Benchmarking the Integration of Complex Systems Study in Southeastern Mechanical Engineering Programs

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Abstract –The faculty and chairs of mechanical engineering programs in the southeastern United States were surveyed to determine whether complex systems study is being integrated into the educational development of undergraduate engineering students. This was accomplished by sending online surveys to college of engineering deans and department of mechanical engineering chairs. The survey asks questions concerning the current implementation and importance of complex systems study in the undergraduate educational development. The results of this survey indicate that there is not a significant amount of integration of complex systems study into the educational development of undergraduate mechanical engineering students. However, the survey results show that the deans and chairs believe that it is important to incorporate complex systems into the undergraduate's engineering curriculum.

Keywords: complex systems, educational development, undergraduates

INTRODUCTION

After World War II engineering education experienced a revolution. It moved from focusing on developing practical skills such as drafting and surveying to more analysis and a focus on the engineering sciences [8]. By moving the focus away from the broader issues associated with developing practical engineering skills, there was some fear that engineering education may become too narrowly focused on the engineering sciences. Prior to this reform, the Grinter report endorsed the need for more science in engineering schools [6]. This report contained a warning, "Engineering educators must never lose sight of the broad issues with which large engineering problems are always associated."

Over 40 years later, the Boyer Commission published a report in which they expressed their strong concerns for the state of education, "We believe that the state of undergraduate education at research universities is such a crisis, an issue of such magnitude and volatility that universities must galvanize themselves to respond…. ….Insofar as they have seen as their primary responsibility the creation and refinement of knowledge, America's research universities have been superbly successful…But in the education of undergraduates the record has been one of inadequacy, even failure" [10].

As powerfully stated by William Wulf, president of National Academy of Engineers (NAE), "Many of the students who make it to graduation enter the workforce ill-equipped for the complex interactions, across many disciplines, of real-world engineered systems" [12]. Wulf suggested that mechanical engineers are increasingly required to solve problems involving complex physical, biological and social systems. NAE has responded to this need by establishing the Engineer of 2020 Project [11]. This project addressed the growing need to pursue collaborations with multidisciplinary teams of experts, because of the increasing complexity and scale of systems-based engineering

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problems. The American Society of Mechanical Engineers (ASME) has also expressed a need to promote a "shared vision of the future of mechanical engineering education in the context of new and rapidly emerging technologies and disciplines, national and global trends, societal challenges for the 21st century, and associated opportunities for the profession"[1].

In order to prepare undergraduate engineering students to master an ever-increasing amount of content knowledge within these systems and develop an ability to think critically and holistically across these systems, educators must first recognize the changing needs of undergraduate engineering students. These changing needs call for a reexamination of the content of current undergraduate mechanical engineering programs. Upon graduation our students need to be prepared to enter the workforce or graduate school. They not only need to analyze problems, but to design under many varying constraints (such as social and environmental ones), to communicate with people outside of specific discipline, and to remain lifelong learners in a rapidly changing world.

Currently, the traditional engineering curriculum is a series of courses that teach simple systems. There is no emphasis on the true complexity of these systems and how they interact with other systems. These interactions can be effectively modeled using a holistic systems approach in order to gain an understanding of the system and its behavior. "Engineers normally will not spend their lifetimes solving purely technical problems. Most engineering problems span a wide range of both technical and non-technical areas" [9]. There is a need to engage students in a new way of thinking about the problems that they will encounter in their careers. Complex systems study is laying the foundation for a revolution of all sciences to move beyond reductionism into holism [7]. This holistic approach involves not only looking at the technical aspects of a system, but the economic, social, cultural, global, and environmental aspects as well. For those interested in introducing complexity into their curriculum, we have discussed creating a complex learning experience for freshmen in a prior paper [5]. However, before educators attempt to change the way that courses are taught, it is appropriate to evaluate the extent to which complexity has been embraced by engineering educators in southeastern universities. The study presented herein determined the progress that is being made toward incorporating complexity into the undergraduate engineering experience. We accomplished this by surveying deans, chairs, and faculty at southeastern colleges of engineering and departments of mechanical engineering.

The authors administered and analyzed the results of this online survey to determine whether the deans and chairs believe that complex systems study is important and is present in their departments of mechanical engineering. In addition, the authors examined how well current programs equip their students to practice at the intersection of these complex systems.

PREVIOUS RESEARCH

In a previous study, the authors put themselves in the shoes of high school seniors residing in the southeastern United States who want an education in mechanical engineering stressing complex systems in addition to the mechanistic, simple systems that are traditionally taught [4]. Using the information gathering technique most familiar to high school students today, the authors turned to the internet to systematically collect relevant information. Information available on the web was reviewed to identify the occurrence and frequency of language and concepts associated with complex systems study (e.g., complexity, complex systems, and emergent properties). Several results and conclusions were drawn from this initial study. A significant level of activity in complexity is present at the university level, but not at the engineering college and mechanical engineering department level. An examination of curriculum, the fundamental indicator of mechanical engineering students' education, showed that slightly less than 26 percent of the sample embraced complexity.

METHODOLOGY

For this current study, online surveys were developed and administered to deans, chairs, and faculty. To administer the online survey, a letter was emailed to the deans and chairs with a link to the online survey. The chairs were instructed to forward the survey to faculty as they deemed appropriate. Three weeks later, another letter was sent to the subjects to thank them for participating and to give those who did not respond a chance to respond.

Sample

All colleges and universities that a) responded to ASEE's 2002 Engineering and Engineering Technology College Profiles in the southeastern region and b) offer an Accreditation Board for Engineering and Technology accredited bachelors degree in mechanical engineering were included in the study sample. Forty-three institutions met this criteria.

Survey Development

The objectives of this survey were to determine if the deans and chairs believe that simple and complex systems study is currently incorporated into the curriculum and to determine if they believe complex systems study should be implemented into undergraduate mechanical engineering development.

The online survey was developed using CTL Silhouette featuring the Flashlight™ Current Student Inventory Version 2.9. The survey questions were developed cooperatively by the research team (See Appendix). Radio buttons were used for questions 1, 2, and 40-43. Only one radio button can be activated at a time. An open answer format was used for question 3. The Likert scale that was used for questions 4-39 offered options of "Strongly Disagree", "Disagree", "Agree", "Strongly Agree", and "Not Applicable."

Questions 1-3 were used to collect demographics from the survey recipients. These demographics include the position of the survey taker, the position of the person whom the survey taker is completing on behalf of (if applicable), and the college that the survey taker represents.

Questions 4-8 and 18-39 were used to determine the extent to which the survey takers believe that simple and complex systems study is incorporated into the curriculum.

Questions 9-17 were used to determine the extent to which the survey takers believe that graduates should have the ability to deal with complex systems. These questions are similar to the ABET criteria.

RESULTS AND DISCUSSION

The first email to the chairs and deans with a link to the survey yielded 29 responses. Three weeks later, the second letter yielded 11 additional responses. We received 14 responses from deans, 20 from chairs, and 6 from faculty.

The survey respondents represented universities that are distributed throughout the southeastern United States. Question 3 asked the respondent "Which college do you represent?" Of the 40 respondents, 23 answered by giving the name of their university, while the other 17 answered "Engineering" or "College of Engineering."

Responses to questions 4 through 8 indicate that undergraduate mechanical engineering students receive a fundamental grounding in engineering sciences, humanities, social sciences, mathematics, and physical sciences. However they do not receive a fundamental grounding in the life sciences (See Figure 1). The life sciences are a subject that embraces complex systems study. Life sciences are also the basis for many of the emerging sub-disciplines in engineering, such as biomedical engineering, earth systems engineering, and nanotechnology.

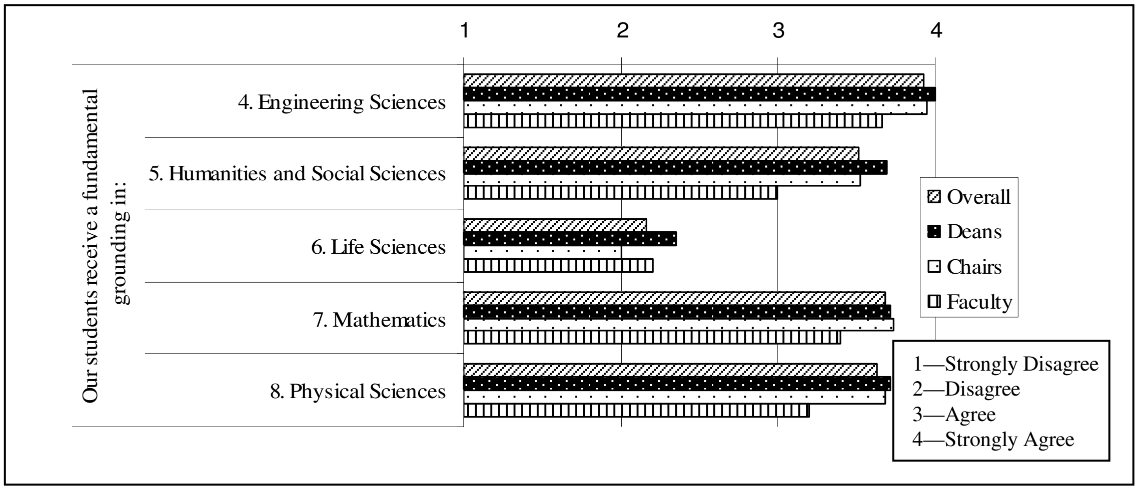

Figure 1: Survey results of questions 4-8

Responses to questions 9 through 17 indicate that the deans, chairs, and faculty believe it is important that undergraduate students have the ability to analyze and synthesize complex systems, apply knowledge, communicate effectively, engage in life-long learning, solve complex and open-ended questions, think critically, tolerate uncertainty, and work in multi-cultural and multi-disciplinary teams (See Figure 2). This indicates that the deans and chairs believe it is important to incorporate complex systems into the undergraduate's engineering curriculum.

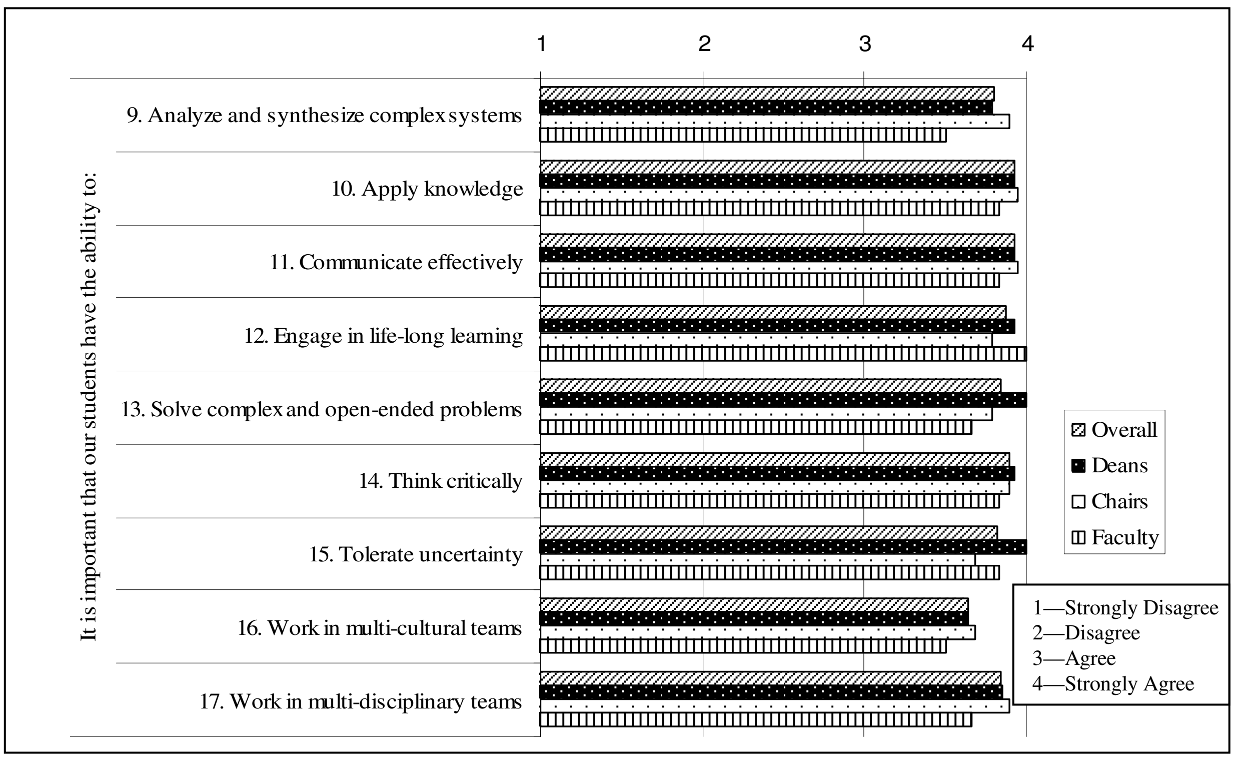

Figure 2: Survey results of questions 9-17

Responses to questions 18 through 31 that address whether the curriculum presents a focus on "emerging" or "evolving" disciplines indicate that the curriculum has a focus on traditional engineering topics, but do not have a focus on broader topics (See Figure 3). The traditional engineering topics include advanced manufacturing, engineering ethics, and information technology. The broader topics include advanced/ intelligent materials, bioelectrics, bioengineering, critical infrastructure, earth systems engineering, financial systems, hazard engineering, health systems, MEMS, nanotechnology, and transportation systems. For the most part, the traditional engineering topics embrace simple, mechanistic systems, while the broader topics embrace complex systems.

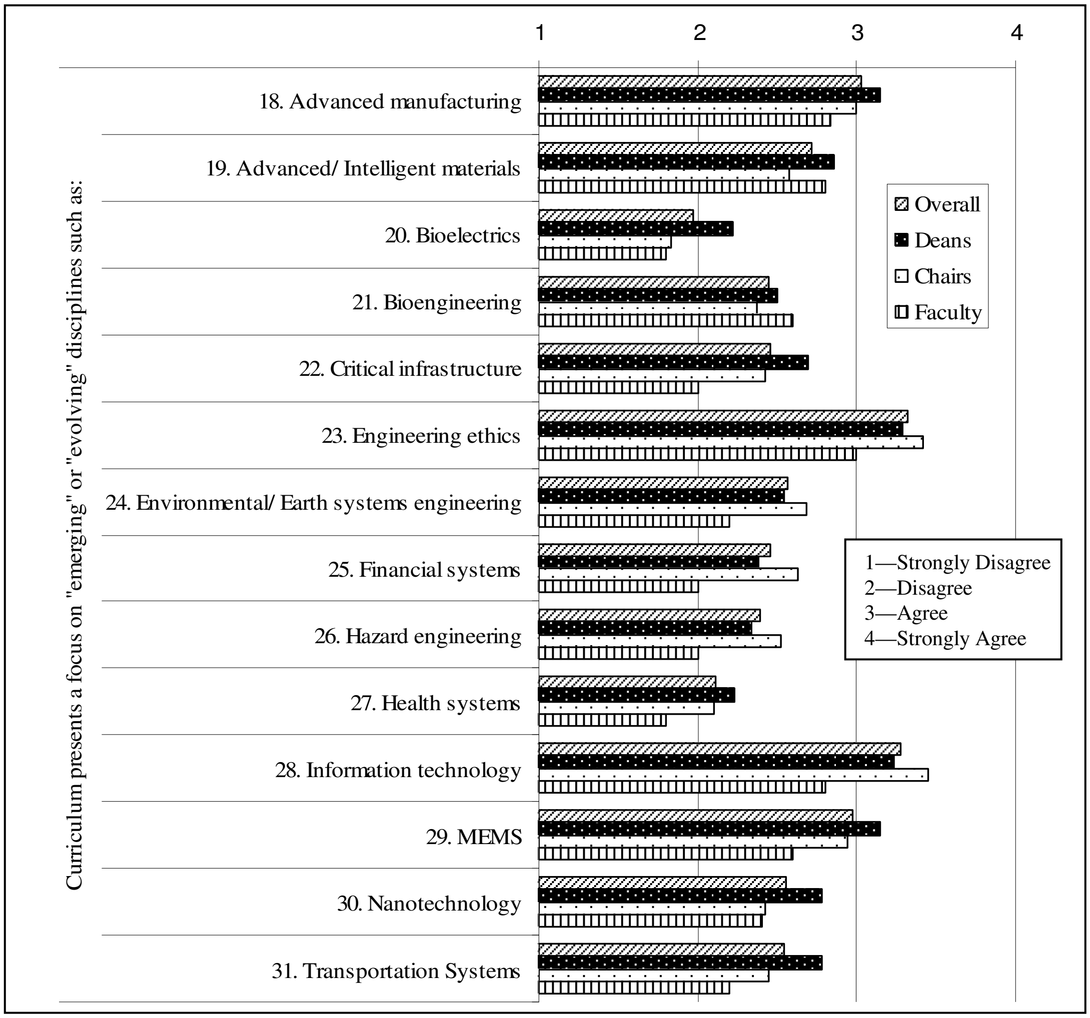

Figure 3: Survey results of questions 18-31

Responses to questions 32 through 39, which address whether students have an awareness of the interrelationship of engineering with varying areas, indicate that students do not have an awareness of the interrelationship of engineering with 'softer' areas, such as aesthetics, culture, law, politics, and social norms. However, the students do have an awareness of the interrelationship of engineering with the economy, the environment, and ethics.

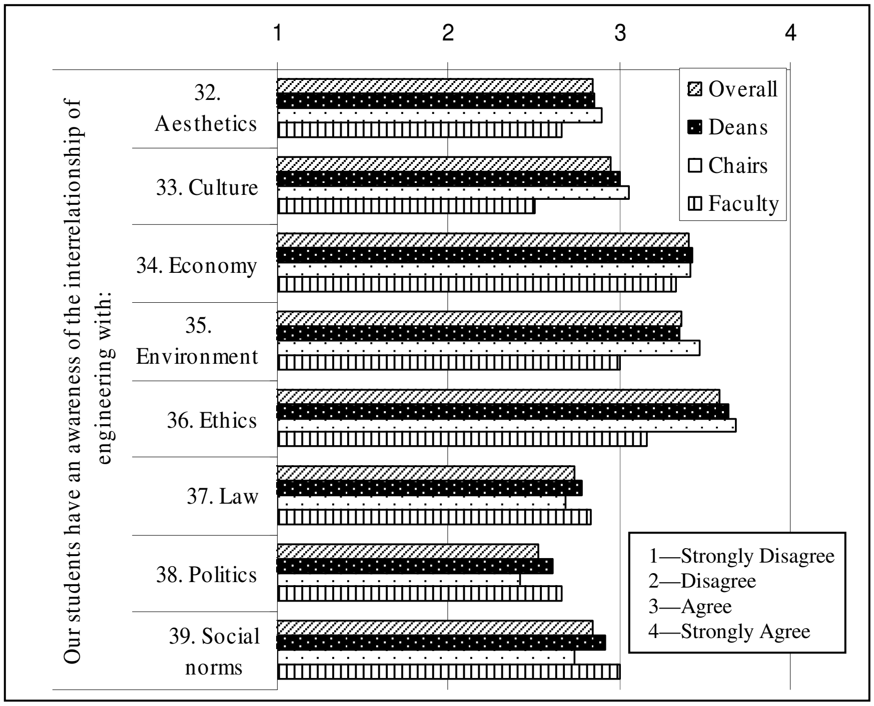

Figure 4: Survey Results of Questions 32 through 39

Four additional questions queried the respondents as to whether their capstone engineering experience provides students with an understanding of complex systems. An overwhelming majority of the respondents answered yes to the four questions in this section.

FUTURE WORK

This research opens up many more questions for future work.

It would be valuable to have faculty and students respond to the questionnaire. For the current research project, we sent letters to the chairs and deans, and requested the chairs to forward the letter to faculty and students as they deemed appropriate. We received 6 responses from faculty and 0 from students. The responses of the faculty differed from the responses of the chairs and deans. Because of the small sample size we cannot draw any conclusions, but these data suggest that the faculty and students may have different responses than the chairs and deans. This may be due to the faculty and students knowing firsthand what goes on in the classroom. The students would provide an invaluable perspective, because they experience a large spectrum of courses throughout their study.

Expanding this research to include all of the United States would be valuable. The results may or may not be similar to those found in the southeast.

Conducting parallel research in different countries would likely lead to very different results. The cold war and world wars have heavily influenced the engineering universities in the United States. In countries without such a strong military influence, there may be much more of an integration of complex systems into the undergraduate engineers' development.

CONCLUSION

Desmond Hudson, President of Northern Telcom Inc., stated that, "My concern is for the students who come out of school suitably versed in mathematics, physics, and the sciences, but lacking an appreciation for literature, history, and philosophy. The view they have is that modern technology is a collection of components rather than an integral part of our society, our culture, our business environment" [9]. There is a need for a change in the current engineering curriculum. The Accreditation Board for Engineering and Technology addresses this need in the current accreditation method, Criteria 2000. It states that the graduates must possess the broad education necessary to understand the impact of engineering solutions in a global and societal context [2].

We would like to suggest that a true measure of the extent to which engineering educators have embraced complex systems study is its inclusion in curriculum and courses. Although few mechanical engineering programs currently meet this measure, the widespread interest in complexity demonstrated in the sample supports the creation of synergistic partnerships to embrace and implement complex systems study into the curriculum.

ACKNOWLEDGEMENTS

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BIOGRAPHICAL INFORMATION

Nadia Craig

Nadia Craig is currently conducting research in the Laboratory for Sustainable Solutions while completing her Ph.D. in mechanical engineering. Her research interests include engineering education, sustainable design, and complex systems science. Her dissertation involves developing a way to incorporate complex systems study into engineering education.

Veronica Addison

Veronica Addison is a PhD Student in Mechanical Engineering conducting research in the Laboratory for Sustainable Solutions. Her research interests include sustainable design, the built environment, complex systems and engineering education.

James Russell

James Russell is a post-doctoral researcher and teacher in the Laboratory for Sustainable Solutions. His research interests include environmental management systems, industrial ecology, sustainable design, and complex systems science. His dissertation "Evaluating the Sustainability of an Ecomimetic Energy System: An Energy Flow Assessment of South Carolina" involved modeling energy flows in both human and natural systems.

Michelle Maher

Michelle Maher is Assistant Professor of Higher Education Administration. Her research interests include the use of technology in educational settings, undergraduate student development, and educational research methodology.

Wally Peters

Wally Peters is Professor of Mechanical Engineering, Director of the Laboratory for Sustainable Solutions, and Faculty Associate in the School of the Environment. His research interests include sustainable design, industrial ecology, complex systems, and environmental/earth ethics.

APPENDIX

Survey for Southeastern Colleges

We invite your participation in an ongoing study investigating the extent to which complexity is being incorporated into mechanical engineering curricula throughout the southeastern United States. For the purpose of this study, we define complexity in line with the statement written by William Wulf, president of the National Academy of Engineering, "[As the world becomes more complex] engineers must appreciate more than ever the human dimensions of technology, have a grasp of the panoply of global issues, be sensitive to cultural diversity, and know how to communicate effectively."

Your college's mechanical engineering department was identified for inclusion in this study because it is ABET accredited and has a noted reputation for educating tomorrow's engineers.

Thank you for your time,

Wally Peters
Department of Mechanical Engineering
University of South Carolina

1. Please select your position

   - Dean
   - Chair
   - Faculty
   - Staff
   - Student

2. If you are taking this survey on behalf of the dean, chair, or a faculty member, please select the button next to the appropriate position.

   - Dean

Chair

Faculty

3. Which college do you represent?

Our students receive a fundamental grounding in:		Strongly Disagree	Disagree	Agree	Strongly Agree	Not Applicable
4.	Engineering Sciences					
5.	Humanities and Social Sciences					
6.	Life Sciences					
7.	Mathematics					
8.	Physical Sciences					

It is important that our students have the ability to:		Strongly Disagree	Disagree	Agree	Strongly Agree	Not Applicable
9.	Analyze and synthesize complexsystems					
10.	Apply knowledge					
11.	Communicate effectively					
12.	Engage in life-long learning					
13.	Solve complex and open-endedproblems					
14.	Think critically					
15.	Tolerate uncertainty					
16.	Work in multi-cultural teams					
17.	Work in multi-disciplinary teams					

Curriculum presents a focus on "emerging" or "evolving" disciplines such as:		Strongly Disagree	Disagree	Agree	Strongly Agree	Not Applicable
18	Advanced manufacturing					
19	Advanced/intelligent materials					
20	Bioelectrics					
21	Bioengineering					
22	Critical infrastructure					

23	Engineering ethics					
24	Environmental/Earth systemsengineering					
25	Financial systems					
26	Hazard engineering					
27	Health systems					
28	Information technology					
29	Microelectromechanical systems					
30	Nanotechnology					
31	Transportation systems					

Our students have an awareness of the interrelationship of engineering with:		Strongly Disagree	Disagree	Agree	Strongly Agree	Not Applicable
32.	Aesthetics					
33.	Culture					
34.	Economy					
35.	Environment					
36.	Ethics					
37.	Law					
38.	Politics					
39.	Social norms					

In your capstone/comprehensive design experience, are the students exposed to:		No	Yes	Not Applicable
40.	Critical thinking			
41.	Experiential learning			
42.	"Real world" experience			
43.	Teaming			