AC 2012-3131: DO STUDENTS DREAM BEYOND LEDS? INNOVATIVE QUALITIES OF IDEAS GENERATED BY FIRST-YEAR ENGINEERING STUDENTS

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Do Students Dream Beyond LEDs?
Innovative Qualities of Student Solutions to an Idea Generation Task

Abstract

One of the goals of engineering education is to help students develop skills and competencies to be innovative. This goal is motivated by the need for innovative engineering graduates who can tackle the complex challenges of an advanced global society. The purpose of this study is to assess engineering students' idea generation abilities in specific aspects of innovation (feasibility, viability, usefulness, desirability, and novelty) at the onset of their education. Seventy-two students completed an idea generation task as part of a course practical exam, listing inexpensive energy-saving solutions for a local library and selecting their most innovative solution. The solutions were scored using a five-point integer scale (with 5 as the highest score). The average scores in each of the five qualities of innovation indicate that students succeeded in viability but failed to consider usefulness, desirability, and novelty. The most common solutions were expected solutions such as replacing current light bulbs with LEDs and installing automatic lighting. Based on these results, we suggest that future research focus on methods to improve students' understanding of the importance of usefulness and desirability as important aspects of innovative design and to consider novel solutions.

Introduction

Engineers must innovate. From designing economically viable renewable energy to reverse engineering the brain, bright, forward-thinking, and imaginative engineers are counted on to address grand challenges and ensure society's successful transition into the future[1]. As such, engineering educators must help students develop skills and competencies to be innovative. Unfortunately, recent studies have shown that engineering students nearing graduation are less innovative than their first-year counterparts, often becoming fixated on existing solutions rather than considering non-traditional alternatives[2].

While minors, courses, and certificates in creativity and innovation are offered at some universities with engineering colleges, these programs are in their infancy. More must be known about student creativity and innovative capacity, especially the innovative qualities of beginning engineering students, so that instructors can better help students develop and/or maintain creativity and innovativeness throughout college and into their careers. In this study, we describe qualities that are essential to innovative design and determine which of these qualities first-year engineering students emphasize in their design ideas.

Model of Innovation

Innovation is often listed synonymously with creativity[3], with common definitions of both suggesting elements of novelty and usefulness[4, 5, 6]. While some distinguish the two by describing innovation as the output of creativity (e.g., Ferrari and colleagues[3]), this distinction alone is insufficient. Novelty and usefulness are essential components of innovation solutions—an innovative solution must in some way differ from existing solutions and must also solve a problem or fulfill a purpose—but these criteria alone do not define innovation. Although ideas can have innovative qualities, innovation is best defined as a process that extends from design to implementation. Hence, in addition to novelty and usefulness, innovative solutions must be able to overcome technological, economic, and entrepreneurial hurdles.

Ford and colleagues[7] describe innovation as a four-stage process consisting of *invention*, *trial production*, *commercial production*, and *diffusion*. During *invention*, an initial idea or a need is recognized. Viable ideas transition to *trial production*, during which prototypes are developed and tested for technical and economic feasibility. Designs that are likely to be commercially viable and desirable to potential users enter *commercial production*, which includes improvement on the trial production and its commercial use. The fourth stage, *diffusion*, captures dissemination and adoption nationally and internationally[8]. Here, products, systems, and processes must remain desirable, useful, and economically viable in order to remain in use and/or production. If an idea stalls any of the four stages, it cannot be considered innovative since it will never reach a necessary level of diffusion. Based upon this definition of innovation, and the hurdles ideas may face on the journey towards diffusion, Table 1 describes five qualities ideas must possess to be considered innovative.

Table 1. Qualities of Innovative Designs

Quality	Description	Importance to Innovation
Feasibility	How easily a product or system can be implemented	If a design is not feasible technologically, physically, or financially, it will never be implemented.
Viability	How easily a product or system can be maintained or sustained	The design outcome must remain economically, physically, and morally viable in order to remain in use and/or production/service.
Usefulness	How well the product or system satisfies a given design problem	The design must satisfy some unfulfilled need; otherwise its development would not continue beyond the early design stages.
Desirability	How well a product or system will be accepted by consumers/users	If intended users do not find the design outcome desirable, they will not use it and it will not achieve widespread adoption necessary to be considered innovative.
Novelty	How different a product or system is from current solutions	The design must differ from existing solutions; otherwise it would not contribute to the innovation process.

Novelty, however, should not be undervalued, as it is critical to innovation[4,5]. In this study, for example, the library is assumed to utilize incandescent light bulbs. Replacing these bulbs with more efficient LED bulbs, a commonly suggested energy-saving tip[10], is feasible (LED bulbs exist), viable (LEDs last longer than incandescent bulbs and are more likely to be available in the future[11]), useful (LED bulbs use about 80% less energy than incandescent bulbs[11]), and is at least as desirable as the current incandescent lighting system. Because this solution is common, it is not novel and would not be considered innovative by many.

Like creativity and innovative, there is no consistent definition of novelty in the literature. Some view novelty in a historical context[6], i.e. a design is novel only if it is unlike all existing designs. To satisfy this criterion for novelty, a design must solve a problem that has never been solved in any context, such as one the engineering grand challenges. Others define novelty as local, i.e. a design is novel if it is new to an organization or field[4].

We view novelty as a combination of these historical and local definitions. Designs that are borrowed or adapted from other areas may be novel, but less so than ideas that radically differ from all existing designs. We recognize that as ideas move through the innovation process, they become less novel. The telephone, for example, revolutionized the way people communicate and is often considered one of the most innovative products of the last 200 years. When the telephone was invented, it had a high degree of novelty. As it moved towards *imitation* and *diffusion*, it became sufficiently common that the idea of talking to someone miles away was no longer all that surprising. In essence, the innovation was already in place. Novelty, thus might be the entry point to the innovation process. Only sufficiently novel ideas will enter the *invention* stage and progress towards *diffusion*. Innovation, then, lies in the balancing novelty with feasibility, viability, usefulness, and desirability.

Research Methods

Setting and Participants

The participants in this study were 73 first-year engineering students (65 male, 8 female) enrolled in a single section of a first-year engineering course at a large Midwestern university. In the course, taught during the spring 2011 semester, students were introduced to engineering professions, engineering design, problem-solving, teamwork, and other engineering fundamentals. The students were grouped into 19 teams of three or four, within which they had worked on course projects and in-class activities for approximately three months. Though innovation was only a secondary learning objective of the course, students were introduced to innovative designs throughout the semester and presented with a definition of innovation containing elements of technical feasibility, economic viability, and desirability[12].

Data Collection

As part of a course exam, students participated in an individual idea generation task (IRB protocol 1106010967). During the previous portion of the exam, they had, in teams, explored the cost, energy savings, and carbon dioxide emission reductions of high-cost energy-saving options such as solar panel arrays and green roofs. For the current task, students were given ten minutes to list inexpensive energy-reduction strategies for a fictional local library, and select and explain their most innovative solution. The main design criteria were energy savings and affordability for the library, thus the problem was positioned as client-driven and economic. The prompt, however, neither encouraged nor discouraged students from considering other stakeholders such as library staff and patrons or proponents of sustainable energy solutions. The individual student output consisted of a handwritten exam sheet, which was later transcribed onto an electronic spreadsheet, with space for ten solutions and an explanation of the most innovative solution they considered.

Since students had prior experience analyzing high-cost energy reduction strategies for a similar library, they were familiar with the energy usage and function of the library and had experience examining a similar design problem. We expected that they would be able to describe reasonable solutions to the new problem, even within the short amount of time. Though prior research suggests that students become fixated on previous solutions when they are presented before an idea generation task[13], we found only three solutions that incorporated solar panels and none that incorporated green roofs among the 72 student-selected solutions.

Though this activity was part of a course exam, and we have used the results to examine student innovativeness, students were only graded based on the number of ideas listed (at least five for a perfect score) and the quality of their explanation of their chosen idea's innovativeness. As such, we do not expect concerns over grade to have influenced the qualitative aspects of student answers. Further, because innovation was described in class as a topic open to interpretation, we do not expect students to hold a uniform view of innovation. Preliminary analysis of students' explanations confirms that students did not conform to one definition of innovation and did not necessarily intend their responses to favor only the business aspects of the design problem.

Data Analysis

Though students listed up to ten possible solutions, we considered only the solutions students selected as most innovative. In part, we did this because some students selected a combination of complementary individual solutions as a best solution; thus no individual solution would reflect the student's overall choice. We also did this because students were encouraged in class to not filter their ideas during the idea generation process; thus all ideas listed may not be ones students would have selected as reasonable solutions given time to reflect. Further, without the accompanying descriptions, we were unable to guarantee reliable assessment of each design's innovative qualities.

There were a total of 72 solutions (we discarded one solution due to lack of clarity), each of which was scored on a 1-5 integer scale (5 the highest possible score) for each of the five characteristics of innovative ideas: feasibility, viability, usefulness, desirability, and novelty. While metrics exist for feasibility[2], usefulness[6,9], and novelty[2,6,9], we selected a holistic, categorical method. This approach offered greater flexibility (i.e. we were able to match the assessment to fit the context of the problem), and has been demonstrated to allow acceptable levels of inter-rater reliability among both domain experts and novices when assessing creativity and related constructs[14,15].

One of the authors began by scoring each of the solutions for feasibility, viability, usefulness, and desirability (novelty was originally excluded from consideration). After two rounds of scoring, each time describing and clarifying how scoring decisions were made, the scoring author developed a detailed scoring rubric for each of the four categories. Using this rubric, the original scoring author and another author rescored the set of ideas independently. We checked inter-rater reliability by comparing the correlation (Spearman's rho) between the authors' scores. The correlations were statistically significant ($\alpha = .05$) for all categories but *usefulness*.

We attributed this discrepancy to two factors. First, usefulness (determined solely by energy cost savings) was difficult to assess based on the limited details students provided for certain solutions. For example, one student suggested a small-scale solar panel array, but did not list the type or power output of the solar panels that would be used. Second, the authors initially disagreed on the energy savings generated by replacing all incandescent lights in the library with LED or CFL bulbs, the second most popular student idea. After comparing calculations and evidence[11], the authors agreed that this solution should receive a 3 for usefulness. Together, the two scoring authors created a slightly modified scoring rubric (presented in Table 2). We used this rubric to complete a final round of scoring. We then re-calculated Spearman's rho between the two authors' scores for feasibility ($\rho = .787$, $p < .001$), viability ($\rho = .614$, $p < .001$), usefulness ($\rho = .551$, $p < .001$), desirability ($\rho = .247$, $p = .036$), and novelty ($\rho = .516$, $p < .001$). All were statistically significant ($\alpha = .05$), indicating acceptable levels of inter-rater reliability. Each solution's final score in each category was the average of the two authors' scores.

Table 2. Final Scoring Guidelines

Score	Feasibility	Viability	Usefulness	Desirability	Novelty
1	Technology or resources don't exist, solution exceeds budget, and/or massive structural overhaul would be needed	Cannot be sustained due to high operation cost, insufficient resource supply, physical instability	Would not reduce the energy consumption or creates new problems	Staff/patrons will rebel against solution (poor aesthetics, disrupts use of the library	Solution is already in place at the library
2	Can be done only with significant renovation and cost near budget	System requires great care and cost to maintain, resources are scarce	Creates no new problems, but offers little energy cost savings (less than 5%)	Staff and patrons will dislike the solution	Solution is considered among common energy-saving solutions[10]
3	Can be done with potentially disruptive structural changes, moderate cost, and available resources	System requires moderate care and cost to maintain, resources are readily available	Creates no new problems and offers moderate energy cost savings (5-20%)	Staff and patrons will be neutral towards the solution	Solution exists but is rarely considered among common energy-saving solutions
4	Can be done with minor structural changes, little cost, and available resources	System is physically robust, resources are available, and maintenance cost is nominal	Creates no new problems and offers substantial energy cost savings (more than 20%)	Solution will enhance the lives of staff and patrons	Solution is a unique intersection of existing solutions
5	Can be done with no structural changes, little cost, and available resources	System is physically robust, resources are abundant, and maintenance cost is no more than existing system	Eliminates library's reliance on energy providers	New patrons and potential staff members will be drawn to the library because of the solution	Solution is completely new to the situation

In addition to individual quality scores, we calculated an overall innovation score, which was the fifth root of the product of each category score. This method retained the 1-5 scale and rewarded consistent ideas (e.g. an idea that scored all 3's is more innovative than an idea that scored two 1's and two 5's). Once scoring was complete, we calculated the mean (out of five) and standard deviation in each category and for overall innovativeness.

Results

Students identified 26 unique solutions to the design problem. Among these, automatic lighting, energy-efficient lighting, and renewable energy devices (including solar panels, piezo-electric flooring, windmills, and river turbines) were the most common solutions. Overall, 60 of the 72 solutions (80%) relied on techniques commonly suggested in energy-saving tip books[10]. The most unexpected solution was a hybrid solution in which the student proposed to reduce the building size, heat via fireplaces, cool with fans only, and increase wall insulation. Figure 1 displays the frequency of each suggested solution.

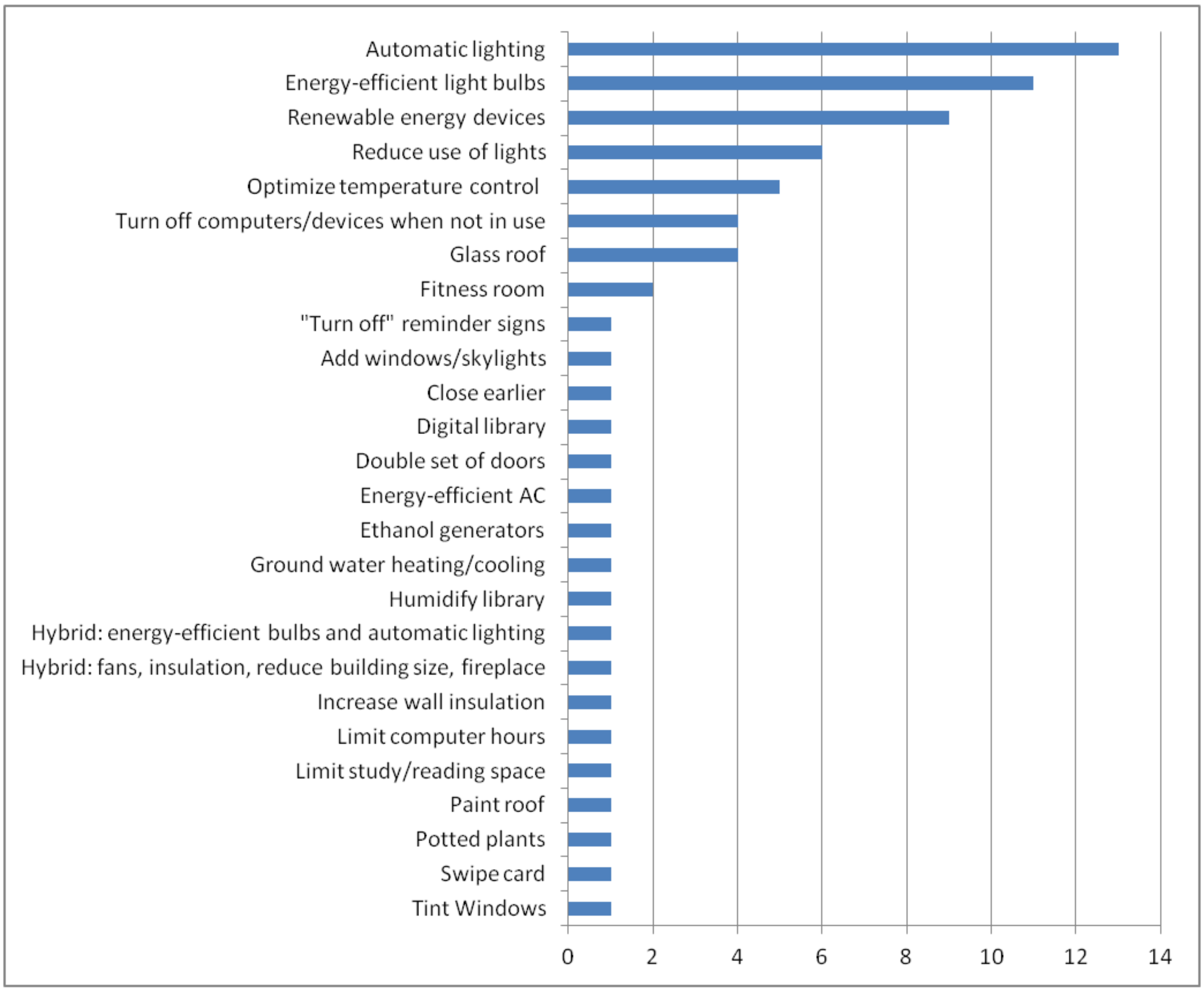

Figure 1. Frequencies of solution types

In Table 3, we present the mean feasibility, viability, usefulness, desirability, novelty, and overall innovativeness scores for each of the 72 student solutions. In Figure 2, we present the proportion of solutions at *poor* (1 or 1.5), *marginal* (2 or 2.5), *acceptable* (3 or 3.5), *very good* (4 or 4.5), and *superior* (5) levels in each of the five categories and overall. The *acceptable* level represents the minimum quality in each category for a solution to be considered innovative. No solutions achieved *acceptable* scores for all five qualities of innovative design.

Table 3. Student Solution Scores on Qualities of Innovative Designs

Quality	Mean (SD)	≥ 3 (Acceptable)	≥ 4 (Very Good)
Feasibility	3.62 (1.05)	53 (74%)	46 (64%)
Sustainability	4.20 (0.70)	71 (99%)	57 (79%)
Usefulness	2.65 (0.59)	36 (50%)	4 (5.6%)
Desirability	2.88 (0.53)	57 (79%)	3 (4.2%)
Novelty	2.35 (0.59)	12 (17%)	1 (1.4%)
Innovativeness	2.99 (0.28)	43 (60%)	0 (0%)

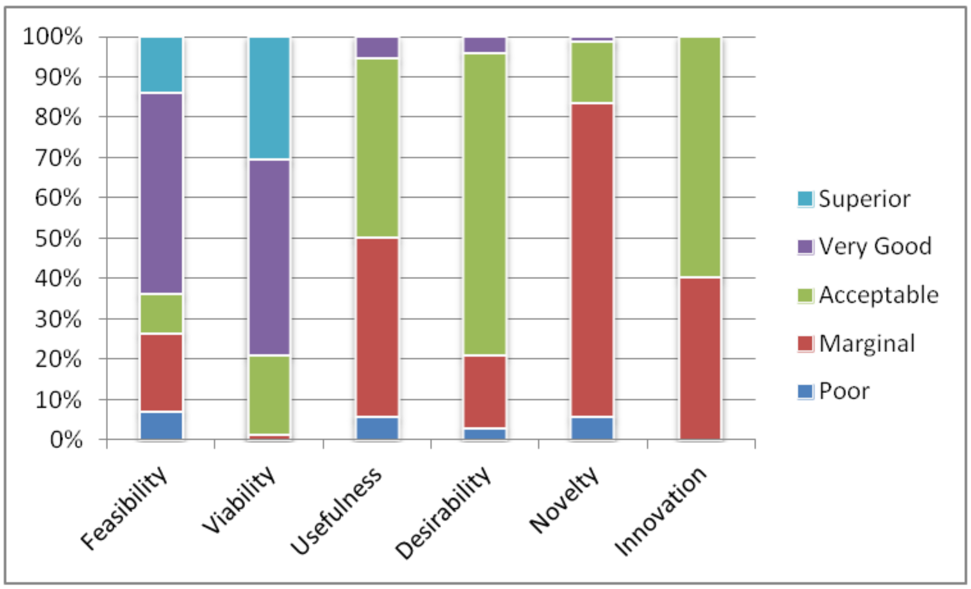

Figure 2. Proportions of student solutions at each of five levels of innovative quality

Discussion

Out of the five qualities of innovative design, students scored the highest on *viability*. The average score was above the very good level and 74% of students' suggested solutions achieved this level. Additionally, students scored strongly in *feasibility*. Results were not as promising for the other three qualities. Among these, students averaged scores below the acceptable level and collectively represented only eight solutions at the very good level. Further, overall innovativeness was slightly below the acceptable level.

Unlike the results of previous studies, these results indicate that first-year students do not derive innovative solutions to design problems. While 60% of students designed solutions at an acceptable level of innovativeness, no scores were at the very good level. All of the solutions fell below *acceptable* on some quality of innovative design, indicating that their solutions would fail to overcome some hurdle during one of the four stages of the innovation process. It is unclear whether the poor scoring in *usefulness* and *desirability* was more a product of innate lack of consideration for users by first-year students, or a product of the design problem, which was focused on the client (the library) more so than other stakeholders. If the problem had been presented as a human-centered problem, the results may have differed.

Unlike previous researchers, we did not find high novelty. There were unique and unexpected solutions, but these were few (20%) and tended to score poorly on the other categories. For example, the average innovativeness was only 2.86 for solutions that scored at least 3 on *novelty*. Further, the highest scoring idea (3.24), replacing current light bulbs with energy-efficient LED or CFL bulbs, was only marginally novel.

Conclusions and Future Work

Among the solutions we analyzed, students tended to favor the business-related or practical aspects (feasibility and viability) over the outcome aspects (usefulness and desirability) and novelty. These results contrast prior research results[2] and are contrary to what one might think, as first-year engineering students are unlikely to have thought much about business and technical aspects of engineering. Prior studies observed that more senior students demonstrate these concerns more readily than first-year students and create less novel designs[2], suggesting that students trade concerns over imagination and uniqueness for business and technical requirements over the course of their undergraduate education. Further, these first-year engineering students describe mostly common ideas rather than the novel or imaginative solutions that were expected. Due to the lack of clarity and elaboration in many of the ideas students identified but did not select, we were unable to investigate whether the solutions students selected as innovative were actually their most innovative solutions.

Since the results of this study differ from previous work, more studies of engineering student idea generation and design are needed to determine how problem type (e.g. user-centered, business-oriented) and setting (design project, in-class activity) may affect design outcomes. If first-year students do tend to focus more on business and technical aspects of design, as the results of this study imply, future studies should explore how to develop innovative skills in engineering students, particularly consideration of desirability for users and usefulness, as well as how to develop novel ideas that also satisfy design requirements.

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