The Student Perspective on the State of Complex Systems in Australian and American Mechanical Engineering Programs

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Abstract –Students from the University of South Carolina and the University of Queensland participated in focus groups to describe and compare the states of complex systems study in engineering educational programs of the United States and Australia. The qualitative data were used to supplement existing survey data that was collected from a sample of American and Australian universities. The purpose of this research was to determine and compare the states of complex systems in American and Australian mechanical engineering programs. The previous study determined that complex systems study is more prevalent in Australian Universities than American universities. This was notable because American universities have an emphasis on liberal arts in the curriculum, while Australian universities teach engineering courses throughout their curriculum. After the focus group data were analyzed, it was determined that the likely reason that Australian students understand complex systems better was because of the required professional experience.

Keywords: complex systems, educational development, undergraduates.

INTRODUCTION

In the context of this paper, complex systems study is defined as an awareness and understanding of the interrelationships of engineered systems with technical and non-technical (i.e., economical, social/cultural, environmental, ethical, and global) systems, even when these systems cannot be broken down into solvable, simple equations. Thus, complex systems study is the study of a holistic system and its interactions with other systems [Amaral, 1], and it is laying the foundation for all sciences to move beyond reductionism into holism [Li, 12]. In the

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realm of engineering, complex systems study requires the engineer to consider not only the technical aspects of a system, but also the social, environmental, economical, ethical, and global aspects. Characteristics that embody a complex systems thinker include the ability to take a multi-scale perspective, the ability to understand the interrelationships between different parts of a system, a strong macro-ethic (defined as an overarching ethical framework for understanding the intersection between human engineered systems and earth systems [Russell, 15]), creativity and flexibility in thought, a strong business sense, the ability to empathize with other people, good communication skills (formal and informal), good metacognitive (ability to self-assess) skills, and an aptitude for lifelong learning. Although the term "complex systems study" is not typically used in the realm of engineering education, it encompasses many of the concerns that have been discussed throughout the history of engineering schools.

The president of the National Academy of Engineering (NAE), William Wulf, has observed that engineers are increasingly required to solve problems involving complex physical, biological and social systems. He lamented, however, that, "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" [16]. In response to concerns such as those expressed by Wulf, this effort examines the extent to which today's undergraduate engineering programs are preparing tomorrow's engineers to successfully encounter, engage, and interrelate complex systems in their professional lives. As complex systems thinkers, graduates will need to understand the interrelationships of engineering with typically non-engineering areas (such as global, social/cultural, environmental, and economical areas), in addition to being life-long learners, effective communicators, and ethical professionals. Recently, NAE has responded to this awareness by establishing the Engineer of 2020 Project [Committee on the Engineer of 2020, Phase I, 6; Committee on the Engineer of 2020, Phase II, 7]. This project addresses the growing need to pursue collaborations with multidisciplinary teams of experts, because of the increasing complexity and scale of systems-based engineering problems. According to the latest publication these teams must have the following attributes: "excellence in communication (with technical and public audiences), an ability to communicate using technology, and an understanding of the complexities associated with a global market and social context" [Committee on the Engineer of 2020, Phase I, 6]. These attributes are in alignment with the attributes of a complex systems thinker.

The leaders from many prominent professional engineering societies, such as the American Society of Mechanical Engineers (ASME) [3][4], the American Society of Civil Engineers (ASCE) [2], and the American Institute of Chemical Engineers (AICHE) [9], have also addressed the need for engineers to solve problems involving complex physical, biological, and social systems. In response to this need, AICHE, ASCE, ASME, and Institute of Electrical and Electronic Engineers are collaborating to offer "Excellence in Engineering Education" teaching workshops for engineering and engineering technology faculty.[American Society of Mechanical Engineers, 3] The ASME have also responded to this need by promoting 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" [4].

A closer look at the engineering education programs in America and Australia will provide two distinct perspectives. Engineering education in America has been heavily influenced by the cold war. This strong defense-related influence has encouraged a mechanistic, simple systems approach in the way that engineers are educated [Dowell, 10]. Australia has a different history; their engineering educational program has been driven by social and environmental systems, which are inherently much more complex.

Before change can be implemented, a reexamination of the content of current undergraduate mechanical engineering programs is necessary. The authors are examining how current engineering educational programs in the America and Australia are engaging their engineering students in the study of complex systems.

RESEARCH PURPOSE

This study investigated and compared the extent of complex systems study integration according to students across two domains, American undergraduate mechanical engineering programs and their Australian counterparts. Out of the focus group analysis emerged a more detailed investigation which focused on three specific components within each educational domain: undergraduate engineering course content, extracurricular activities, and work experience.

RESEARCH DESIGN

The first author conducted focus groups with undergraduate mechanical engineering students at the University of South Carolina and at the University of Queensland. The research team advertised the focus groups by emailing flyers, posting flyers throughout the department, requesting professors to announce the focus groups to their classes, and personally visiting classes to encourage students to attend the focus groups. Students of each level (freshmen/ 1st year, sophomores/ 2nd year, juniors/ 3rd year, and seniors/ 4th year) were invited to attend a separate focus group. The students were offered incentives to participate in the focus groups; these included a raffle ticket for a free iPod shuffle and snacks at the focus group meeting. Eleven undergraduate mechanical engineering students (five juniors and six seniors) at the University of South Carolina (USC) and seven students (five 3rd years and two 4th years) at the University of Queensland (UQ) participated in focus groups.

Methodology

Qualitative and quantitative data was previously collected via online surveys at 10 universities in Australia (Group of Eight engineering) and 10 Research I universities in the US [Craig, 8]. The qualitative data collected in the present research project was meant to augment previously collected survey data. The results of the focus group research were used to provide context for the previously collected data--the previously collected data provided breadth in the analysis, while the current data provided depth.

The research team developed the focus group questions. The focus group protocol contained 14 open-ended questions that were designed to generate discussion from the focus group participants. The first author analyzed the responses to three open-ended questions that addressed complex systems study integration. These questions are as follows:

> "For the purposes of this study, complex systems study is defined as an awareness and understanding of the interrelationships of engineered systems with technical and non-technical (economical, social/cultural, environmental, and global) systems.
>
> - How have your fellow classmates learned about complex systems during your undergraduate education?
> - In your department's undergraduate curriculum, how have your fellow classmates developed an understanding of the interrelationships of technical and non-technical systems?
> - Describe educational opportunities that incorporate complex systems (e.g. courses, projects, work experiences, extracurricular activities)."

Special precautions were taken in order to ensure the validity of the focus group questions. One author, Wally Peters, is an expert in the area of complex systems, while Michelle Maher is an expert in education. These authors helped develop and approve the content of the survey. Due to cultural and linguistic differences, the responses to some of the questions may have misleading results.

Study Variables and Analysis

The research team recorded and transcribed the focus group discussions. Nvivo, a qualitative analysis software program, was used to code passages within the interview transcriptions. To begin analysis, the first author reviewed transcripts to develop descriptive codes, which identified broad themes across students' responses. The descriptive codes were initially constructed based on the researcher-generated categories, i.e., by coding the responses to focus group questions. The responses to the question, "Do you think that you and your fellow classmates have learned about complex systems during your undergraduate education?" were coded as "complex systems." The first author then constructed subsequent descriptive codes based on the participants' responses. The descriptive code, "connections" was developed in response to the following student response: "There are these different threads, there's the actual mechanical side of designing things, and then there's heat and thermo and such, and there's fluid mechanics. You see relations between them but no one has actually really said this is how all of this comes together to build a machine or something." The first author coded and then re-coded the transcriptions 3 weeks later to establish trustworthiness [Leydens, 11]. The authors then reviewed these codes to determine emergent patterns within the transcriptions.

RESULTS

The state of complex systems in American and Australian mechanical engineering educational programs according to undergraduate students was compared for the following categories: courses, extracurricular activities, and work experiences. These categories emerged after studying the coded transcriptions. Responses within these specific categories were compared and contrasted for American and Australian student responses.

Courses

The prevailing theme throughout the focus group discussions was that complex systems were only briefly covered in the participant's courses (See Excerpt A in Table 1). The courses that were usually cited were an American freshman introduction to engineering course, an Australian freshman introduction to professional engineering course, or a senior capstone design course. The students indicated that complex systems was only briefly covered in these courses, the main focus was on the technical aspects of engineering (See Excerpt B in Table 1). Some students mentioned that complex systems were included as an aside in other courses; however, they noted that it would be easy for students to miss the mention of complex systems. Overall, the students indicated that they felt that technical aspects of engineered systems were the only aspects that were comprehensively covered throughout their courses.

Table 1. Excerpts from the Interview Transcriptions that are within the Courses Category

		Student Excerpts
A.	Australian Junior	"We probably touched on them, but whether we have gone into them deep enough to say that we understand them. We have a knowledge of them. We probably don't understand them fully."
B.	Australian Junior	"But mostly we … focus …on the technical aspects. …. The only one I'd say that they nailed at uni [university] is technical. The social/ cultural is going to be very person dependent…But in terms of economical and environmental and global, we just scratched the surface."
C.	American Senior	"Exactly. We still need a writing class, but sending us to the English department is pretty inane. … learning how to write an expository paper on … the color of the sky is … different than writing a lab report"
D.	American Junior	"Sometimes you can make a connection on your own…Fluids and thermo both are basically talking about the same stuff. And there's other classes that crossover all of the time. But I really hope that there's some class that we can take as seniors that pulls everything together…otherwise its just all these ideas… It would help to have some instruction on how to put them together"

A difference between Australian and American engineering programs that surfaced in the focus groups was the inclusion or exclusion of liberal arts courses in the curriculum. The Australian students indicated that they were not required to take liberal arts courses. In the American focus groups, the students' overwhelmingly agreed that liberal arts courses were not particularly helpful in their engineering educational development (See Excerpt C in Table 1). However some students indicated that the liberal arts courses were necessary to provide a well-rounded college education. The students agreed that the liberal arts courses were not only unconnected to their engineering courses, but that they were also difficult to reconcile with engineering concepts. For example, the juniors explained that when they tried to apply what they learned in their English courses to assignments in their engineering lab courses, they were not successful. Their engineering professors preferred lab reports that are in a structure similar to the way they were taught in high school science courses. The seniors suggested that explicitly connecting liberal arts courses with engineering courses would remedy this problem, i.e. offering a technical writing course in the place of the English course. Some students also suggested that instead of taking a fine arts elective, an option to take another engineering elective would be beneficial to their educational development. A theme that is beyond the scope of this paper that surfaced in the American focus groups was the lack of an apparent connection between the different courses within engineering (See Excerpt D in Table 1).

Extracurricular Activities

The American and Australian students indicated that complex systems could be introduced through departmental extracurricular activities such as the SAE formula car or the solar boat. The students also indicated that extracurricular activities help one become a well-rounded person, which is a characteristic in alignment with complex systems thinking (See Excerpt A in Table 2). However, the American and Australian students expressed that these departmental extracurricular activities were not accessible to the majority of the students (See Excerpt B in Table 2). American and Australian students expressed confusion about the departmental extracurricular activities program being such a small program (See Excerpt C in Table 2).

Table 2. Excerpts from the Interview Transcriptions that are within the Extracurricular Activities Category

		Student Excerpts
A.	Australian Junior	"People think that if you automatically get good grades, you get paid more. You will get a good job, and that's just not true. It depends on the character that you have and, the extracurricular activities are great themselves, but they also, I think, are character building. And that's probably a big thing. And I'd push that, probably even more than, as much as the engineering."
B.	Australian Junior	"If the uni [university] wants to be building better people on the whole. Then they need to be looking at schemes for everyone as opposed to 10 or 15."
C.	American Junior	"Well, I mean it's not like you don't have enough time to do them. You could definitely do that stuff and still do your schoolwork. It was kinda confusing to me why we don't have a bigger program like that. I understand that people have to work and they've got to do this. It definitely should be a lot bigger than what it is. We definitely do have the capability of doing it."

Work Experiences

The difference that stood out most prominently among the different components (courses, extracurricular activities, and work experience) was the difference in work experience between the American and Australian engineering students. In Australia, the accreditation body, the Institute of Engineers, requires that all students have exposure to professional engineering practice. At the University of Queensland, engineering students are required to complete 60 days of practice approved by the executive dean, and write a 1000 to 1500 word report on their professional experience to meet the accreditation requirements; however, in the US there is not a comparable requirement.

The Australian students explained that the required work experience elicited a true understanding of the different aspects of complex systems (See Excerpt A in Table 3). The work experience provided context for the required courses, which led to an increased likelihood of learning. An Australian senior completed her work experience during the summer after taking an engineering management course, and after the work experience she understood the purpose of the required course (See Excerpt B in Table 3). An Australian junior recommended requiring work experience at an earlier time in the curriculum so that they can have context for their courses (See Excerpt C in Table 3). The American students recommended requiring work experience (See Excerpt D in Table 3), however their discussion of work experiences was very general, and less than half of the students had work experience in an engineering environment (45%).

Table 3. Excerpts from the Interview Transcriptions that are within the Work Experiences Category

		Student Excerpts
A.	Australian Senior	"I think work experience is really the only time when we gain exposure to everything outside of the technical…when I went into my work I wasn't really all that helpful on the technical side, because you're still an undergrad [undergraduate] you can't really do much more. … Beyond vac work [vacation work, referring to required work experience]…I don't really think we dig much into it [complex systems]."
B.	Australian Senior	"I did my vac work after that course [management course]. I found the course really beneficial when I was in vac work. But I found that I didn't enjoy it when I did the course. I thought it was useless. But now I understand."
C.	Australian Junior	"After I did my first set of work experience I came back and could sit in certain lectures and relate to stuff a lot more…As soon as something comes up that you can actually relate to you're much more likely to pay attention to it… and to look into it properly. So if they did that earlier on and people could get a good feel for what they needed, then they'd pay a lot more attention and focus on the right stuff later on and throughout their degree."
D.	American senior	"If you could drag some experience into that classroom knowledge and make it part of the curriculum. I think you could put out a better student and a better applicant."

DISCUSSION

The student's responses suggest that complex systems study is not prevalent within their undergraduate engineering development program. For both American and Australian students, a few design-based courses introduced complex systems concepts. The American engineering undergraduate program was developed under the assumption that requiring the students to take humanities courses would make them well-rounded people [Rugarcia, 14]. If this assumption were valid, then the students would mention their humanities courses as a source of learning about the concepts of complex systems. The inclusion of humanities courses in the curriculum may need to be reconsidered, if indeed the students are not gaining from them what was intended. The students agreed that extracurricular activities and work experiences would be an opportune place to learn about complex systems study. The American students spoke about extracurricular activities and work experiences very generally, which suggests that have limited personal experience participating in extracurricular activities or working. This could be a deficit in the American engineering educational development system. A possible remedy to this is to offer more support (personnel and finances) to extracurricular activity programs. A possible remedy to the lack of work experience is to encourage or require students to acquire work experience prior to graduation.

This pattern of responses in the student focus groups leads to an important question that is beyond the scope of this research: does the departmental and course structure discourage students from understanding the connections and interrelationships between different courses and disciplines? In order to explore this question further, the chair of the mechanical engineering department was interviewed. In the interview he was asked, *"Students receive fundamental grounding in liberal arts courses, but we have found that many of these students simply are not connecting material from their liberal arts course to their engineering courses. Does this surprise you?"* He responded, *"No, that doesn't surprise me, because as engineers we kind of make them think in a different way, and they end up thinking that way, because we are more numbers-based people…even sometimes we'll show numbers that don't make sense, but we are happy to see the numbers, which again is a deficiency for us. Relating numbers to the physics…is something that we are not doing more and more."* This question needs to be explored further in future research.

CONCLUSIONS

This research project involved conducting focus groups with undergraduate mechanical engineering students at the University of South Carolina and at the University of Queensland. The qualitative nature of this study resulted in a depth of understanding of student's perceptions of the inclusion of complex systems study integration in their undergraduate educational development. There is a minimal amount of complex systems study present in required undergraduate courses. In America, the required humanities courses are not a source for complex systems integration. Extracurricular activities would be an opportunity to learn about complex systems; however none of the student participants reported participating in extracurricular activities. Both American and Australian students were disappointed with the opportunities to participate in extracurricular activities. Prior to attending the university, the students believed that extracurricular activities would be a large part of their college experience; however they were not successful in securing a position on the extracurricular teams. The Australian students learned about complex systems during their work experience and understood the purpose of required courses after their work experience. American students believed that work experiences would expose them to complex systems study; however they did not personally have any work experience. Overall, these findings suggest that the educational experience could be altered in many ways to expose students to complex systems, i.e. restructure the curriculum, support larger extracurricular programs, and/or require work experience.

This study benchmarked the state of complex systems study in engineering educational programs in America and Australia. The authors and others [Craig, 8; Chubin, 5; Pink, 13; Rugarcia, 14] strongly suggest that engineering graduates need to have a holistic understanding of engineering and how engineering influences and is influenced by the world around it. Ways to change the existing engineering educational development emerge when comparing American and Australian engineering educational programs. These changes could begin to address many of the recurring concerns in engineering education, such as understanding the interrelationships of engineering with typically non-engineering areas (such as global, social/cultural, environmental, and economical areas), in addition to being life-long learners, effective communicators, and ethical professionals.

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