UNIVERSITY OF NEBRASKA-LINCOLN COLLEGE OF ENGINEERING

UNDERGRADUATE ENGINEERING EDUCATION TASK FORCE

FINAL REPORT

March 15, 2018

TASK FORCE MEMBERS

Tim Wentz (DSAEC), Chair	Yi Qian (ECE)
Myra Cohn (CSE)	Chungwook Sim (CIVE)
Linxia Gu (MME)	Henk Viljoen (ChBE)
Roger Hoy (BSE)	Tareq Daher, special contributor

PREFACE

The UNL College of Engineering provides great value to its students. A committed body of faculty are engaged in delivering a high-quality educational experience, and enjoy a supportive university environment. We have an active committee for Continuous Teaching and Learning, and various departments within the College also offer similar resources and support for improvement of teaching. At the university level, there is growing momentum and enthusiasm around the science of teaching and learning (methods and approaches driven by research and data (Wieman, 2015)) and cross-disciplinary support exists in the form of various professional development programs. At the same time, there is a great opportunity for growth and improvement in how the undergraduate curricula across the College are delivered and the impact on students. The purpose of this report is to gather in one place a variety of ideas and information in order to better leverage our strengths, identify areas for improvement, and advance the quality of the undergraduate experience in the College.

The remainder of this report is organized around several themes, notably: *principles* that should underpin our efforts to create excellent undergraduate experiences, concepts on how curriculum can be *structured* effectively, methods and techniques that can enhance the *in-class* experience, and the corresponding synergistic activities which occur *outside* the formal classroom. Although the subsequent sections are organized under these themes, it should be noted that effective undergraduate education implementation involves components of all of these, which need to be woven together synergistically in a holistic approach rather than treated as independent elements of the undergraduate experience (Ambrose, 2013). The report closes with recommendations for action.

GUIDING PRINCIPLES

Commitment to community, diversity and inclusion

The undergraduate curriculum should embrace diversity in all aspects (race, gender, ethnicity, sexual orientation, nationality, disabilities, etc.). Our curriculum needs to equip students to function in a diverse workforce, and develop engineering solutions to address needs of diverse clients. Who we teach is as important as how and what we teach. Our recruiting efforts need to provide success pathways for underrepresented groups to enter the engineering profession. Our teaching and advising strategies should reflect our commitment to diversity and inclusion. The Complete Engineer Initiative is an example of a program that highlights are commitment to the holistic development of our engineering students.

Complementary and synergistic experiences in and out of class

Learning theories point out that for learning to be transferred to real life, students need to be exposed to learning that is practiced in an authentic context. In some theories, knowledge is considered to be "transformed" rather than "transferred" – students reconstruct their knowledge in a way that they can understand it (Larsen-Freeman, 2013). Therefore, a complete education includes in-class instruction (knowledge acquisition) as well as out-of-class experiences which facilitate this transfer or transformation. This is exemplified in what Fink (2003) calls "significant learning." Another way of putting this is that a complete education includes in-class and out-of-class activities which are synergistic and/or complementary. This can take many forms, including labs, research experience, internships, clubs, and so forth – any context in which students can apply what they learn in class. UCARE is a very successful example, as are ¼-scale tractor and Baja teams. We want to reach a larger cross-section of our students in similar ways (offer a sufficient breadth of these opportunities), such that all students can find their unique place in engineering.

Connecting theory to practice and preparing for the workforce

Another aspect of this is the need to connect theory to practice. Ultimately the purpose of an education is to prepare students for the workforce. Therefore, a quality engineering education will provide bridges or connections between knowledge gained in class and its application in engineering practice. This can involve experiential learning and internships.

Faculty development and accountability

Excellence in teaching and learning necessitates a commitment by the faculty to professional development. The College should provide opportunities and incentives for faculty to learn and adopt evidence-based teaching practices. An expectation of excellence in teaching requires accountability through the annual evaluation, promotion and tenure processes. Evaluation of teaching needs to be more holistic and include course evaluations, peer engagement, personal reflection, and professional development. Currently, the ARISE workshops, and COPUS peer observation initiative are examples of programs available for faculty development.

CURRICULUM STRUCTURE

Portability and flexibility in first-year curriculum

Our curriculum should provide opportunities for students to switch majors within the college during the first year without extending time to graduation. Students often don't know the differences between engineering majors. Strategies for this include common first-year curriculum for the college and portability of introductory courses to majors. While it is important to recognize the needs of the different engineering programs, our curriculum should allow for students to explore different engineering majors and transfer seamlessly within the college early in the program. This should help with retention and graduation rates. Introductory courses should emphasize what engineering is and provide opportunities to engage in engineering activities to keep students engaged as engineering majors.

Curricular flexibility and removal of bottlenecks

Engineering student success can be measured in many different ways, including the number of students who complete an engineering degree (van den Bogaard 2012). To complete a degree, a student must satisfy all requirements associated with the degree. To help improve student success and reduce the time to complete a degree, removal or reduction of curricular bottlenecks and improved curriculum flexibility should be considered. Wigdahl, et al. (2014) present a method for quantifying the efficiency with which students can progress through a degree by considering a curriculum to be a directed graph where courses are represented by nodes and pre/co-requisites are represented as directed edges. Curricular efficiency metrics are then defined. These include the total degree hours, curriculum rigidity (number of edges divided by the number of nodes), the maximum number of prerequisites of any course in the curriculum (maximum in degree), the maximum number of follow-on courses (maximum out degree), the longest path through the curriculum (expressed as number of nodes), and the number of bottleneck courses (nodes with in degree greater than three or out degree greater than three or total degree greater than five). Efficient curriculums have low numbers for all efficiency metrics.

Using Wigdahl et al.'s metrics, an analysis of several majors in the College of Engineering were done using curriculum flow charts provided to the task force by task force members. The results of the analysis are shown in Table 1. The graph analysis illustrates differences in majors. Civil engineering is the least rigid of the majors followed closely by software engineering and electrical engineering. The most rigid major is mechanical engineering. Civil engineering and software engineering also score well in terms of the lowest maximum number of prerequisites for any course of 2. Mechanical has the highest maximum number of prerequisites for any course at 6. Biological systems, civil, computer science and electrical engineering all have the lowest maximum number of follow-on courses for any course at 4. The rest of the majors examined are at 5 for this measure. The longest path through the curriculum defines the fewest number of semesters needed to successfully complete the requirements of a major.

For all majors, the longest path may be longer as all majors have technical electives that are likely to have a prerequisite not readily evident. A more thorough analysis of civil engineering was done to examine this issue. For civil engineering, the longest path would include a design or technical elective. The graph of the civil engineering major (Lincoln campus) is shown in Figure 1. The lengthening of the longest path from technical electives is shown by the prerequisite link shown between several required 300-level civil courses and the technical and design electives that must be taken from 400-level civil classes. If this more thorough analysis had not been done, the longest path would have been reported as 6 courses.

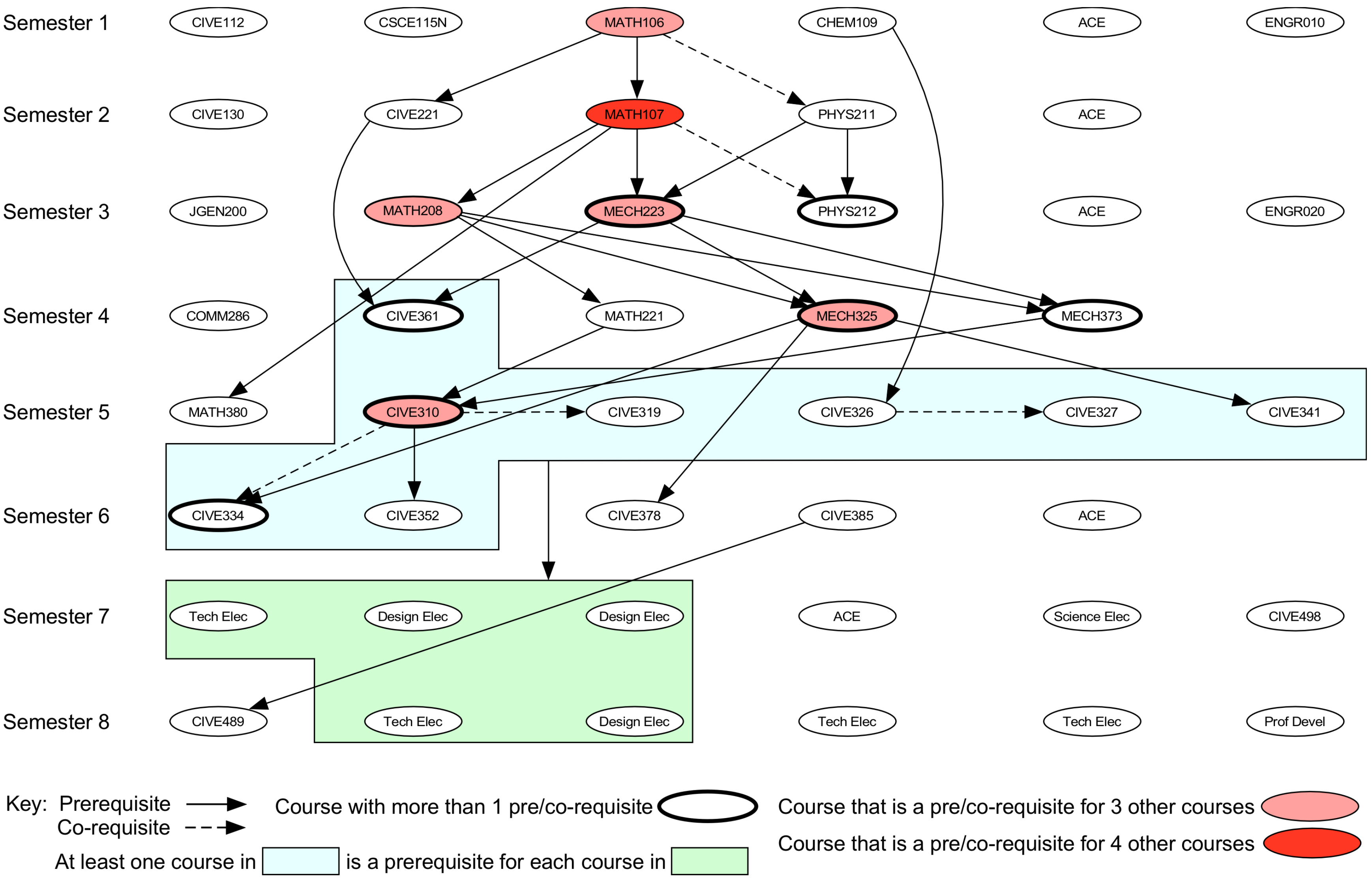
It is likely that for all other majors examined, the longest path reported in Table 1 may be longer by one semester. If that is the case, some majors may require more than 8 semesters to complete the degree. Further analysis would be needed to determine the details; the analysis would need to take account of co-requisites. The last measure of curriculum efficiency is what Wigdahl et al. refer to as bottleneck courses. Per Wigdahl et al.'s definition, civil engineering has no bottleneck courses while mechanical engineering has seven.

Table 1 – Summary of Graph Analysis of Several Majors

Accredited Degree	**Total Credits (credits)**	**No. of courses (nodes)**	**No. of Pre/Co-requisities (edges)**	**Curriculum Rigidity (edges/nodes)**	**Course(s) with maximum number of pre/co-requisites (maximum in-degree)**	**Course(s) with maximum number of follow-on courses (maximum out-degree)**	**Longest path (# of courses)**	**No. of Bottleneck Courses (degree in>3; degree out >3; degree in&out >5)**
AE (MS)	165	78	59	0.76	AE8030 (**4**)	MATH1960 (**5**)	**7**	**3** - MATH1960; PHYS2110; AE8030
BSEN (BS)	133	46	37	0.80	BSEN344 (**4**)	MATH208 (**4**)	**8**	**2** - BSEN344; MATH208
CHME (BS)	131	46	48	1.04	CHME453 (**4**)	MATH107 (**5**)	**8**	**4** - MATH107; CHME202; CHME331; CHME453
CIVE (BS)	130	45	28	0.62	PHYS212, MECH223, CIVE361, MECH325, MECH373, CIVE310, CIVE326, CIVE334 (**2**)	MATH107 (**4**)	**7**	**1** - MATH107
CSCE (BS)	126	43	36	0.84	CSCE488 (**4**)	CSCE230, CSCE155E, MATH106 (**4**)	**6**	**4** - CSCE230, CSCE155E, MATH106, CSCE488
SOFT (BS)	124	41	26	0.63	CSCE235, CSCE451, CSCE322, CSCE486 (**2**)	SOFT260, SOFT261 (**5**)	**7**	**2** - SOFT260, SOFT261
ELEC (BS)	126	44	29	0.66	ELEC306, ELEC317 (**3**)	ELEC216 (**4**)	**8**	**1** - ELEC216
MECH (BS)	129	45	58	1.29	MECH343 (**6**)	MATH208 (**5**)	**7**	**7** -MATH107, MATH208, MECH223, MECH350, MECH380, MECH343, MECH446

Key	
	🟩 Best
	🟥 Worst

Figure 1 – Graph Representation of the Civil Engineering Curriculum



Broadening the “intro” to engineering

A study of data on changes of major in the college showed that many students do not declare their engineering major with full confidence. In other words, many students elect to change their major at some point, but remain within the college. In order to support students in their goals and work within the credit-hour, financial, and other constraints imposed on students, this finding suggests that not only should barriers to timely changes of major be reduced as much as possible, but engineering curricula should include enough exposure early-on so that students can make informed decisions about their major program of study and find where they fit best. Some of our programs include “intro” courses, and others do not. For those intro courses that exist, it is quite uncommon to see a broad, multidisciplinary approach in which students see their major discipline framed in context alongside other engineering disciplines. Such a broad “general intro to engineering” course may be an effective way to put the needed information and first-hand experience in the hands of students so that the changes of major which they elect to make can be done in a timely manner and lead to their success as students. This may also serve to attract other students not initially declaring engineering majors.

Introducing design early

Fundamental to all kinds of engineering are the processes of analysis and synthesis. An introductory course which examines these processes could be interesting to a wide audience. It would be useful to those interested in engineering as a career and it could be interesting for those who are simply curious. Analysis means breaking a problem into smaller simpler pieces. We do this by recognizing the rules which govern physical systems. Each part of a system interacts with other parts of the system according to a set of rules. By discovering and using this set of rules we can see where the spaces between the simpler pieces are and we can break the problem apart into its components. Synthesis involves taking simple components and putting them together according to a set of rules to create a complex system which performs functions we need.

An introduction to engineering would illuminate the process of analysis - the discovery of the physical rules that govern interactions and the tools we use to isolate the subsystems - and synthesis - taking well understood simple components. We could do this for a variety of systems - economic systems, biological systems, and the systems of most interest to us in our particular fields.

In cognitive neuroscience, the process of visual cognition is a relatively well understood process - the subsystems are the different parts of the cortex. The process of analysis and synthesis occurs in the signals that pass through the various parts of the cortex. In economics, we could look at the global trade system - again identifying subsystems and the modes of interactions between the subsystems. For engineering applications, the task (from our point of view) is simpler. For example, in circuit analysis there are only two rules - the sum of currents entering a node is equal to the sum of currents leaving it, and the potential drop between two nodes is independent of the path taken to go from one to the other. Using these two rules we could show how to analyze circuits which might be of interest to the students. Synthesis at a simple level would involve understanding how to put together components to make something of interest. Programming is an excellent example where analysis and synthesis are both needed.

A course built carefully with an eye to both entertaining and informing can be developed which would provide an introduction to engineering and lead to courses in design in different disciplines.

Multidisciplinary capstone

The current approach to capstone experiences across the college is relatively fractionated. Each program rightly controls its own strategy for achieving ABET-related goals, a number of which are pertinent to capstone experiences, and capstone courses are structured somewhat differently in each program. Although the current ABET language mentions “an ability to function on multidisciplinary teams,” the multidisciplinary aspect is absent for many of the projects. Students generally form teams within their own engineering discipline which limits students' exposure to new and different vocabulary, requirements/constraints, and ways of thinking about problems. To be truly responsive to the spirit of this ABET student outcome, it would be beneficial to create a college-wide structure within which multidisciplinary capstone teams could be formed. Students need a well-defined pathway by which they can opt-in for interdisciplinary experiences which are interesting to them. This would also be consistent with the need for curricular efficiencies, as a single course sequence could replace a host of discipline-specific ones. It would also be consistent with the desire to provide experiences which are authentic and encourage the transfer of learning to workforce-relevant scenarios.

IN-CLASS IMPLEMENTATION

Connecting theory to practice through active, problem-based and outcomes-based learning

For meaningful learning to take place, theory should be connected to practice not only through co-curricular activities but also in the classroom. This can be carried out through the use of scientifically supported methods such as active learning and problem-based learning. It can even be as simple as showing videos of how a principle is applied in the real world. Instructors have flexibility to find and/or develop approaches which are suitable to the subject matter of their courses and consistent with other in-class methods of student engagement they may already be using. (Professional development opportunities should be provided to faculty seeking to correctly and effectively implement these types of strategies.) Designing courses based on student outcomes is widely recognized as a best practice. Student outcomes clarify what students should expect to learn, help students learn more effectively, and make graduates’ skills and knowledge clear to employers. Incorporating techniques such as authentic performance tasks and performance-based learning and assessment techniques throughout the engineering curriculum can help faculty formulate and assess student outcomes in terms of the skills students will use in practices while providing students with engaging and meaningful learning opportunities to acquire and practice the critical skills necessary to solve real-world problems.

Labs, shops and collaboration spaces

Highly accessible labs, shops, maker spaces, design spaces and other hands-on and collaborative environments are a characteristic of cutting edge engineering programs. Increasing access to these types of spaces can be expected to increase student engagement, solidify learning as knowledge is transferred outside the classroom, and attract students who are interested in getting involved beyond the rubber stamp of a class grade. Labs, shops and collaboration spaces can serve dual purposes, supporting components of coursework as well as independent co-curricular activities.

As we embrace curriculum that connects theory to practice, and incorporates more team-based projects, student access to facilities should provide for flexibility in when/how learning occurs. The success of Adele Learning Commons demonstrates student need for collaborative work-spaces. Our engineering facilities (design labs, maker spaces, machine shops) should have expanded availabilities to our students. As enrollments increase, such expanded access could also enable open laboratory concepts to ease class scheduling constraints. Specific issues related to explore include training opportunities for students, staffing, and hours of operation.

Developing metacognitive, lifelong learning and communication skills

The ultimate outcome of student learning is the application of learned skills and knowledge to real-world problems post-graduation. Metacognition (thinking about thinking) is key to the development of lifelong learning, and communication skills are key to working with others. The 'Complete Engineer Initiative' has begun to address the critical need for technical skills to be paired with non-technical competencies through activities in the classroom, co-curricular programs and through service opportunities. Extending the work started by the 'Complete Engineer Initiative' to help students develop non-technical skills can be accomplished without sacrificing technical content through explicit efforts to teach metacognitive skills and communication skills in engineering courses using strategies such as self-regulated learning and reflective writing.

High-impact educational practices rooted in data and outcomes

High-impact teaching practices have been shown to increase student retention and student engagement. Students who use these approaches also tend to earn higher grades and retain, integrate and transfer information at higher rates [Kuh, 2008]. Students in the College of Engineering currently benefit from these practices in the classroom beginning with their first-year seminar and culminating with their capstone courses and projects. Other high-impact teaching practices offered at UNL to augment classroom experiences include learning communities, service learning, undergraduate research, and internships. These teaching practices provide students with diverse abilities, interests, and motivations additional opportunities to meet their educational needs and objectives. And, while many students have participated in these optional practices, the college should encourage more students to participate by continuing to actively promote these outside-the-classroom practices, and by providing more opportunities and more diverse opportunities, and by educating students about the many advantages of participating in these practices.

SYNERGISTIC ACTIVITIES

Emphasizing extracurricular opportunities

Because of the interconnection between in-class learning and out-of-class knowledge transfer, students should be encouraged to engage in extracurricular activities related to the practice of engineering. This involves a messaging component and a support component. In the media that students consume coming from the College of Engineering, there should be a strong theme indicating that involvement in these types of activities is valuable. Concurrently, the behavior has to support that message; in other words, faculty and staff have to believe in the message enough to actively support those extracurricular activities and contribute to imbuing them with real value.

Research opportunities

The Association of American Colleges & Universities has a list of high-impact educational practices (AACU, 2018). One of these is undergraduate research. Research opportunities need to be provided, especially for high-performing students. These research activities are part of the fabric of the learning experience and a stepping stone to graduate study, and serve as a crucible for transferring classroom knowledge and supplementing it with additional training. Student research experiences are also valuable for increasing retention of high-achieving undergraduates in our graduate programs. Existing strengths and opportunities such as the UCARE program should be leveraged, and possibly complemented with further enhancements. Incentives for faculty to participate in undergraduate research may be appropriate in order to build this pipeline.

Service learning

One of the high-impact practices on the AACU list (AACU, 2018) is service learning, in which students apply their disciplinary knowledge in the form of service to the community. Whereas these types of extracurricular activities (e.g., Engineers Without Borders, EWB) are often treated as clubs, Purdue has an integrated service learning program called Engineering Projects in Community Service (EPICS) and tie clubs like EWB into this program. This stresses the importance of design-based, hands-on projects. This model of service learning seems to engage students at a personal level, bring out their interest in applied engineering, and strengthen retention.

Learning communities

Learning communities (LCs) are on the AACU list of high-impact practices (AACU, 2018) and provide an opportunity for students to form meaningful connections with each other and with a faculty/staff member. Students in UNL engineering LCs are retained at a higher rate than students not in learning communities (84.7% vs 81.3%). The retention gains do not correlate with grade differences. Average cumulative GPA of LC students are less than cumulate GPA of non-LC students (2.85 vs. 3.03). It would appear that LCs could be an effective retention strategy for at-risk student population. Currently, engineering LCs include three in thematic areas (robotics, engineering to change the world, engineering human performance) and one in a disciplinary area (computing for good). Opportunities exist to increase the number of engineering LCs organized not only by major but also by additional thematic areas and specific student populations (pre-engineering, first-generation etc.).

Internships and co-ops

Internships are included in the AACU list of high-impact practices (AACU, 2018). Although it is not feasible for all students to be placed in internships, these direct disciplinary experiences should be encouraged and facilitated, as they provide opportunities for professional advice and coaching in addition to the value of the practical experience gained. In some limited cases, it is appropriate for these activities to be counted as credit towards the degree.

Mentoring

A key commonality between internships/co-ops and learning communities is the mentoring aspect. In co-ops and internships, the student is mentored by at least one professional in his/her field. In learning communities, students are typically mentored by one or more peers (students in the same or similar programs but ahead in their timeline). Mentoring can also come through alumni involvement, academic advising, and other avenues. Whatever its origin, it helps students to find their place within their discipline, become more engaged, and see their education in the context of long-term goals.

Bridge programs

Bridge programs are designed to prepare students for a successful first-year engineering experience by providing:

- Supplemental math instruction emphasizing future Calculus I success
- Strategies and planning for academic success
- Participation in a community service project
- Interaction with faculty/staff, current students and alumni
- An opportunity to meet other new College of Engineering students
- A unique experience and introduction to the life of an engineering student

Currently engineering bridge programs include Engineering Readiness Academy (ERA) City Campus and ERA Scott Campus. Both programs last approximately seven days and require students to live on campus during the program. Both programs limit the number participants to 30 or under. Target applicants have an ACT math score between 24 and 28. It is anticipated that students participating in bridge programs will have a higher retention rate when compared to students with similar math ACT scores not participating. Opportunities exist to increase the number of students participating in engineering bridge programs. Opportunities may also exist to integrate bridge programs and learning communities.

CONCLUSION

Many of the ideas presented above are already in various stages of implementation in the college. However, there is much to be learned from others and much improvement to come. Examples of successful efforts elsewhere include Purdue's EPICS service-learning program, Michigan State's CoRe program (including courses, tutoring, advising, professional development, and peer connections), a highly flexible engineering curriculum at Dartmouth, and the NAE Grand Challenges Scholars program (a combined curricular, co-curricular, and extra-curricular program focused on five competency areas).

The concepts, ideas, and recommendations contained in this report need follow-through. Currently, the Curriculum and Academic Standards Committee in the College of Engineering is burdened with administrative tasks (reviewing and approving course updates, hearing student grade appeals, etc.) and is not explicitly charged with developing or coordinating a broader vision for curricular reform. Similarly, the committee on Continuous Improvement in Teaching and Learning is largely oriented on supporting ABET accreditation efforts across the college, and its scope of responsibility does not explicitly cover large-scale curricular change. Therefore, formation of a separate working group may be necessary in order to carry out and/or act on any recommendations in this report deemed worthwhile.

References

AACU (2018). “High-impact educational practices,” https://www.aacu.org/leap/hips
Ambrose, S. A. (2013). “Undergraduate Engineering Curriculum: The Ultimate Design Challenge,” The Bridge 43(2): 16-23.

Fink, L. D. (2003). *Creating Significant Learning Experiences: An Integrated Approach to Designing College Courses*, Jossey-Bass, San Francisco.

Larsen-Freeman, D. (2013). “Transfer of learning transformed,” Language Learning: A Journal of Research in Language Studies, 63:S1.

van den Bogaard, M. (2012). "Explaining student success in engineering education at Delft University of Technology: a literature synthesis." European Journal of Engineering Education 37(1): 59-82.

Wieman, C. and Gilbert, S. (2015). “Taking a Scientific Approach to Science Education, Part II—Changing Teaching,” Microbe 10(5): 203-207.

Wigdahl, J., G. L. Heileman, A. Slim and C. T. Abdallah (2014). "Curricular Efficiency: What Role Does It Play In Student Success?" 121st ASEE Annual Conference & Exposition.