122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #11146

Incorporating a Graduate Research Activity in an Undergraduate Vibrations Course Design Project

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Abstract

A standard component in our junior-level vibrations course is a design project. This project is generally an extended homework assignment where student teams are given a somewhat partially-defined or open-ended problem to analyze, with the outcome of providing specific design recommendations appropriate to the nature of the problem assigned. Many times, these design problems are chosen from those provided in some undergraduate textbooks. This paper, however, describes an experiment in which the design problem given to the students is based on a sponsored research project conducted by the faculty member and his graduate students. The research project involved the development of acoustic velocity sensors to replace pressure-measuring hydrophones in a submarine sonar system. As a starting point for the design project, the undergraduates are given the results of an advanced analytical model that predicts the ideal behavior of the velocity sensors operating in water. Based on these model results, the students were then given two tasks: 1) define the necessary characteristics of a sensor mounting system that would allow the sensor to function as desired; and 2) design a suspension system that would allow for the necessary mounting behavior, and provide the physical interface between the replacement sensors and the existing sensor support system. The actual physical dimensions and weights of the various system components were given to the students as constraints in their design development. The educational goal of this effort was to engage students in a challenging and timely project that combines vibration analysis along with creative design opportunities.

In addition to the normal grading of the students' reports, a specially designed assessment tool was implemented to gauge the students' reaction to the use of this kind of design project. Specific topics of interest include: 1) is this kind of project perceived to be more relevant (real-world vs. 'academic'); 2) to what extent does the research-based element affect the students' perceptions and opinions about the value of the project; and 3) does this kind of project contribute to the students' desire to be engaged in undergraduate research?

Introduction

It is common practice to incorporate so-called design projects in undergraduate engineering courses. These are not the 1- or 2-semester long senior capstone design projects found in most curricula, but rather these are typically extended homework assignments intended to engage students in problem definition and open-ended solution discovery. They are also intended to serve as 'platforms' for the relevant material in the course itself. Indeed, these types of activities are part of the ABET EAC Criteria 3 and 5[1], and the projects are found in many sophomore- and junior-level engineering courses.

Inclusion of such a design project in our junior-level vibrations course has been the norm for many years. The duration of the project is on the order of one month, and typically carries the same percentage (e.g. 10%) of the total course grade as the entire set of homework assignments. Students are formed into 2- or 3-person teams to work collaboratively on these design projects.

This vibrations course is taught by a variety of faculty members, and the specific nature and details of the design project used in the course have varied accordingly depending on the instructor. Oftentimes, the idea for the design project comes from the textbook or other course materials. There are many excellent projects available from these sources that do provide the intended experience for the students.

At the same time, there has been a growing emphasis on sharing research experiences with undergraduate engineering students, and engaging them directly in the research programs associated with the faculty. There are numerous papers that have examined the benefits of engaging undergraduates in research, and there is generally widespread agreement about the positives effects such as increased retention and graduation rates[2,3]. Perhaps the most common way of engaging undergraduate students in research has been through the use of formal undergraduate research (UGR) experiences. Indeed, these are widely available in many disciplines, including engineering, and they receive significant financial support from most federal funding sources, notably the National Science Foundation, as well as from individual campuses. Given the well-known positive impacts on students arising from participation in these formal UGR programs, the author was interested to explore the extent to which faculty-based graduate research activities could be leveraged to expand the research-like experiences of undergraduate engineering students.

Research Project

A sponsored research project recently conducted by the author was chosen to be used in the course-based undergraduate design project. The goal of the research project was to assess the feasibility of replacing acoustic pressure-measuring hydrophones with acoustic velocity vector sensors in undersea surveillance systems. The reason for this proposed change was to increase the ability to detect and localize acoustic sources such as other marine vessels (both on the surface and submerged). An underwater hydrophone, like an in-air microphone, detects acoustic pressure, which is a scalar quantity. Therefore a single hydrophone is unable to estimate the direction to the acoustic source. On the other hand, an acoustic velocity vector sensor is able to directly measure both the presence, and the actual direction of travel, of an acoustic wave. Thus, the project involved a timely and useful system-level development in order to provide a better estimate of the direction to the acoustic source.

The project, as presented to the undergraduate students, consisted of two tasks. The exact wording presented to the students is shown below in italics:

***Task 1*: Mount Requirements for Velocity Sensor**

In order to function as intended, the velocity sensor must be able to move as a rigid body while supported by its mounts. The mounts, in turn, are attached to a bracket which is rigidly affixed to a supporting structure. Therefore, a baseline analysis should be performed in which the velocity sensor is treated as a lumped mass (m_{eq}*) while its mounting is treated as an equivalent stiffness (*k_{eq}*) and an equivalent viscous damper (*c_{eq}*). Such a model is shown below in Figure 1 where* Vs *is the rigid body velocity of the velocity sensor and* Vo *is the acoustic velocity associated with the pressure wave in the water.*

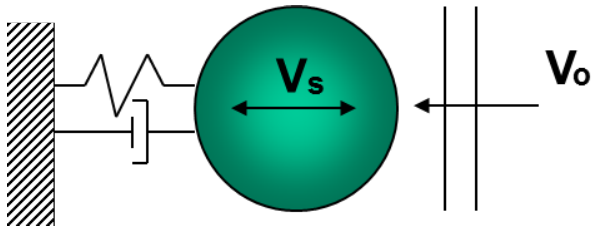


Figure 1. Schematic Diagram of Mounted Velocity Sensor

A theoretical analysis[4] of this model was performed and leads to the following result for the ratio of the sensor velocity to the actual acoustic particle velocity of the pressure wave:

$$\frac{V_s}{V_0} = \frac{3}{1 + 2\frac{\rho_s}{\rho_0}\left[1 - \left(\frac{\omega_s}{\omega}\right)^2 + 2i\zeta\frac{\omega_s}{\omega}\right]}$$

where:

ρ_S *is the density of the acoustic velocity sensor;* ρ_o *is the density of sea water;*
ω_S *is the mounted sensor natural frequency,* $\omega_s = \sqrt{k_{eq}/m_{eq}}$*;* ω *is the circular frequency of the signal to be detected,* $(\omega = 2\pi f,\ 100Hz \le f \le 2{,}000Hz)$*; and* ζ *is the damping ratio of the sensor mount.*

Goal of Task 1: Provide recommendations for the mounted natural frequency and the mounting damping ratio in order to allow optimum velocity sensor function.

Task 1 represents a relatively straightforward application of engineering vibration analysis. Ideally, the velocity measured by the sensor, V_s, should be the same as the acoustic particle velocity of the incoming wave, V_o. For purposes of this project, the students were asked to only consider the magnitude of the velocity ratio and not to worry about the phase response. That is, only the magnitude of the complex-valued velocity ratio shown above was of interest.

The necessary details associated with examining this velocity ratio as a function of frequency were reviewed in class so that the students could confidently determine the correct dependence on frequency. Given this information, they could then consider the analysis in a global, design context in order to determine critical design criteria for the sensor mounting system. The desired outcome of this analysis was the realization that acceptable system behavior required the mounted natural frequency of the velocity sensor to be less than approximately one-third of the lowest signal frequency of interest. The graph of the magnitude of the velocity ratio vs. frequency ratio is shown in Figure 2.

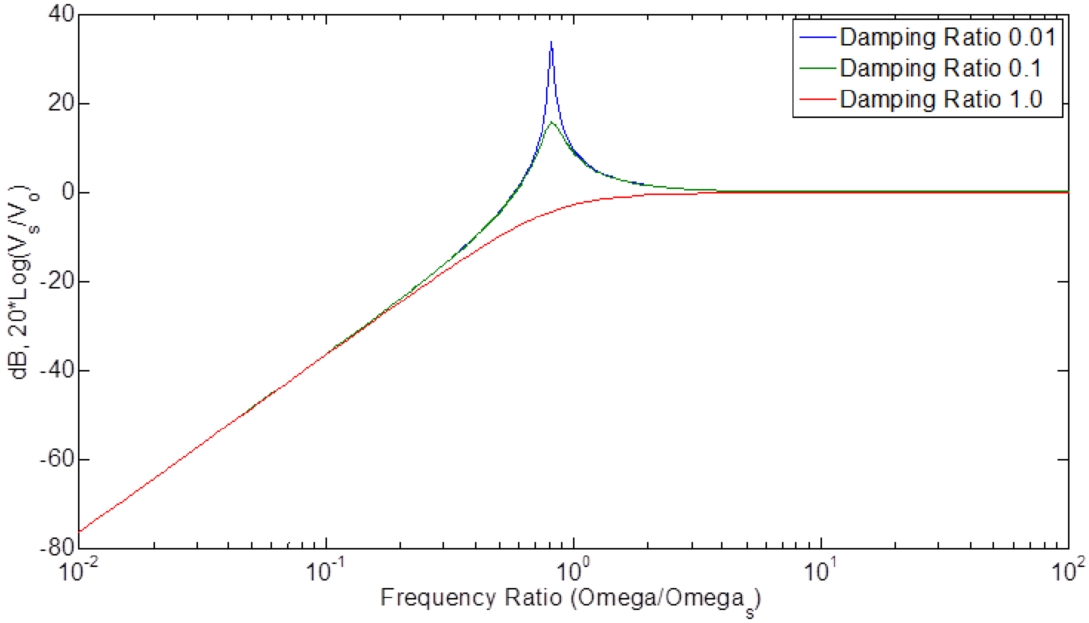


Figure 2. Velocity Ratio vs. Frequency Ratio

<u>Task 2</u>: Preliminary Design for the Sensor Mounts

Having determined a recommendation in Task 1 for the mounted natural frequency of the sensor, Task 2 asks you to develop a preliminary design for the suspension system that will achieve the desired value of mounting stiffness (it is not necessary to consider damping in this preliminary design).

As shown in the Figure 3 below, the original hydrophone and the prototype replacement sensor are cylindrical bodies with smaller cylindrical mounting lugs on each end. The suspension system to be designed must attach to (or be an integral part of) a modified hydrophone mount and support the sensor via the cylindrical mounting lugs. A photo showing the original hydrophone in the existing mounts is also shown below in Figure 4. The diameter of the circular mounting lugs on the replacement sensor is 0.5 inches, and their length is 0.75 inches. The weight of the replacement sensor is 2.0 lbs.

Goal of Task 2: Develop a preliminary design for a sensor suspension system that will fit within the 2-inch diameter circular cutout in the hydrophone mount and provide the necessary stiffness for desired sensor operation.

Task 2 was much more open-ended and presented the opportunity for creativity. In this task the students were asked to recommend a preliminary design for a suspension system that would provide the necessary mounting stiffness, and to allow the sensor to be physically accommodated. In this preliminary or conceptual design, detailed drawings were not required, but rather just a concept for mounting the sensor with enough supporting analysis to validate the basic idea. This was done in order to keep the scope of the design project within prescribed bounds considering it to be but one component of the semester long course.

To provide more detail, the original hydrophone mounts are identified in Figure 3. The mounts consist of rubber-coated flat plates with a circular cutout. Within the circular cutout region there are four elastomeric fingers, or tabs. These tabs are the physical interface between the mounting lugs on the ends of the original cylindrical hydrophones and the hydrophone mounts. In the original design, the role of these lugs was simply to hold the hydrophone in place while providing for the ability to insert and remove the hydrophone without dismantling the mounting plates.

In order to accommodate the function of the new velocity sensors, these lugs had to be replaced with a new design that would allow for physical motion of the velocity sensor body while at the same time keeping it supported by the mounts and still provide for the ability to mount/dismount the sensor. This is a much more difficult task than that required in the original system, and the conceptualization of a possible design was the goal of Task 2. The potential solutions that were identified included variations on the original design utilizing relatively flexible tabs for holding the velocity sensor while providing the required longitudinal compliance of the tabs. Others included the use of curved spring strips, similar to leaf springs, within the circular cutout region. In all cases, it was sufficient to present the overall design concept, along with enough details regarding material and dimensions to validate the idea.

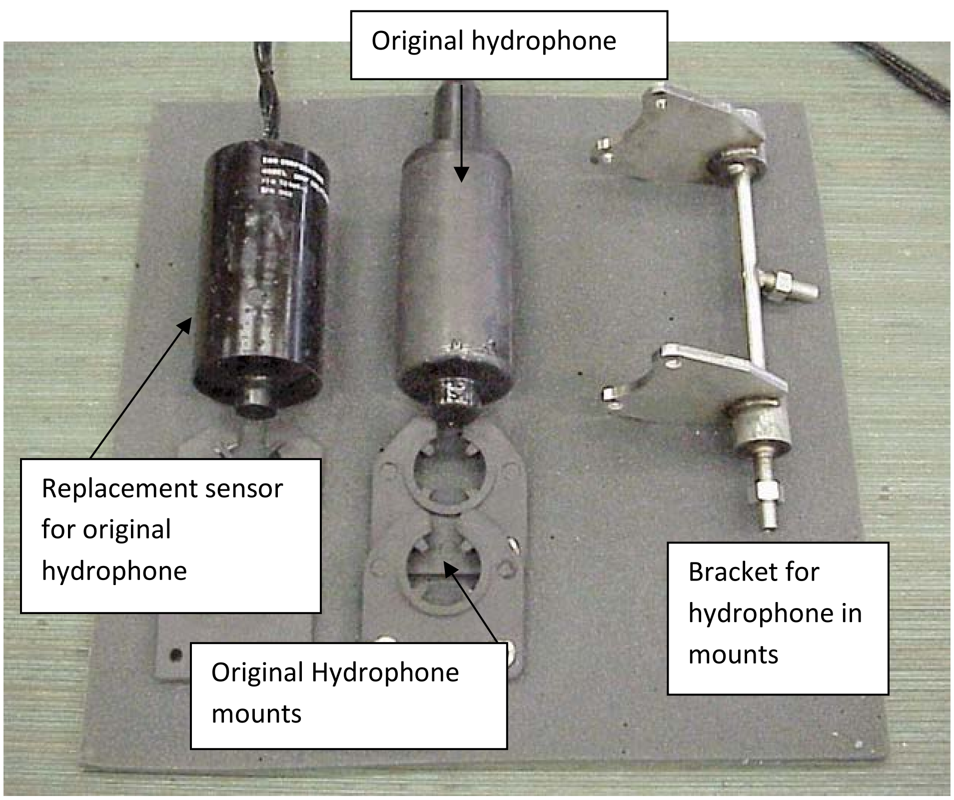


Figure 3. Details of Velocity Sensor and its Mounting System

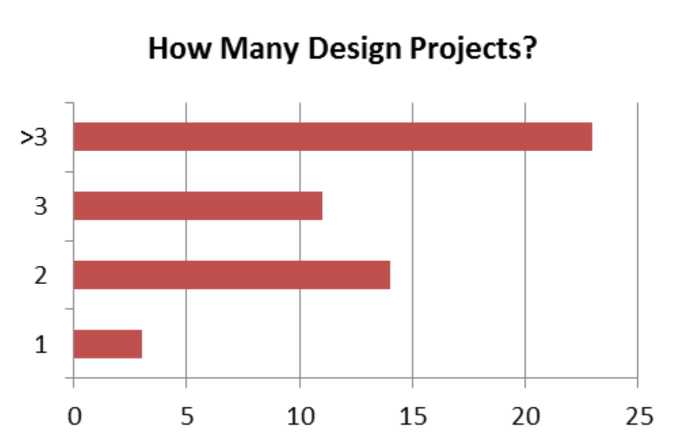
Figure 4. Original Hydrophone in Existing Mounts

Assessment

The following questionnaire, consisting of 4 questions, was administered to the students after the completion of the design project. The response details (the number of students responding to each choice) are presented after each question, along with a brief discussion. A total of 51 students responded to the questionnaire. Overall discussion and summary comments are made in the Conclusions section following the assessment results.

1 – Including this design project, how many design projects have you had in all of your engineering courses?

A) 1
B) 2
C) 3
D) More than 3

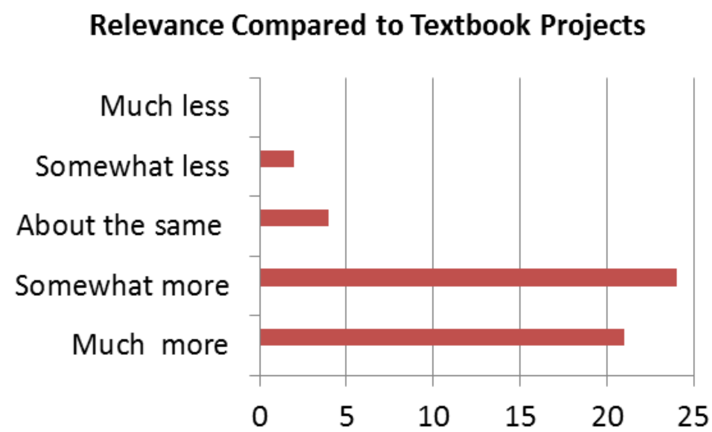


This data shows that nearly all of the students (94%) had at least one previous experience with a design project in their coursework, and 34 (67%) students had experience with at least 2 previous design projects.

2 - This design project was developed from a real-world graduate research activity rather than from a textbook-based assignment. As such, what is your overall perception of this project as compared to textbook-based assignments in the following ways:

2a – Relevance of this project to you compared to textbook-based assignments:

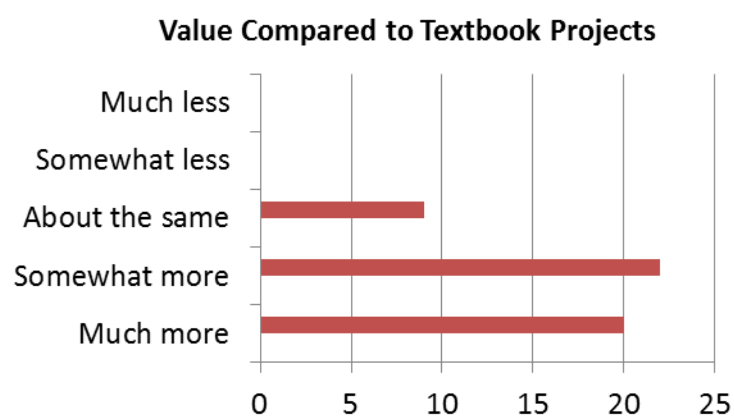
A) Much more relevant
B) Somewhat more relevant
C) About the same relevance
D) Somewhat less relevant
E) Much less relevant



The students expressed the overwhelming opinion that the design problem based on a research project was either somewhat more (24 responses, 47% of all) or much more (21 responses, or 41% of all) relevant than design problems based on textbook problems. While this was a gratifying response, it should perhaps not be too surprising. The very idea of basing an activity on a recent project or situation has the attribute of being a 'current event' as compared to most textbook material. In addition, the fact that the research project was an externally funded activity means that it was a real-world topic and therefore of some practical importance.

2b – Value of this project to you compared to textbook-based assignments:

A) Much more valuable
B) Somewhat more valuable
C) About the same value
D) Somewhat less valuable
E) Much less valuable

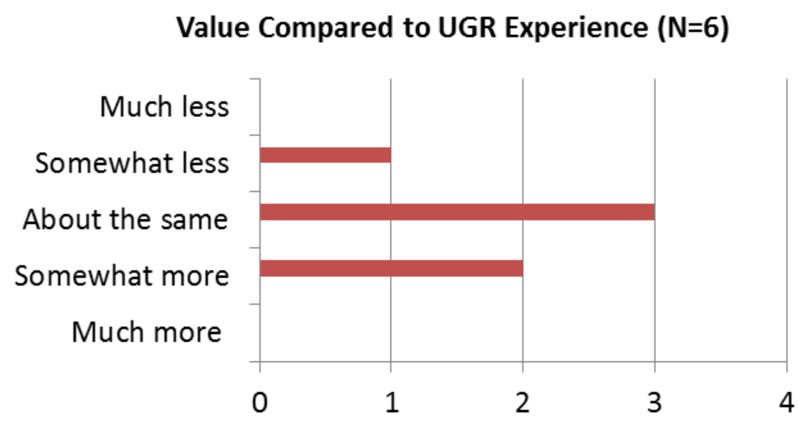


The students again expressed the overwhelming opinion that the design problem based on a research project was either somewhat more (22 responses, 43% of all) or much more (20 responses, or 39% of all) valuable to them than design problems based on textbook problems. This, too, was a gratifying response. The author interprets this response to indicate that the students felt that this research-based design problem, and the knowledge they gained from working on it, provided them with knowledge and skills that enhanced their individual preparation and competiveness for an engineering career.

3 - Undergraduate research experiences are popular among engineering students. Have you participated in a formal undergraduate research experience?

3a – If ‘Yes’, then how would you compare this design project to your research experience? This design project:

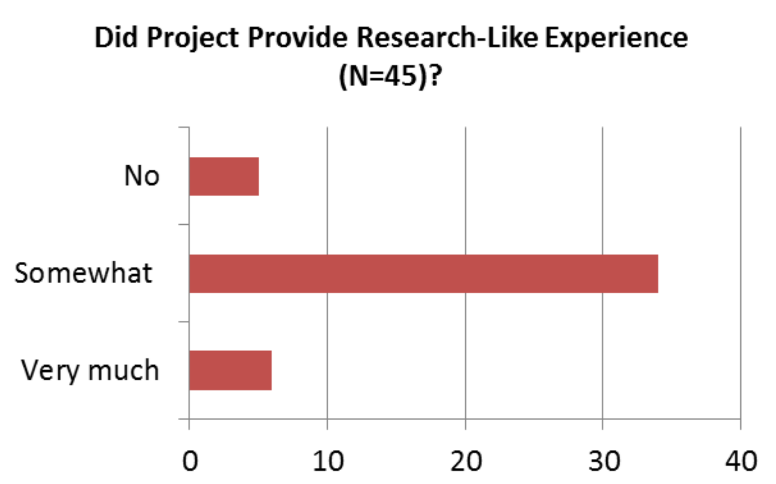
A) Was much more valuable
B) Was somewhat more valuable
C) Had about the same value
D) Was somewhat less valuable
E) Was much less valuable



Only 6 students, 12% of the total, reported having participated in a formal undergraduate research (UGR) experience prior to this course. These students felt, on average, that the value of the research-based design project was about the same as the UGR experience. Although this is a small sample size, it is interesting that no one felt that the design experience was much more, or much less, valuable than the UGR experience.

3b – If ‘No’, then to what extent did this design project provide a research-like experience for you?

A) Very research-like
B) Somewhat research-like
C) Did not provide a research-like experience



The majority of the students in the course, 45 or 88% of the total, reported never having had a formal UGR experience. Even so, they were asked to judge to what extent the research-based design project provided them with a ‘research-like’ experience. Not too surprisingly, since there was not a direct UGR experience for comparison, most students said that the design project afforded somewhat of a research experience. Relatively few, and in nearly equal numbers, expressed that the design project experience was either very research-like, or not research-like.

4 - Please provide any written comments regarding this design project experience:

84% of the students provided some written comments regarding the design project experience. The comments spanned the range from positive to negative, although the overwhelming sense was one of satisfaction with the project. Some of the negative comments were associated with missing information or details in the project, lack of satisfactory direction, or the fact that there was no opportunity to build and test their designs. Most of the positive comments liked the application of the course material to real-world problems, and the fact that they were able to work on something that appeared to be a current and important problem. Many students stated that the experience gained from this kind of design project was important in 'expanding' their overall education and represented a true added value to their formal coursework.

Conclusions

The goal of this paper was to assess the students' reactions to, and their opinions about, an undergraduate design project that was developed from a recent sponsored graduate research activity. Since 94% of the responding students had previous experience with at least one course-based design project prior to the research-based design project, the data gathered from this assessment was judged to be valid.

Students were first asked about their perception of the relevance and the value of the research-based design project as compared to textbook-based design projects. These results were overwhelmingly positive: 88% of the students judged the research-based project to be more relevant to them, and 82% of the students judged the research-based project to be of greater value to them. Only 4% of the students stated that the research-based project was of less relevance to them, while there were no statements of perceived less value as compared to textbook-based projects. These are important results and show that bringing graduate research activities into undergraduate classrooms via design projects can be an effective way to positively impact the experiences of undergraduate students. This certainly does not take anything away from other methods of leveraging graduate research, but it perhaps points to an additional way in which faulty research can add value and relevance to the undergraduate experience.

Along these lines, it was of interest to see to what extent the research-based design project experience would provide an impact similar to the traditional undergraduate research (UGR) experience. Unfortunately, only 12% of the students had participated in a formal UGR experience prior to this course, so it would be difficult to draw too much from the results. Nevertheless, when asked about the perceived value of the research-based design project compared to the UGR experience, most students responding felt that the experiences were generally of the same value to them. Perhaps of greater interest was the absence of any expressed opinion indicating that the design experience was either of much greater or of much less value. On balance, the author is very pleased with this result, and it provides an indication that the use of research-based design projects can deliver some of the same positive experiences to students as the traditional UGR programs. In addition, the use of research-based design projects in undergraduate courses can have an impact on many more students than possible through formal UGR programs.

Lastly, the students who had not had a formal UGR experience were asked to judge to what extent the research-based design experience afforded them a 'research-like' experience. Even though they did not have a direct experience for comparison, 88% of the students in this group expressed the opinion that the design project did provide some positive research-like experience. Perhaps one of the most important aspects of this result is the indication that the students felt that there was value in research, and that they saw graduate research as having a positive effect on their undergraduate experience.

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