process.
K-12 students echibit a higher degree of creativity than higher education students.	K-12 students exhibit a higher degree of creativity in sustainability than higher education students.
Personality types or preferences have an impact on one's ability to be creative.	Personality types or preferences have an impact on one's sustainable design ability.
Design teams can be more effective than individuals at creating innovation	Design teams can be more effective than individuals at creating sustainable designs.
Innovative design outcomes depend upon the input of very creative individuals.	Innovative sustainable design outcomes depend upon the input of very creative individuals.

Participants responded, voluntarily, to the surveys online at their own convenience prior to attending their respective conferences. Responses were not required for every question. Participants also had the option to retake the survey. If a respondent participated twice only the final response was analyzed.

We compared the two sets of responses, the innovation set and the sustainability set, to investigate differences in perspective. The comparison focused on the number of respondents agreeing or disagreeing with a statement, and a comparison of the scaled results. For the innovation set, the Likert responses were scaled to a five (5) point scale to compare the averages and perform a statistical analysis assuming unequal variance.

3 RESULTS

The survey results yielded 12 items of demographic or background information and 16-17 statements on technical perspectives for each participant. The innovation set had 38 respondents, and the sustainability set had 21. These are high response rates given the significant expertise and experience of the participants in sustainable and innovation research. This section presents the overall results for of the study, before discussing them in Section 4 thematically and in reference to the research question comparing perceptions of innovative design and sustainable design.

3.1 Demographic Questions

This section summarizes the two sets of self-reported demographics. In Figure 3, the sustainability set are represented by dark filled columns, and the innovation set are the white (empty), bordered columns. These demographics provide context for comparing differences in opinion or trends found in analysis of the technical questions.

Some of the major demographic differences in the two sets of participants occur due to their age and country of origin. The innovation set was 67% U.S. citizens, with 5% Europeans, 16% from Asian, and 11% from other countries. In contrast, the sustainability set was only 19% U.S. citizens. Most of the sustainability set were Europeans (67%), with 10% Asian and 5% from other countries. In addition to the difference in nationalities and cultural backgrounds, the sustainability participants were generally younger. The largest group of participants of the sustainability set were between 20-30 years old (43%), while 19% of the innovation set fell in that range. Most participants of the innovation set were between 30-40 (44%), while 24% of the sustainability group were between 30-40. The professional status of the two groups also differed somewhat. While the innovation group was 89% professors, 9% research scientists and 1% other, the sustainability group consisted of 43% professors, 5% lecturers, 19% research scientists, 24% other and 10% engineers from industry. Both groups had a majority of educators and researchers in design, innovation, sustainability or all three.

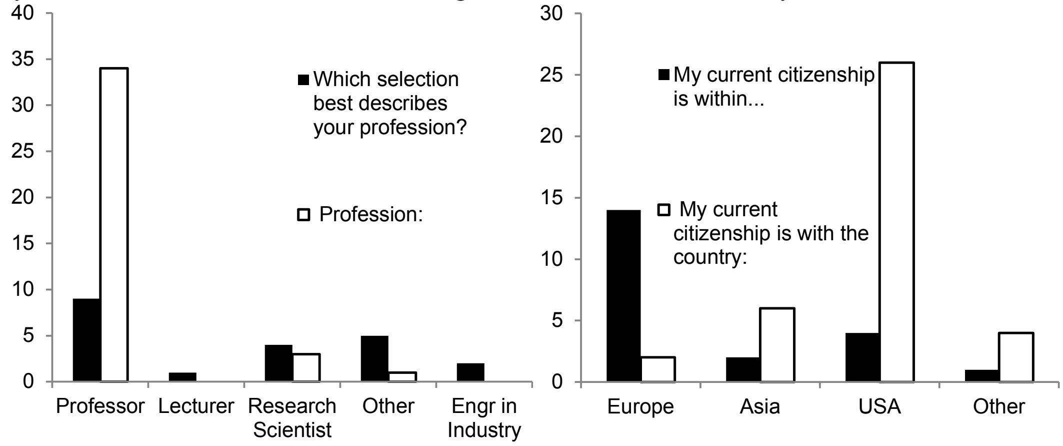

Figure 3: Respondents in the sustainability group [black] are younger and more diverse

Respondents also provided estimates of their practical design experiences that help describe their level of expertise and knowledge of practice. Of the sustainability group, 61% had worked in a company performing engineering design, while 82% of the innovation group had such experience. 47% of the sustainability group had consulting experience, while 71% of the innovation group had consulting experience. 62% of the sustainability group had industrial design experience, and 53% of the innovation group had industrial design experience. While 24% of the sustainability group included named inventors on patents, 48% of the innovation group included named inventors on patents. Additionally, 67% of the sustainability group had experience teaching product design, and 71% of the innovation group had such experience. Finally, 58% of the sustainability group had developed tools or techniques for innovative design, and 63% of the innovation group had developed tools or techniques for innovative design. These results indicate that the participants were well-versed in engineering design with most having significant practical experience in innovative design.

3.2 Technical Questions

Table 1 details the results of the two technical surveys. The left side details descriptive statistics for the innovation set, and the right side provides results for the sustainability set. The center column shows the *p-value* for a Students t-test of the null hypothesis that the two sets are indistinguishable, assuming unequal variance. From this analysis, the most significant differences, those samples yielding *p-values* below 0.05, are the following two statements: "The use of analogies is a necessary part of the innovation process," and "Undergraduate engineering programs inhibit creativity and innovation as the students proceed in the program." While the innovation group (89% professors) had a strong agreement that analogies are a necessary part of the innovation process, the sustainability group (47% professors) had a neutral response, with only 43% of respondents agreeing. The statement that undergraduate engineering programs stifle creativity was somewhat agreed upon by the innovation group, with 61% agreeing, but yielded a more neutral and, in part, a negative response from the sustainability group, with 15% agreeing.

4 DISCUSSION

The technical questions of both surveys can be organized by four major themes: (1) Processes and Methods of Design; (2) Collaboration in Design; (3) Characteristics of People who Design; and (4) Education. Each of the following subsections discusses one of these four themes.

Table 2: Comparison of the survey results

						Strongly Disagree			Neutral		Strongly Agree	
	% Agree	Error	Std. Dev.	Scaled Average	pvalue	-3	-2	-1	0	1	2	3
Brainstorming is an effective technique for creating innovative ideas.	87%	0.3	1.0	1.1	0.07	2	1	1	1	11	12	10
…creating sustainable ideas	62%	0.5	1.1	0.6			1	3	3	11	3	
The use of analogies is a necessary part of the innovation process.	95%	0.2	0.7	1.4	0.00	0	0	1	1	7	17	12
…part of sustainable design.	43%	0.4	1.0	0.3			1	3	7	9	1	
Undergraduate engineering programs inhibit creativity and innovation as the students proceed in the program.	61%	0.3	1.0	0.5	0.03	1	2	3	7	12	8	3
…inhibit sustainable thinking…	15%	0.4	0.8	-0.1			1	3	13	2	1	
Modeling of a design problem, i.e., generalizing or clarifying it, is a critical part of the early innovation process.	92%	0.2	0.8	1.5	0.43	0	1	0	2	3	18	14
...[identical question]	76%	0.5	1.0	1.3			0	2	2	5	12	
Designers / people become blocked (fixated) on particular solutions depending on how a problem is stated.	92%	0.2	0.7	1.4	0.06	0	0	2	1	4	22	9
…how a sustainability problem is stated.	62%	0.5	1.1	0.9			1	1	5	7	7	
The presence of people from outside disciplines during ideation can hinder the ideation process.	8%	0.3	1.0	-1.4	0.16	16	13	4	1	2	0	1
…ideation process for sustainable design.	19%	0.6	1.3	-0.9			10	4	3	3	1	
The physical design environment is critical to assist and empower innovation.	84%	0.3	0.9	1.2	0.58	1	0	1	4	4	20	8
The working culture…	71%	0.4	0.9	1.3			0	0	5	4	12	
The physical design environment is critical to assist and empower innovation.	84%	0.3	0.9	1.2	0.07	1	0	1	4	4	20	8
The work space…	62%	0.5	1.1	0.7			1	2	5	8	5	
During idea generation, all constraints should be suspended.	47%	0.4	1.3	0.2	0.66	1	6	8	5	8	4	6
During generation of sustainable ideas…	43%	0.6	1.3	0.1			4	3	4	8	2	
During idea generation, all negatives or criticisms should be avoided.	62%	0.5	1.4	0.4	0.16	1	8	3	2	8	9	6
During generation of sustainable ideas…	67%	0.5	1.1	0.9			0	4	2	7	8	
The use of analogies can cause fixation during the innovation process.	55%	0.4	1.1	0.2	0.75	3	4	1	9	14	7	0
…during the sustainable design process.	35%	0.5	1.0	0.1			1	4	8	6	1	
K-12 students exhibit a higher degree of creativity than higher education students.	39%	0.4	1.2	0.1	0.62	3	3	5	11	6	4	4
..creativity in sustainability…	15%	0.3	0.6	0.0			0	3	14	3	0	
Personality types or preferences have an impact on one's ability to be creative.	74%	0.4	1.1	0.8	0.72	1	3	0	6	11	11	6
…one's sustainable design ability.	81%	0.2	0.4	0.9			0	0	3	18	0	
Design teams can be more effective than individuals at creating innovation	68%	0.3	1.0	1.0	0.15	0	1	2	9	6	9	10
…creating sustainable design.	71%	0.4	0.9	1.3			0	0	5	4	12	
Innovative design outcomes depend upon the input of very creative individuals.	64%	0.4	1.1	0.2	0.65	1	5	6	1	17	4	2
Innovative sustainable design outcomes…	52%	0.5	1.2	0.4			1	5	3	9	3	
Innovative design... very open individuals.	74%	0.3	1.0	0.9	0.49	0	1	5	2	9	12	7
Innovative sustainable design outcomes…	76%	0.4	0.8	1.1			0	1	3	11	6	

4.1 Process and Method

Design processes and methods include those statements concerning tasks, tools, or guidelines for the design process. This theme covers six of the questions in the survey.

Brainstorming: both groups generally agreed that brainstorming is an effective technique for design, whether it is specifically sustainable or innovative. Nevertheless, a larger percentage of the sustainability group disagreed with the effectiveness of brainstorming. The reason for disagreement could result from increasing awareness of the limitations of brainstorming (Diehl and Stroebe, 1987; Mullen et al., 1991; White et al., 2012) or from perceived limitations specific to sustainable design.
Constraints: When thinking of sustainability, constraints and limitations of the earth's resources is a primary concern, so it would seem that thinking about constraints and criticisms would be a necessary part of the problem definition and idea generation process. The results, however, show that the innovation and sustainability groups shared a neutral perspective towards withholding constraints during the design process. Future research should expand upon existing work, such as that of Knoblich *et al.* (1999) where the authors note that designers may apply inappropriate constraints based on past experiences. A larger percentage of the two groups agreed with the guideline of withholding criticism, and it is likely that this result ties-in with perspectives of good teamwork and open-mindedness addressed in the later subsections.
Analogies: Differences in perspectives occurred when the statements included more cognitive aspects of the design process. One of the two significantly different responses is the statement that: "The use of analogies is a necessary part of [sustainable design] / [the innovation process]." Since sustainable design literature often makes analogies with nature (O'Rourke and Seepersad, 2013), it is unlikely that the difference in perspective occurred because of sustainability considerations. It is more likely that the participants were unfamiliar the role of analogy as a cognitive underpinning of design (Gick and Holyoak, 1980). The sustainability group had fewer professors and may have had less familiarity with the analogy literature. This disconnect is less evident when the topic of fixation (Jansson and Smith, 1991; Linsey et al., 2010) is introduced into the statements. These results demonstrate a need for advancement of analogical reasoning and ideation techniques, and, perhaps, the necessity of teaching analogical reasoning techniques in the classroom (Krager et al., 2011).

4.2 Collaboration

Two statements existed within the theme of collaboration. The first asks whether teams can be more effective than individuals at creating innovative or sustainable designs. Both groups agreed with this statement, and none of the sustainability group disagreed. It would be expected, given the interdisciplinary nature of sustainability (economic, social, and environmental development) that teams would be more effective. This interdisciplinary nature of ideation is addressed further in the follow-up question about the presence of people from outside disciplines. Some participants felt that the presence of people from outside disciplines can hinder the ideation process, but most disagreed. Furthermore, the spread is similar for both groups, regardless of sustainable or innovative nature.
Another question related to teamwork arose from a pilot study for the sustainability group. Pilot participants asked for clarification of the phrase "physical design environment," leading to the creation of two separate questions for the sustainability group. The original statement was rephrased as "work space" and a new, additional question addressed "working culture." Although the two groups are not statistically significant at an alpha of 0.05, there was a nearly significant disagreement between the two groups. While the innovation group felt that physical environment is important to innovation, the sustainability group did not find it as important. In contrast, the sustainability group strongly felt that working culture is important to sustainable design. These results reveal opportunities for further research into physical and social aspects of a working environment that empower innovation and sustainable innovation.

4.3 Characteristics of People

The two groups had similar beliefs about the importance of different types of individuals in the design process. The respondents felt that creative individuals are important to both innovative and sustainable design. This agreement increased when considering "open" individuals. While 64% of the innovation group and 51% of the sustainable group felt creative personalities are important, 68% and 72% (respectively) felt that open individuals were important. The increase in agreement and nearly full Likert scale change in the average (0.24 to 0.97 and 0.38 to 1.33) indicate that training individuals who are more open-minded is an area of interest. Note a slightly stronger response by the sustainability group to the concept of open-ness. Although the *p-value* is 0.15, it makes sense that the kinds of radical changes in lifestyle (Notter et al., 2013) required by sustainability may require more openness by designers and consumers. Nevertheless, it is difficult to imagine a person who is creative, but not open. Teasing out the difference in perspective between these two traits could be useful for our understanding and teaching of creativity.

Aside from open-ness, the two groups had very similar average responses for the importance of personality types to sustainable and innovative design. The innovation group displayed a wider variance, indicating that there may be a difference in opinion with regards to innovative ability and sustainable design ability as opposed to performance in the earlier, open/creative questions.

4.4 Education

Education is one of the two thematic areas in which the sustainability and innovation groups differed significantly. Neither group felt there was a difference in creativity between K-12 students and higher education students. In contrast, the innovation group felt that undergraduate engineering programs may stifle creativity and innovation. Although it may vary by institution, recent research suggests that university engineering and design courses do enhance creativity (Kershaw et al., 2014). The sustainability group was significantly more neutral (*p-value* of 0.03). These responses could be due to differing opinions on sustainability and creativity, or educational cultures in the U.S. and Europe as the innovation group was 67% U.S. citizens and the sustainability group was 67% Europeans. Neither group felt that abilities were enhanced by curricula (i.e. strongly disagreed with this statement). Therefore, the results demonstrate a need to address the way we teach sustainability, creativity, and innovation in our universities.

4.5 Innovation and Sustainability

The close agreement and high *p-values* within the results show that many of our perspectives of innovation processes apply to sustainable design. Therefore, collaborations between these sustainability and innovation researchers could provide significant broader impacts to engineering design and sustainable development in practice.

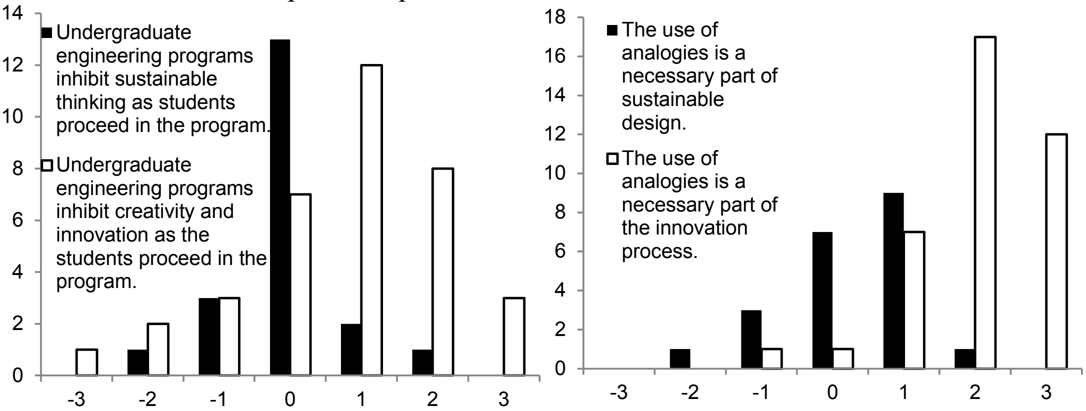

Figure 4: Education and Analogies Yielded Different Perspectives

Surprisingly, the role of analogies was not as appreciated by the sustainability group (Figure 4), despite the prevalence of natural analogies in sustainable discussions in popular culture and the literature and the importance of analogy to cognitive processes. It is possible that some of the respondents were familiar with difficulties in applying analogies (Chan et al., 2011; Fu et al., 2013), especially distilling sustainable ideas from bio-mimicry and bio-inspired design (O'Rourke and Seepersad, 2013; Reap and Bras, 2014), but, despite these criticisms, the cognitive study of design emphasizes the importance of analogies to design (Fu et al., 2014; Gick and Holyoak, 1980; Markman et al., 2009). Because these responses do not reflect current research, there is a strong need to increase awareness of the cognitive underpinnings of design across the international community.

Figure 4 illustrates a second difference in perspectives regarding teaching of sustainability and innovation. While the innovation group felt that the education system stifled creativity, the sustainability group did not indicate a belief that higher education influences sustainable thinking. Recent studies suggest that the innovation group is misinformed, and that engineering graduates who take design courses have increased creativity at the time of education (Kershaw et al., 2014). Because neither group disagreed with the statement that engineering programs stifle creativity or sustainability, it is essential that our community does more to address these two areas of design in our curriculums.

5 CLOSURE

These results are a first contribution towards understanding how cognitive science, innovation techniques and creativity theories can be connected to the very real problem of sustainability. The two surveys of experts in design at an NSF conference and a Design Society conference yielded similar perspectives on design processes for sustainability and innovation and corroborate findings that sustainability and innovation are closely linked. Therefore, future tools and research thrusts in sustainable design should look towards the innovation, creativity and cognitive science literature.

Although constraints, limitations, and needs define sustainability, expert responses and the innovation literature (Knoblich et al., 1999) suggest that suspending these constraints and focusing on a limited set of appropriate constraints can lead to more innovative sustainable design. The end result could be products, services, systems, and businesses similar to the later stages of sustainability and innovation as outlined by Nidumolu *et al*. (2009).

Education needs revealed from the responses include analogical thinking, open-mindedness, creativity and sustainable thinking. There are many pitfalls to analogical thinking, such as fixation or applying inappropriate constraints (Chan et al., 2011; Knoblich et al., 1999), but greater awareness of how to use analogies properly for sustainability can result in radical change and innovation (Reap and Bras, 2014). Additionally, respondents valued open-mindedness. This response could be tied with the needs of teamwork and collaboration, and research is needed for greater understanding of these perspectives.

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