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Making a First-year Impression: Engineering Projects That Affect and Connect

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Introduction

After years of having passed through multiple assessments, iterations, and updates of the core General Engineering courses in the first-year program at Northeastern University (NU), several engineering professors wondered the following, "With our engineering courses so full of activities, topics, and projects, how can we identify which of those elements have the greatest impact on our students?" It was time for a more detailed reflection on all that had been put in place in the first-year courses in order to identify which pieces are most effective in influencing, inspiring, and/or guiding our students into their particular pathways of engineering.

At NU, the first-year engineering curriculum is fundamentally common for all majors and students take an Engineering Design course and a Problem Solving and Computation course in a two-semester sequence. There is pressure for these two introductory engineering courses to accomplish a myriad of things alongside content delivery, such as prepare students for the demands of college, expose them to the engineering majors, provide relevant hands-on and real-world projects, develop algorithmic and critical thinking skills, and get them excited about their engineering career path. There are a number and variety of projects accomplished by the students that are designed to meet these multiple objectives and goals. In order to investigate the impacts of these projects, students were surveyed at the end of their first year in engineering. In addition to documenting their major –or undeclared status– key elements of the survey asked students to identify which projects and activities had the most impact on their *decision to continue* in engineering, which had the most influence on their *choice of major*, and which had served to *connect them* most closely to a major, or to engineering in general.

Cornerstone Course Foundation. The purpose of this research is to show how to use these reflections to guide course and curriculum development in an intentional and efficient way. Many universities have been introducing *cornerstone* design courses, using hands-on projects, looking for real-world challenges and problems to meet the many objectives named above. These reflections were deliberately gathered at the end of the first year, as students are deciding on majors, and have the projects most fresh in their minds as influencing their decision. In developing their version of a cornerstone course at McMaster University, it was noted, "The objective of the Cornerstone is to instill in first-year engineers enjoyment from learning, motivation to continue learning, and genuine intellectual curiosity about the engineering in the world around them." [1] And, from the Royal Institute of Technology in Sweden, "The purpose of cornerstone projects is to introduce the students to their future professional role as design engineers," and "The primary aim is to teach design methodology and to enable the students to practice and improve teamwork skills.[2]

Similarly the CoRe Experience at Michigan State begins with the partnership of a Design Course and a Programming/Modelling course and states, "The courses introduce students to the team design process and analytical tools used in the engineering profession," noting, "Especially for the design course, the projects are open-ended and completed by interdisciplinary teams, leading to creative, divergent solutions to engineering problems." [3] Finally in advocating creative project-based course elements for new engineering students, Haungs, Clements and Janzen (2008) state, "Cornerstone courses involve creating an interesting problem, possibly in an unfamiliar field, working and managing student teams, and assessing individual and team contributions while accommodating the skill level of incoming freshmen."[4]

Finally, at the University of Wisconsin-Madison, the challenge of cornerstone course design is discussed very thoroughly.[5] These courses are charged with providing insight into professional practice, learning the engineering design process along with many of the basic college skills previously mentioned. Add to that the retention of students in engineering, helping them make an informed major choice and keeping in mind gender inequities and diversity. "Few cornerstone courses can meet all of these demands with rotating course directors, minimal resources and students with diverse backgrounds new to the demands of college level engineering courses." All of this underlines the reason for the current variety of course elements seen in these first-year programs, and the daunting task of evaluating and redesigning any curriculum and course.

Common Threads. In recent years, the common themes that emerge in designing a first-year engineering program rally around the idea of setting up the incoming first-year student for success. As indicated in Hagenberger *et al.* (2006) these might include "freshman orientation" in other disciplines that focus on academic survival skills such as time management, studying for exams, and balancing work and social life, or courses in engineering used to provide students with knowledge of the different engineering disciplines necessary to effectively select a major.[6] Other content is focused around exposure to real-world problems. Key findings in the current literature show that real-world problems –when presented in an active and experiential learning environment– increase student interest, possess pedagogical effectiveness, and help to facilitate initial learning and transfer of that learning to other contexts.[7] Engineering programs, therefore, have been and continue to be redesigned with strong hands-on components and/or design experiences to motivate student learning, enhance student engagement and increase comprehension of fundamental engineering principles.[8]

Along with many other universities, The Michigan State University College of Engineering has responded to the need for students to have the ability to innovate, communicate, and perform at the highest levels in an increasingly global and demanding world by integrating the first-year engineering academic program with an engineering living-learning community.[9] Their program consists of two introductory courses. The first provides a set of broad, team-based, hands-on design experiences as well as an introduction to topics common across all engineering disciplines. The second course introduces problem solving and mathematical modeling of engineering problems and systems.[10] Other programs, such as at Ohio Northern University, focus around the ABET Criteria for engineering programs to require that students attain specific learning outcomes, including understanding engineering in both a global and social context, and designing within multiple realistic constraints.[11] They addressed this criterion by developing a first-year 'capstone' course to center around the design of a poverty alleviation device.

At Worchester Polytechnic Institute, a "Great Problems Seminar" was designed to bring first-year engineering students into meaningful contact with current events, societal problems, and human needs with a focus on large global issues such as: food and hunger, energy and its utilization, health and healthcare delivery and the NAE Grand Challenges on team work, report writing and presentation skills.[12] Similarly, the College of Engineering at the University of Arizona received an NSF Transforming Undergraduate Education in STEM (TUES) grant to develop learner-centered materials and strategies for an existing first-year engineering course around the Grand Challenges called the GC DELI (Grand Challenges: Discover, Explore, Learn and Imagine).[13] At George Fox University a transformed first-year program was developed around the objectives of 1) exposing the first-year engineering student to the work of engineering through hands-on activities and projects in engineering problem solving and design, and 2) to train and equip the student in the application of the basic and essential skills and tools utilized in the engineering problem-solving and design process.[14] And finally at West Virginia University, the previous two-course sequence consisted of a “problem-solving and design” course, followed by a “programming” course was redesigned to carry the unifying concept of the problem-solving and design process throughout both semesters.[15]

The first-year curriculum at Northeastern University has many of the common threads described above and has undergone a number of similar iterations over the years.[16,17,18] As mentioned previously, it is common for all majors and the two general engineering courses each year typically have about 25 separate sections of approximately 30 students each. The first course focuses on learning the principles of engineering and design; this is accomplished through active learning in areas such as needs assessment and problem formulation, abstraction and synthesis, analysis, and implementation, along with report writing and presentations in relation to projects that students produce in teams. There is a strong emphasis on applying technical knowledge and developing problem-solving and decision-making skills. The second course concentrates on developing algorithmic thinking skills and the solutions to real-life problems using software tools such as Mathworks’ MATLAB and the C++ programming language. Here, problems are derived across all majors. The course also has a hands-on component using low-cost programmable microcontrollers and various electronic components that students use to solve real-world engineering design problems. In addition, students will take a complement of Math, Physics, and Chemistry courses.

Motivation. There are countless other universities and colleges adopting this framework for their first-year curriculum and the impetus begins with observations and inquiries similar to the ones seen here. As this university moves forward with a vision for developing an effective and connective cornerstone-type course profile, the ongoing objective is to help the students envision their involvement in real-world engineering initiatives. Accordingly, understanding the impact of relevant projects and course elements informs the addition, replacement and/or selection of them and provides an intentional framework for meaningful early engineering coursework. Knowing what influences the students’ choices at the time they are completing the first year and finalizing these decisions, can guide what we emphasize or cover, and what should be considered and/or reconsidered when designing new course elements for the future.

Methodology

The objectives and nature of this research were discussed with all instructors of first-year students and an electronic version of the questionnaire/survey was sent to all for initial review. Following revisions and updates, the final survey tool was delivered to all first-year engineering instructors to distribute to their current students at the end of the academic year. This was at the conclusion of their two-course introductory engineering sequence. Students were to complete the questionnaire and upload it electronically for their instructor to forward the anonymous documents to the research team.

A copy of the survey is attached in Appendix A. According to university IRB policy, this research falls under exempt status:

> "Administrators frequently conduct survey research to evaluate and improve university programs and services. Most of these surveys are anonymous and do not request sensitive information and therefore do not require review by [the] University's Office of Human Subject Research Protection (HSRP)."[19]

The authors' of this paper have administrator status; the survey was discussed with the Office of Human Subject Research Protection to confirm this exempt status. Objective data was analyzed statistically and multi-rater reviews for content analysis were performed on the open-ended responses, with final review of all coded data for consistency and clarity.

Results: General Overview

Of the potential pool of approximately 600 first-year students in introductory engineering courses, 155 submitted confidential responses to their instructors. This amounts to a 25.8% sample of the population of interest.

Gender. There were 77% male responders. While this is slightly lower than the overall current enrollment percentage, which is reportedly 80% male, a Chi-Square analysis seen in Table 1 determined that the gender profile of the respondents was a representative match to that of the College of Engineering's enrollment ratio:

Table 1. Analysis of Respondents' Gender Profile.

GENDER PROFILE	Male	Female	Total
Observed	119	36	155
Expected	124	31	155
Chi-Square calculation: $\chi^2 = 0.315367$ - Sample is representative in gender ratio			

Engineering Major. Respondents represented all engineering majors, with less than 3% of non-engineering responders being students taking these first-year engineering courses from other programs. The breakdown of majors is shown in Table 2 below. This is fairly representative for the College of Engineering; Mechanical and Civil Engineering are the largest enrollments, followed by Electrical and Computer Engineering, then Chemical Engineering and Industrial Engineering.

Table 2. List of Respondents' Engineering Major Profile by Percentage.

MAJOR	Percentage
Civil	26.5%
Mechanical	25.8%
Electrical/Computer	23.2%
Chemical	16.6%
Industrial	7.9%

Results for Individual Questions

In order to evaluate the whole picture, the replies to all questions were reviewed and categorized for all responding first-year students. The responses in relation to the impact of course elements were coded and grouped according to the following classifications: (1) aggregate overview, (2) decision to continue in engineering, (3) choice of major, (4) connection to major, and (5) suggestions for expanding and emphasizing or eliminating or de-emphasizing course elements. Patterns emerged in the responses as shown below; other notes, comments and observations will also be discussed.

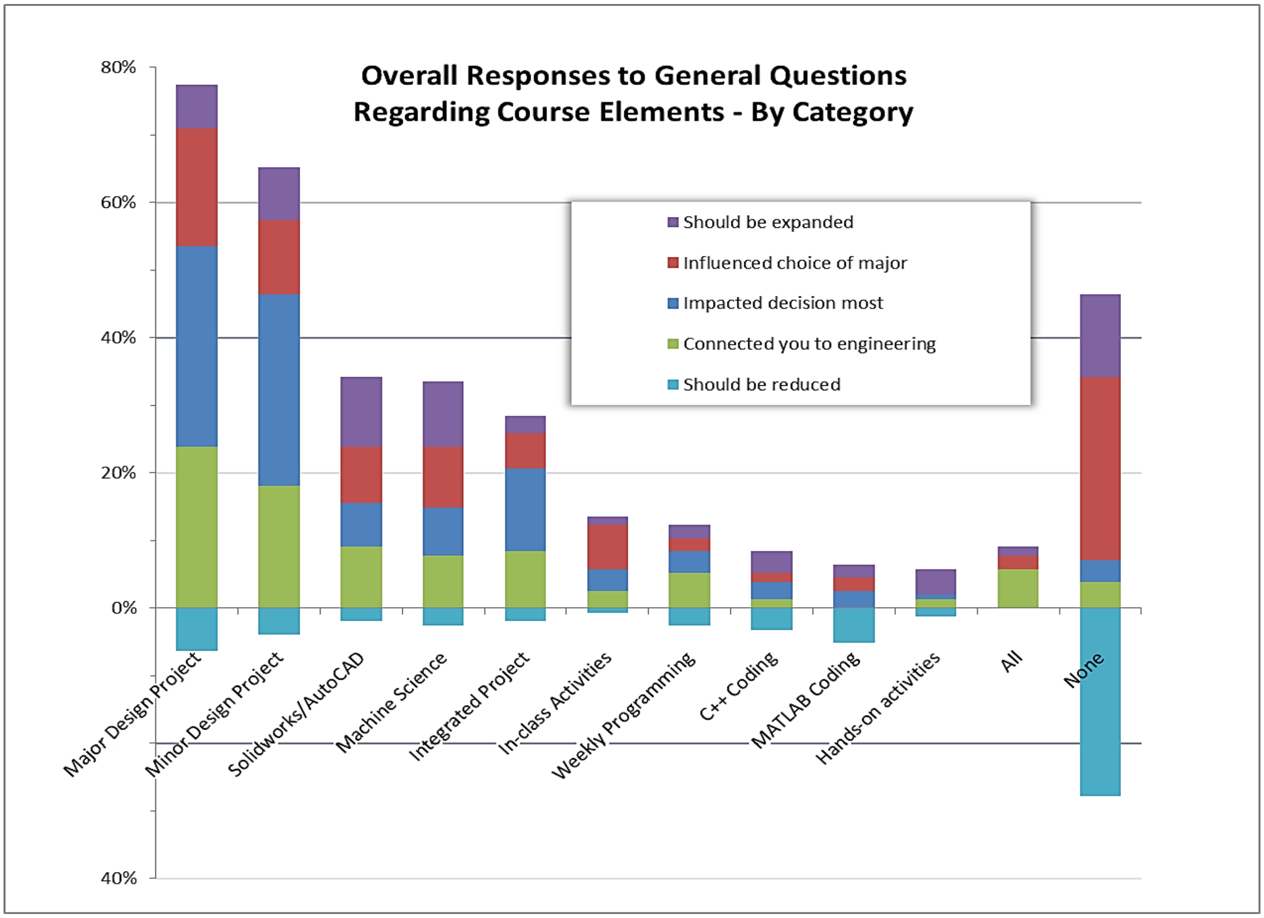

Figure 1. Overview of aggregate responses to all questions regarding effect of first-year course elements.

All of these figures have a similar list of elements in the responses, which are explained in these next paragraphs. The Minor Design project is hands-on, small team, design-and-build, accomplished early in the term, with a short assignment window of approximately 2-3 weeks. There are different Minor Design projects across the sections taught by various instructors– design and build an alternative energy vehicle to meet criteria, build a pasta bridge to hold a maximum load, design a device to protect a pumpkin from a 50-foot freefall, or develop a modular custom aircraft engine support stand. The Major Design project is conducted in groups of 3 to 4, and over a longer period of about 7- 8 weeks. This is a more complex problem, generally humanitarian, environmental, or service-based. The students follow the design process, adding to the project each week. Some students may create a simple prototype. The Major Design project is a more in-depth project, designed primarily on paper. These projects are found in the course usually taken in the fall semester of the first year.

In the spring semester, most students take the Engineering Problem Solving with Computation course, programming in MATLAB and C++. The Machine Science work is hands-on hardware and software integration, with a breadboard wiring, peripherals and associated C-programming to drive the hardware. The students do a project with Machine Science, and also an Integrated Project that involves programming in both languages, based on a real-world problem. Both of these projects show a significant impact as well. Combined, 20% of the students listed these as having a bearing on their choice to continue in engineering. There are skill-based and specific elements, such as AutoCAD and SolidWorks, or MATLAB and C++ coding, these are generally part of the course. Weekly programming are assignments that involve skills, but are more complex, with planning documents and engineering problem solving that requires some programming. In-class activities are those activities that do not require work outside of class such as group work, in class practice of concepts, or short programming exercises in class. Hands-on activities are those such as Tower of Straws or other projects that are definitely seen as hands on by the students, those were coded as such because the students used those words.

The data seen in Figure 1 above shows that the Major Design Project has the strongest effect on the students, in impact, in choice of major, and in connecting them to engineering. The data also shows that other projects and activities have a significant effect, and that having a variety of projects serves to reach nearly all. *None of the students said that none of the projects worked*. In fact, many listed several projects in response to single questions and many named several different projects throughout the course of their surveys. As we find so often in teaching, a similar number of students will indicate they want less of a particular project type as those who indicate they want more.

Another trend in the data was that if a student knew what engineering major s/he wanted coming into the program, there was *typically one project that helped cement that choice*, often related to that major, and possibly another project that helped them *determine what they did not want to do*. Minor Design projects, which are design-and-build are mentioned, along with weekly homework programs. These are both listed in many categories. The responses show that certain projects are perceived as connected to particular engineering majors, and participating in those clearly helped students make decisions on those majors. In the comments, the students also reported that they prefer the real-world applications, the hands-on aspects, and the sense that they were seeing actual engineering problems. This is neither surprising nor unique. What is of interest is that the essential elements are identified in order to produce the most meaningful and authentic results for the students' decisions and pathways. In addition, several students expressed that the two courses could be integrated, thus wanting design and programming connected. Upcoming sections will discuss the questions separately with more detail, and evaluate more of the comments provided by the students in each area.

Question: What projects or activities had the most impact on your decision to continue in engineering?

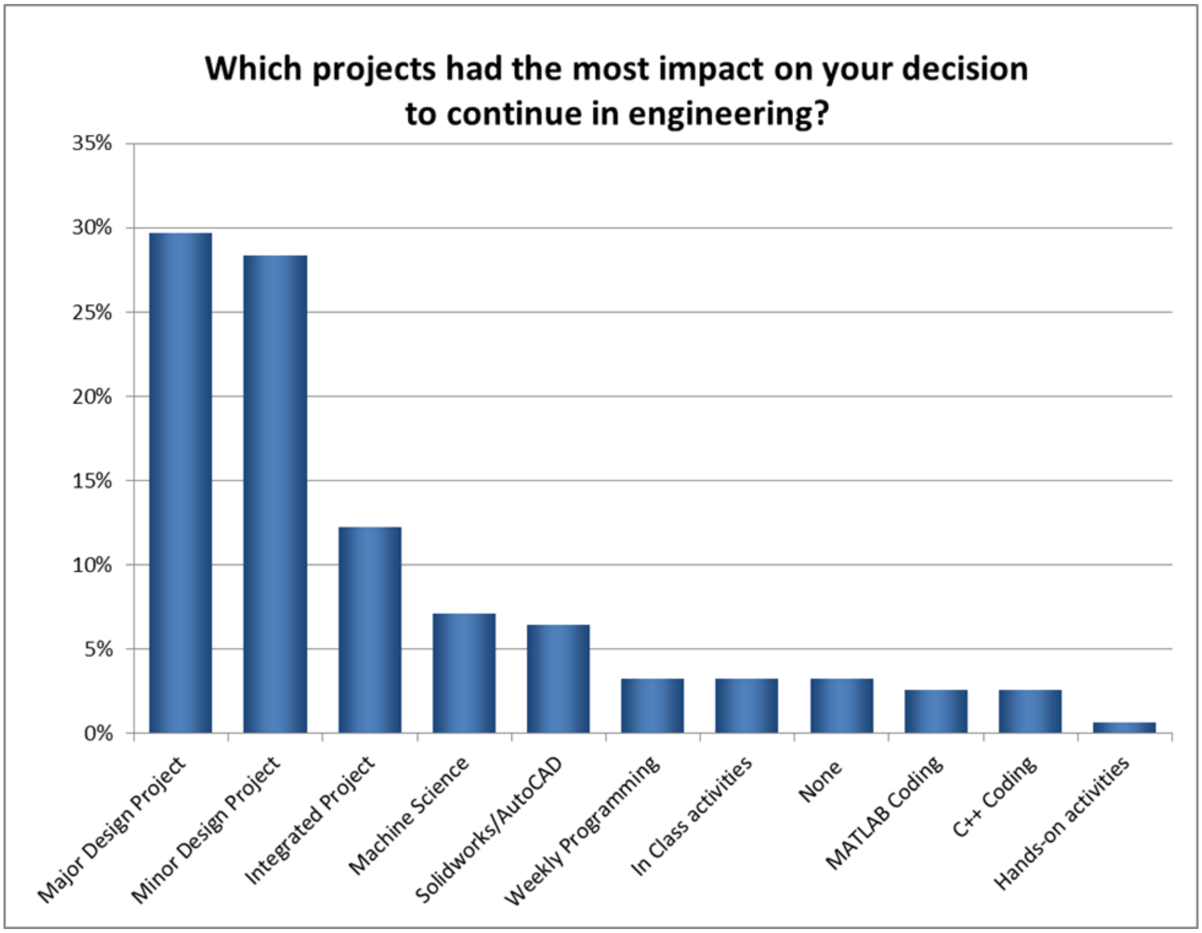

Figure 2. Responses as to which course elements affected the decision to continue in engineering as a major.

As seen in Figure 2, the two design projects showed the largest impact; approximately 58% of the students listed those.

The impact of all 4 projects, namely the Minor and Major Design projects, Machine Science and its project and the Integrated Programming project is what prompts the development of future first-year courses. The students are benefiting from the hands-on projects (Minor Design and Machine Science), appreciating what that brings to their learning about *doing engineering*, and equally seeing the value of the in-depth approaches and real-world problems coming in the Major Design and Integrated Projects.

Students' remarks further help highlight what they emphasize, enjoy, and begin to relate to. Many mentioned the engineering design process in their explanations. Other comments were:

"I felt like a real engineer"
"[It]… made engineering real"
"I understand the reality of a working engineer"
"Engineering has many applications to help the world", "design to benefit society"

We would be hard-pressed to decide not to have any of the listed elements in any future revisions of the first-year curriculum. The comments were not solicited; rather they were included voluntarily by the students. Some specific projects were named, yet there seemed to be more emphasis on the project type, not only on their project. There were a few students who mentioned that there was not a project choice in their area of interest, or that the projects had a certain engineering major more emphasized than they would have liked. The concept of options and selection is starting to emerge.

Question: What projects or activities had the most influence on your choice of major?

This question posed a bit of a conundrum. The first-year courses focus on helping students learn about the engineering majors in hopes that they would make informed decisions on what would be the best fit for them, and the results from Figure 1 might indicate that this is not being accomplished. Upon further investigation, we noticed that many students told us that *they had already decided on their major*, so the *projects or activities did not influence that choice*. NU has approximately 40% of the incoming first-year class as undecided in a major, meaning 60% have made an advance commitment in some form. In addition, the survey was given at the end of the year, and it is likely that a combination of factors had helped students to decide already. For example, they are required to be in a one-credit course titled Introduction to the Study of Engineering, for which they attend events and meetings designed to help them explore majors and make informed decisions, along with the work we do in these two foundational 4-credit courses.

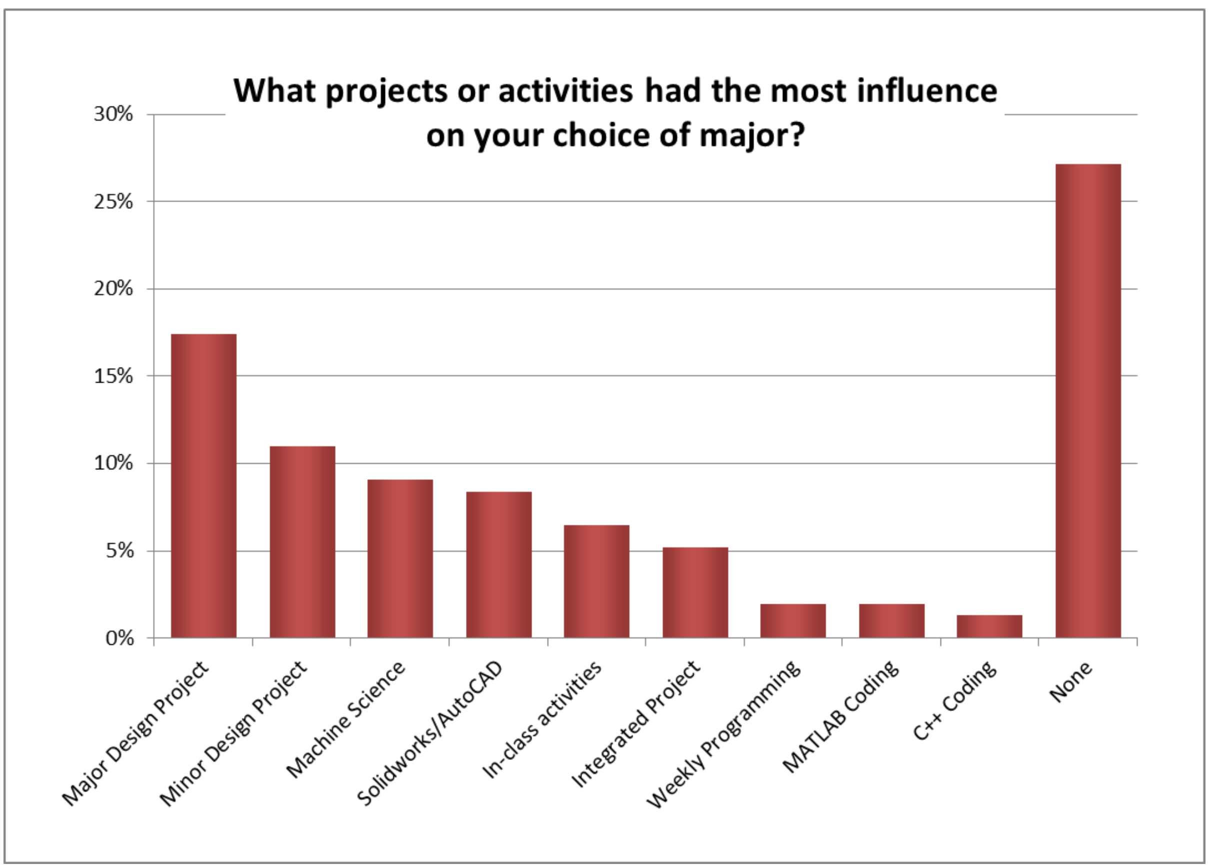

Figure 3. Responses as to which course elements most influenced choice of [engineering] major.

In reviewing the results in the Figure 3, we see the projects in design and programming again. SolidWorks and AutoCAD, along with weekly programming projects have moved into the spotlight, with some influence. The comments reflect that these weekly homework-type activities sometimes *confirm a right choice of major*, or help a student *decide which paths they do not want to pursue*. The prevalence of the "none", and "N/A" answers brought on the realization that a differently worded question might have elicited more directed responses.

Question: What projects or activities connected you most closely to your major, or to engineering?

Figure 4 below shows that the top five responses refer to the 4 projects previously highlighted – two design, two programming– and the graphics modules. The first-year students have a strong sense of the need to start acquiring skills, and their success in both programming and in graphics accomplishes that. Students indicate that they appreciate the design process and its importance, and being able to define a technical skill, such as the using graphics software, wiring breadboards, or writing programs, resonates with them as they start building resumes. Couple that with the fact that almost 50% of the students are Mechanical or Electrical/Computer engineering majors, and this makes sense as these projects have a flavor relative to these majors. So what do we take forward from this set of results? That *exposure to a wide range of topics and projects help to connect them to their field*, either to a major or to engineering in general.

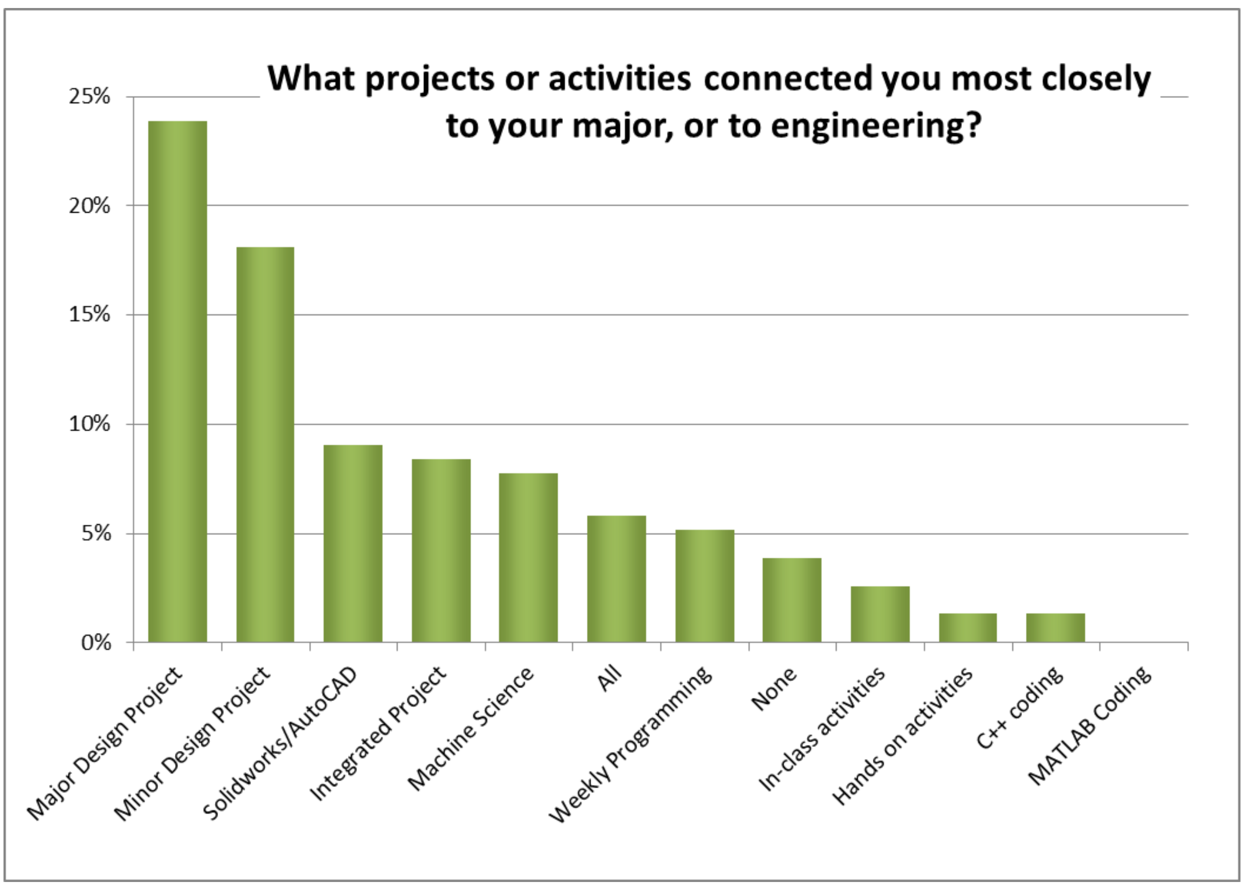

Figure 4. Responses as to which course elements connected students to their area of engineering.

For connecting to a major, the comments are extremely helpful; the students express that they learned about engineering, they were exposed to engineering methods, it was relevant, they got a feel for their major and engineering, that the projects were integral to their career progress, exposed them to the engineering method of assessing and solving problems, that the projects showed the type of thought and analysis required in the engineering design process, that they can think creatively and flexibly like an engineer. There were many comments along these lines. The overwhelming essence is that the constellation of projects and activities provided the connection to engineering they were seeking. There were very few negative remarks, except for a rare comment noting that some did not get to experience a project in their particular major area. This is likely a function of the fact that instructing professors are chosen from all departments and that each has a tendency to focus on projects from their specific discipline.

Question: What projects or activities should be expanded or emphasized more in class?

The scale of the graph in Figure 5 should be noted. It is about half the size of the previous charts' because many students left this blank. The highest percentage is "*none*". Many students wrote nothing should be changed, and similar responses were provided in open-ended opportunities. The next 4 responses following "*none*" that recommend expansion run from approximately 6% to 10%, again including the two design projects, along with Machine Science and graphics.

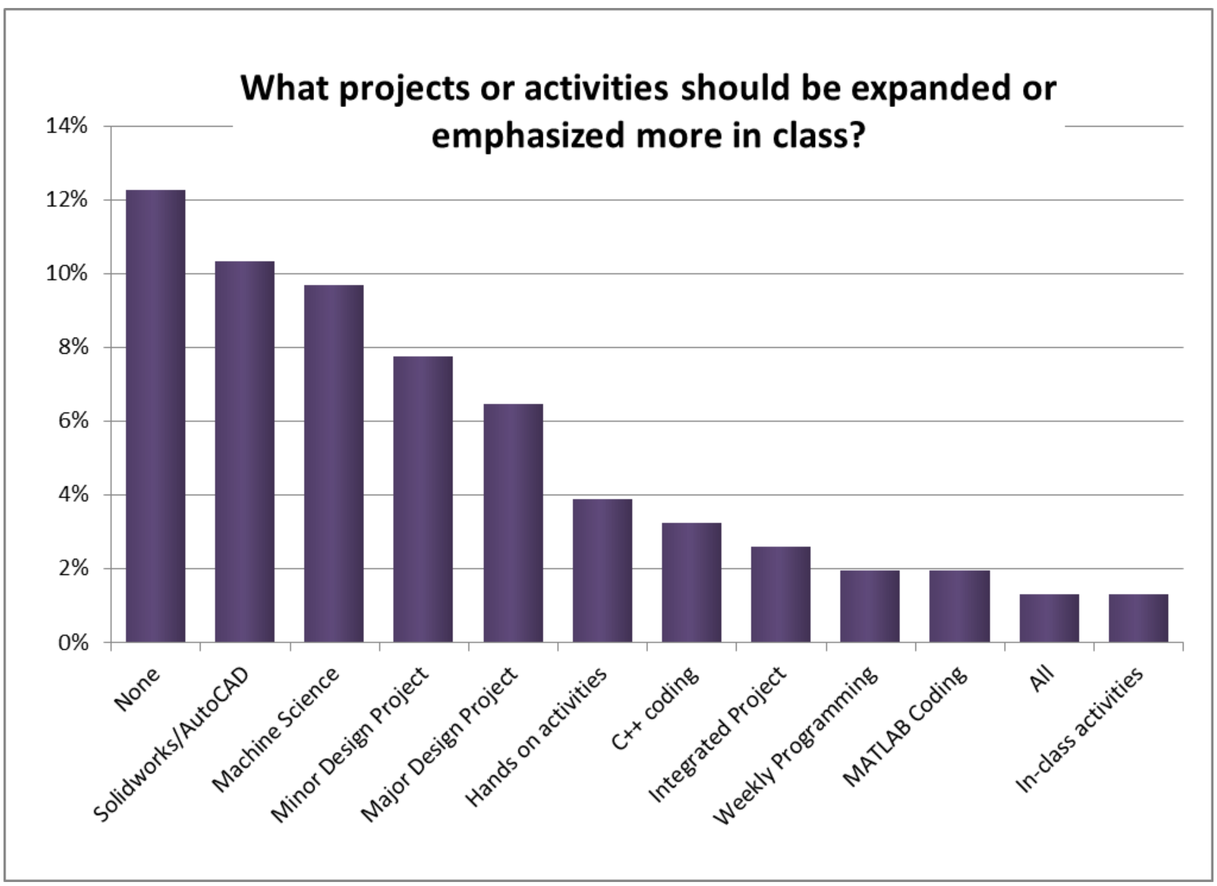

Figure 5. Responses as to which course elements should be expanded upon or emphasized more in class.

There are more telling comments provided in the open-ended section of this question, with the following suggestions of note:

- *Creativity exercises*
- *Interdisciplinary work*
- *Design of new products*
- *Cover more types of engineering*
- *Expand the minor design project*
- *Real life application of engineering*
- *Major design project should require a prototype*

Overall, the students recognize the value of the different projects and activities, and want to expand on some of these valuable aspects, such as skill building, designing, prototyping, programming, and applying design to real-world.

Question: What projects or activities should be emphasized less or omitted?

The overwhelming response here concerning elements, activities, and projects to omit or remove from the first-year curriculum is "*none/nothing*" as seen in Figure 6. All of the topics that have been so prevalent in having an influence on the first-year experience are close to or less than 5% when considering reducing their presence.

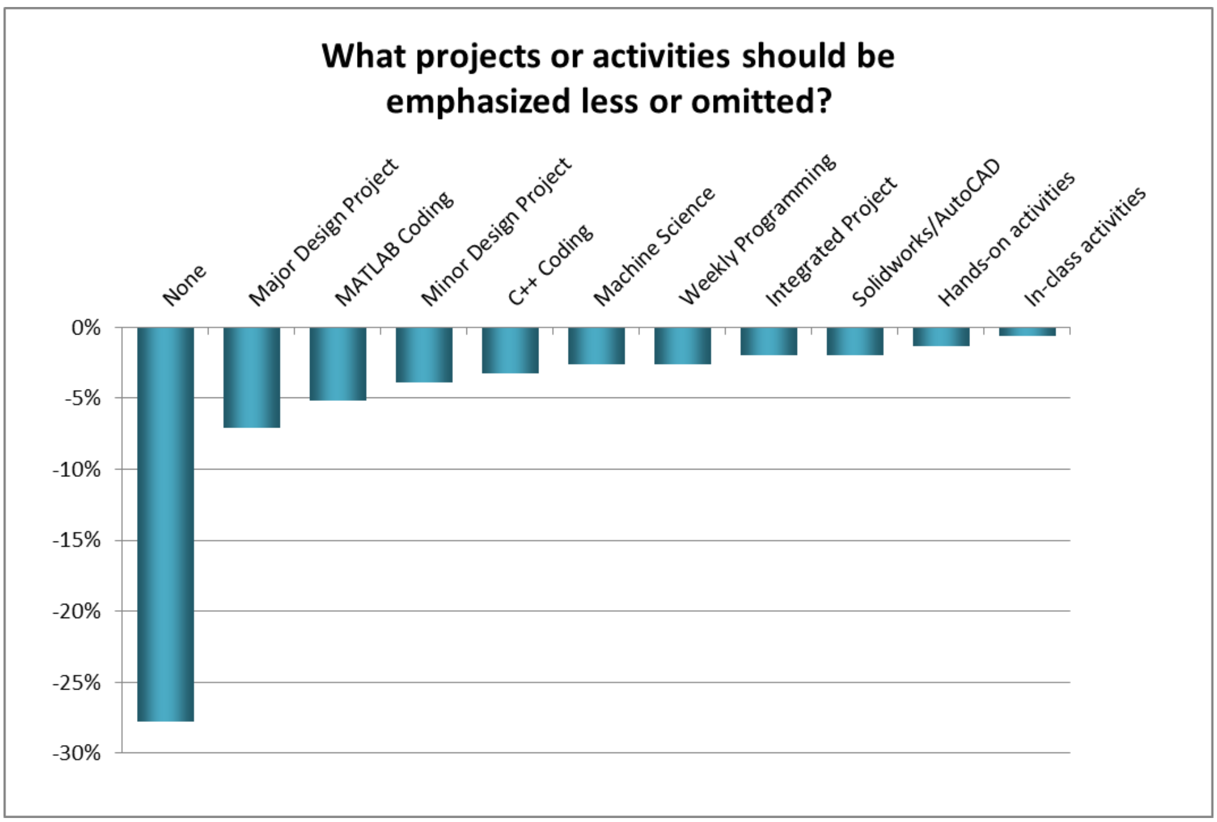

Figure 6. Responses as to which course elements should be de-emphasized or eliminated.

For this aspect of the survey, there are fewer comments. One pattern in the remarks indicates that they don't think they will need or use a particular course element. For example, a civil engineer may indicate s/he may never use MATLAB or programming, or a chemical engineer may not expect to use SolidWorks in their chosen engineering discipline. We all know this is not necessarily true, but is a shared feeling for some. So, "*not useful for my major*" is a common thread. Some other comments state that there is too much group work because it is time consuming, however, many of the previous sections had far more comments stating that group work was valuable and important to engineering, and that they had learned a great deal from the team projects. A few students also stated they wanted to do less writing, a valuable, oft unappreciated skill for engineers.

Question: What projects or activities should be added to courses if feasible, or switched for another project or activity?

This question focuses on more formative thinking and does not have the same clustering of responses as the others. Most were left blank; a few themes emerged, however. Of the substantive responses provided, 30.3% mentioned in some way to *combine projects and even combine the two design and programming courses*. This was entirely uninitiated and not led by the question at all, but seemed to be a suggestion that the students wanted to put forth. It was mentioned in some other sections occasionally, but most often here. Also noted was *having more choice*, particularly in selecting the final programming project (Integrated Project). *Open-ended problem solving*, and *expanded design projects* also make the list in plural. It appears that at least some students are ready for a bigger scale, and some also mentioned wanting to be able to implement their designs.

Discussion and Conclusions

Where do we go from here? As in all technologies and fields, we constantly see new developments or the refocusing of needs that require us to adapt or we will be left behind. Similarly a course or curriculum must transform in order to keep pace with new scholarship or even changing demographics. What we have seen here with our research is that our students are pointing us to projects that have value with real-world applications and hands-on experiences in order to help guide and cement their future engineering pathways. These are the ones that they connect most to and therefore are able to make informed decisions about their choice in major. Also these projects usually give the students a sense of accomplishment and it has been shown that they are more likely to persist in engineering –another reason to require a curriculum with opportunities for challenge. As we have seen before we will have to be careful as it is impossible to please everyone and we will have students for whom some projects will not be in favor when compared to others.

At NU plans are in motion to begin a pilot first-year cornerstone course to be implemented in the fall of 2014 modeled around many of themes described above. The course is planned to incorporate elements of both the first and second semester courses combined with the intention of having major-specific sections (or more tailored to a limited number of majors) to allow for further exploration of a major by the students. There appears to be an advantage in this new curriculum for the student who has decided early on what major they will pursue in that it would free them up to explore introductory courses in that major in the second semester of the first-year that are not usually seen until the Sophomore year. A common first-year curriculum was instituted in the past because of the many students that are undecided, and accommodations will need to be made for those students who are undecided upon entry into the university, so that they still have options to explore other majors without a penalty. Another element of change that has also pushed the need for revised curriculum is the large number of students coming in with college credit, either AP or other. The need to accelerate the exploration and offer more choice is partly driven by this new student profile. As with any change in curriculum, we will start with this pilot and then use adequate assessment to validate the changes before rolling it out to the entire program.

There are a number of stakeholders affected as we look at redesigning a curriculum. There are the college and university administrators analyzing data and having various agendas, such as retention, or assessment of learning, or global experience opportunities. There are department faculty who want students to be exposed to majors in order to make the best informed choice and be committed to and prepared for that major. There are advisors and first-year faculty who want to set the students up for success in the right career path. And the students who want engaging, even fun, experiential real-world engineering applications and a sense of what it is "to be an engineer", along with being prepared for and familiar with college life and demands. And there may be skills that the students must have to continue, such as graphics, programming or mastering other software, alongside their calculus, physics, chemistry, and biology. It is tempting to give up trying to meet the needs and demands of all constituents. However, the themes of the Grand Challenges of Engineering and the successful standing elements of the current courses serve as the perfect building blocks for the cornerstone course, adding new methods of teaching and learning to the mix. Using simulators, educational games, 3-D printing, embedded systems and other newly emerging tools may provide means for accomplishing this multi-criteria optimization. The focus is on tying as much together as possible with the projects, yet keeping variety and choice. Part of the solution is often telling the students why –why this problem, why this skill, why this approach.

Results of this work have taught us to not assume that students know why the course has each element, or that they value teamwork. These building blocks can be customized by each instructor, with themes and challenges that personally resonate with them. With guidance from these results, adding to that what has already been proven to work and incorporating new relevant themes and focus, our first-year engineering courses can yet again transform with a new look, yet still retain some of the cherished gems of the old.

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Appendix A. Questionnaire.

Survey – Reflecting on the First Year in Engineering

Year of Graduation:______ **Major:**______ **Gender:**______

This year in GE 1110 ("Design") and GE 1111 ("Comp"), you have participated in a number of projects and activities. Examples of these from GE 1110 are the minor projects (design and build), major project or service-learning projects, tower of straws, design deconstruction and from GE 1111 weekly programming assignments, integrated programming projects, Machine Science projects as well as many others. Please check the box for the projects you participated in, provide a brief description, and then answer the questions below:

_____ **Design**: Minor Design Project: Topic: ____

_____ **Design**: Major Design Project: Topic: ____

_____ **Design**: Other Activities: ____

_____ **Comp**: Weekly Programming Projects: ____

_____ **Comp**: Machine Science Challenges: ____

_____ **Comp**: Machine Science Final Project: ____

_____ **Comp**: Integrated Project: ____

_____ **Comp**: Other Activities: ____

As you reflect on these projects, consider (and name) what projects or activities:

Had the most impact on your decision to <u>continue in engineering</u>? Explain why.

Had the most influence on your <u>choice of major</u>? Explain why.

<u>Connected you most closely</u> to your major, or to engineering? Explain.

Over Please →→

***Continued*: As you reflect on these projects, consider (and name) what projects or activities:**

Should be expanded or emphasized more in the class? Why?

Should be emphasized less or omitted? Why?

Should be added to these courses if feasible, or switched for another project or activity? This can be a new project or activity, not being done in these classes at all at this time. Describe as much as possible, including any source of information if known.

Thank you!