

ASSESSMENT REPORT FOR Group 2: Cycle 1 - Fall 2017 - Fall 2019

Mission Statement

“The Biomedical Engineering Program at the University of South Carolina prepares its graduates technically and professionally to meet the growing demands for positions in biomedical engineering industry and academia or continuing studies in graduate programs and medical schools. By continuously improving the undergraduate and graduate programs, the Program responds to the rapidly changing field of biomedical engineering to serve as an effective resource and partner for industry, government, and academia.”

The B.S. degree in biomedical engineering fits into the program’s mission of developing technically and professionally competent biomedical engineers.

Goal 1.

"Graduates will practice in a professional career or pursue an advanced or professional degree in which they are contributing to scientific, professional, and/or local communities through the improvement of human health."

Goal 1 refers to the technical grounding that graduates receive. By preparing technically competent engineers, this goal supports the mission to “*prepare...graduates technically*”.

Table I - Curriculum

Table II - Curriculum Map of Learning Outcomes

Curriculum

The curriculum for the BS in Biomedical Engineering is summarized in the major map presented in Table I. This curriculum was revised based upon data gathered from faculty and students and implemented beginning in Fall 2017. Biomedical Engineering courses are related to the Learning Outcomes as depicted in Table II, indicating the emphasis of each course for the respective LO. Learning Outcomes of the Biomedical Engineering B.S. Program are derived directly from the prescribed Engineering Accreditation Commission of ABET student outcomes to ensure that consistency is maintained between the two accreditation bodies throughout the process of assessment, evaluation, and curriculum improvements.

Technical electives can be fulfilled with mathematics, biology, chemistry, or engineering courses chosen from an approved list.

Engineering electives can be fulfilled with engineering or computing courses chosen from an approved list.

Biomedical engineering electives are chosen from an approved list of courses from biomedical and other engineering disciplines. A complete list of all approved electives can be found in the Biomedical Engineering bulletin: http://bulletin.sc.edu/preview_program.php?catoid=88&poid=5718&returnto=2551

Required courses in general education meet requirements defined by the University.

Learning Outcome 1.

Ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.

Measures and Criteria

Biomedical Engineering (BME) students need to be knowledgeable in many different fields of science, including mathematics, biology, chemistry, physiology, and physics. Students apply the knowledge that they acquired in these subjects in the early parts of the curriculum to solve progressively complex problems typical of those encountered in biomedical engineering practice, demonstrating increasing mastery of LO 1

from freshman to senior year. Twelve core courses from freshman to senior year have been selected from which to evaluate student performance with respect to application of mathematics, biology, physiology, chemistry, physics, and basic engineering topics: BMEN 101 Introduction to Biomedical Engineering, BMEN 211 Computational Tools for Biomedical Systems, BMEN 212 Fundamentals of Biomedical Engineering, BMEN 240 Cellular and Molecular Biology with Engineering Applications, BMEN 263 Introduction to Biomechanics, BMEN 271 Introduction to Biomaterials, BMEN 290 Thermodynamics of Biomolecular Systems, BMEN 321 Biomonitoring and Electrophysiology, BMEN 345 Anatomy and Physiology for Biomedical Engineers, BMEN 354 Transport in Biological Systems, BMEN 363 Bioinstrumentation, and BMEN 391 Kinetics in Biomolecular Systems. Due to the implementation of a new curriculum in Fall 2017, BMEN 363 was not offered to the junior class before the Spring semester of 2020. Hence, BMEN 363 will not be used for the assessment of LO1 during this assessment cycle but will contribute to the qualitative and quantitative assessment of LO1 during the Fall 2020 to Fall 2022 assessment period.

Attainment of LO 1 is evaluated both qualitatively and quantitatively in the manner described below.

Qualitative Assessment:

The Assessment Committee in close cooperation with each course instructor determines students' attainment of LO 1 based on individual exam problems, quizzes, homework, project work, or other oral or written assessment testing the students' ability to identify, formulate, and/or solve complex engineering problems by applying principles of engineering, science, and mathematics in each of the twelve courses mentioned above. For this, instructors are required to disclose examples of their assessment of LO 1 (this may be exam/ quiz questions, homework or project assignments where students were asked to apply certain science principles to engineering problems) as part of an extensive course review document as described in "Methods". Within this document, course instructors are also required to reflect in writing on key student competencies and key deficiencies regarding LO 1. Upon review of the LO 1-specific assessments by the Assessment Coordinator, the Assessment Committee meets with the respective instructor for further discussion and feedback. The Committee then assesses how well LO 1 was attained in the respective course and assigns a letter grade according to the following system:

A: Learning/course outcome is not only attained but exceeded; little to no room for increasing student performance or confidence

B: Learning/course outcome is comfortably attained; improvements that could raise the level of student performance or confidence are still perceived

C: Learning/course outcome is attained, but this attainment is marginal; improvements that could raise the level of student performance and confidence are obvious

F: Learning/course outcome is not attained; major improvement is required to raise student performance and confidence to acceptable levels

Temporally, attainment of LO 1 is expected to improve as students progress through the curriculum. Courses in freshman and sophomore year (BMEN 101, BMEN 211, BMEN 212, BMEN 240, BMEN 263, and BMEN 290) are expected to receive a qualitative grading of a grade of C or higher, whereas courses in junior and senior year (BMEN 271, BMEN 321, BMEN 345, BMEN 354, and BMEN 391) are expected to receive a grade of A or B.

In addition to the annual course review process, attainment of LO 1 is also assessed via feedback from students as collected during the student course evaluations at the end of each of the twelve courses. Open ended questions in all eleven core courses are examined by the assessment coordinator for qualitative student feedback regarding LO 1 and discussed with the course instructor during the course review meeting.

Quantitative Assessment:

Course evaluations administered at the end of each course determine the level of confidence that students have with respect to their ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. This is accomplished with closed ended questions to be answered using a Likert scale. Students are expected to increasingly gain confidence in this area as they advance from freshman to senior year. At least 65% of students must report high levels of confidence in their ability to identify, formulate and solve complex biomedical engineering problems in BMEN 101 and BMEN 211 (freshman year), at least 70% of students in BMEN 212, BMEN 240, BMEN 263 and BMEN 290 (sophomore year), at least 75% of students in BMEN 271, BMEN 321, BMEN 345, and BMEN 354 (junior year) and at least 80% in BMEN 391 (senior year).

In addition, an on-line exit survey of graduating seniors, administered annually, determines the level of confidence that students have with respect to LO 1 upon graduation. At least 85% of graduating seniors must respond that they have a high level of confidence in their ability to apply basic science and mathematics knowledge to complex biomedical engineering problems.

Direct Quantitative Assessment for LO 1:

The last class in the twelve-class sequence mentioned above, BMEN 391, contains a semester-long project in which students need to design a reactor that produces a desired yield under defined constraints. This semester-long complex engineering problem was chosen as a direct learning measure for LO1 since students need to apply principles of chemistry, biology, thermodynamics, and mathematics to solve this open-ended engineering task. Student performance on this assignment is assessed and the average score and grade are recorded. Students typically take this class in their senior year and should be knowledgeable in applying sciences and math to solve open-ended engineering problems. It is expected that at least 85% of all students receive a grade of A or B in this assignment.

Methods

Five primary assessment tools are employed to assess that students are meeting the criteria for individual learning outcomes (LOs), two qualitative ones (1, 2) and three quantitative ones (3, 4, 5).

(1) Qualitatively, attainment of learning outcomes in applicable courses (Table II) is assessed by the Assessment Committee in the form of annual course reviews. The Assessment Committee is comprised of the Assessment Coordinator, the Director of the Biomedical Engineering Program, the Undergraduate Director of the Biomedical Engineering Program as well as members of the Undergraduate Committee of the Program. The instructor of a course is asked to prepare a course review document detailing which student assessments in the course connects to the respective LO and provide information on average student performance in these student assessments. For this, the instructor is asked to reflect in writing on students' key competencies and deficiencies for each individual course outcome connected to the respective LO. Lastly, the instructor is asked to reflect on the success of changes to the course compared to the previous offering, if applicable, and to recommend changes to the upcoming course offering. The Assessment Committee together with the respective course instructor reviews all materials and assigns a letter grade (A, B, C, F) for each course outcome supporting the respective LO according to the following system:

A: Course/Learning outcome is not only attained but exceeded; little to no room for increasing student performance or confidence

B: Course/Learning outcome is comfortably attained; improvements that could raise the level of student performance or confidence are still perceived

C: Course/Learning outcome is attained, but this attainment is marginal; improvements that could raise the level of student performance and confidence are obvious

F: Course/Learning outcome is not attained; major improvement is required to raise student performance and confidence to acceptable levels

The course reviews, including outcomes from the Assessment Committee discussions, are then compiled by the Assessment Coordinator, and filed in the Main Biomedical Engineering Office with access to all faculty. Letter grades below B will result in more in-depth follow-up communication or meetings with the instructor to discuss possible options for improvement of learning outcome attainment. Since course reviews are held twice a year just before the start of the Fall and Spring semester, respectively, to discuss the respective previous year's Fall and Spring classes, qualitative assessment will end with Spring 2019 courses for this assessment period. This timing ensures that feedback about each course is handed to the instructor of a class just as they are preparing for their upcoming class when feedback is most critical.

(2) Student comments as collected in course evaluations at the end of each course offering are reviewed by the Assessment Coordinator and may provide additional qualitative feedback on each LO connected to the respective courses (see Table II). The Assessment Coordinator is present for all course review meetings, where qualitative student feedback in relation to LOs 1 to 7 for individual classes will be discussed in detail.

(3) Quantitatively, student attainment of individual LOs is assessed by probing students for confidence in the respective LO on a closed ended questionnaire at the end of each course connected to the respective LO (Table II) using a Likert scale. Student confidence is reported in % students who display "high or very high" levels of confidence in this student outcome and is expected to rise for each LO as students advance from freshman to senior year.

(4) Additionally, at the end of each spring semester, student exit interviews are conducted for students that graduate in May or during the upcoming Summer or Fall semesters. The Director of the Program will conduct these interviews; the Assessment Coordinator is present to take notes. Students are asked to assess the outcomes of their education including LOs 1 to 7. Student responses to both closed ended questions to be answered using a Likert scale and open-ended questions are collected in each of these areas and compiled by the Chair of the Assessment Committee. The compiled data is distributed to the Assessment Committee and the Assessment Coordinator and discussed at a designated meeting of the Assessment Committee for the purpose of listing student strengths and weaknesses and formulating action items for improvement of learning outcomes and program goals. Discussion comments and action items will be documented by the Chair of the Assessment Committee and filed in the Biomedical Engineering Office. Generally, 85% or more of graduating seniors are expected to show high or very high levels of confidence in each of the seven LOs.

(5) For each LO a specific assignment that assesses and exemplifies the respective LO has been chosen as a direct assessment of whether the Program is achieving the attainment of this LO. All assignments chosen are assignments handed to upperclassmen as they near graduation. Generally, at least 80% of students are expected to receive a grade of B or higher in the respective indicator assignment.

Results

Attainment of course outcomes connected to LO 1, the ability to identify, formulate and solve complex engineering problems by applying principles of engineering, science, and mathematics, as assessed in yearly course reviews is summarized in Table 1.1. Due to the implementation of a new curriculum in Fall 2017, BMEN 363 was not offered to the junior class before the Spring semester of 2020. Hence, BMEN 363 will not be used for the assessment of LO1 during this assessment cycle but will contribute to the qualitative and quantitative assessment of LO1 during the Fall 2020 to Fall 2022 assessment period. Courses in freshman and sophomore year are expected to receive a grade of C or higher in all relevant course outcomes in their course review; courses in junior and senior year must receive a grade of B or higher in all relevant course outcomes (see Table 1.1). The criterion was achieved for all freshman and sophomore classes with most classes receiving an A or B in the attainment of connected course outcomes except for the Fall 2018 offering of BMEN 240 where the course outcome "Ability to synthesize mathematical modeling concepts of biological molecules with cell and molecular biology to solve biomedical engineering problems." received a grade of C.

Student confidence regarding LO 1 as collected through student course evaluations in all applicable courses and during an exit survey for graduating seniors is reported in Table 1.2. Student confidence in LO 1 is expected to increase from 65% of students feeling confident or very confident in their ability to identify, formulate and solve complex engineering problems in freshman year up to a minimum of 85% of students

feeling confident or very confident in this LO by the time they graduate. A breakdown of minimum expected percentages for each year is listed in Measures and Criteria. Across the curriculum all classes met their minimum percentage of students feeling confident in LO 1 except for the Spring 2018 offering of BMEN 211 (freshman year; 64.1% instead of 65%), the Fall 2018 offering of BMEN 212, the Fall 2018 offering of BMEN 240, and the Spring 2019 offering of BMEN 263 (sophomore year; 24.2%, 52.2%, and 41.3%, respectively instead of 70%). Percentages rose sharply for junior classes, with all classes meeting the criterion except for BMEN 354. At the time of graduation, 90.4% (May 2018) and 92.2% (May 2019) of students feel confident or very confident in their ability to identify, formulate and solve complex engineering problems by applying principles of engineering, science, and mathematics.

As a direct measurement of student attainment of LO 1, the ability to identify, formulate and solve complex engineering problems, project grades on an open-ended reactor design as assigned during the senior class BMEN 391 have been collected and are summarized in Table 1.3. The criterion of at least 85% of students receiving a grade of A or B in this assignment has not been met in the Fall 2017 offering (78%). In the following two years, 100% of students received a grade of A or B in the same assignment, exceeding the criterion.

Tables for LO 1

Use of Results

Courses in freshman and sophomore year are expected to receive a grade of C or higher in all relevant course outcomes in their course review; courses in junior and senior year must receive a grade of B or higher in all relevant course outcomes (Table 1.1). The criterion was achieved for all freshman and sophomore classes with most classes receiving an A or B in the attainment of connected course outcomes except for the Fall 2018 offering of BMEN 240 where the course outcome “Ability to synthesize mathematical modeling concepts of biological molecules with cell and molecular biology to solve biomedical engineering problems.” received a grade of C. This low grade is also reflected in students’ low confidence levels in LO 1 (Table 1.2) for this course offering. This was the first offering of this course after implementation of the new curriculum. In open-ended questions collected as part of the course evaluation students identified a disconnect between the biologically focused lectures administered by one of the instructors and the engineering-focused lectures taught by a different instructor. During the course review the Assessment Committee and both instructors decided to integrate the two different lectures more, with the engineering portion being introduced in the biology lectures prior to the engineering seminar. Additionally, a new textbook was chosen that has a higher focus on quantitative biology. The Assessment Committee will follow up with both instructors as well as with the student evaluations during the next course review cycle in August of 2020 to see if attainment of course outcomes have improved in the Fall 2019 offering.

Other sophomore classes that also showed low student confidence levels for their first course offerings since the implementation of the new curriculum are BMEN 212 (Fall 2018) and BMEN 263 (Spring 2019). These courses were new to both instructors and students and lower perceived confidence of students’ ability to solve engineering problems may be due to material and homework adjustments during the first course offerings as well as the lack of peer tutors for these classes. Both BMEN 212 and BMEN 240 improved student confidence in the following course offering (BMEN 212 from 24.4% to 80.5% and BMEN 240 from 57.5% to 67.3%). BMEN 263 has only been offered once since implementation of the new curriculum. The Program will continue to monitor student performance and confidence in LO 1 as well as attainment of individual course outcomes connected to LO 1 in these courses and work closely with the course instructors to improve students’ ability to identify, formulate and solve complex engineering problems with the use of science and math principles.

In freshman year, students narrowly missed the criterion of 65% of students expressing high confidence in LO 1 during the Spring offering of 2018 (Table 1.2). In the open-ended feedback section of course evaluations and during open-ended questions and senior exit interviews students noted the disconnect between learning computational tools without being able to apply them to engineering problems this early in the curriculum. Likewise, BMEN 211 instructors noted that students lack the knowledge of biomedical systems and the engineering skills at the freshman level to successfully employ and strengthen simulations and modeling skills. On the other hand, comments from open-ended questions and senior interview discussions and faculty feedback identified the need for more exposure to higher-level modeling tools in the

curriculum, including a broader spectrum of software packages and programming languages. Hence, the Undergraduate Committee has proposed to move the Modeling and Simulations course to a later timepoint in the curriculum where students have the necessary engineering, anatomy and biomolecular background and are able to focus on improving their modeling and simulation skill sets and can explore more advanced computational software and applications thereof. This will equip seniors in the Program with a wider and more specialized tool set to tackle their senior design projects and will in turn provide graduates with a better understanding of the field of biomedical engineering in general. The discontinuation of BMEN 211 and simultaneous creation of a senior-level modeling class BMEN 411 Modeling and Simulation of Biomedical Systems was confirmed via a positive BME faculty vote; submitted for approval through the College and University and will go into effect in the Fall of 2020.

In junior and senior year, all course outcomes met the criterion of a grade of course review grade of A or B except for the Spring 2018 offering of BMEN 354 Biotransport where two of the three course outcomes connected to LO 1 received a grade of C. Likewise, the criterion of 75% (junior year) and 80% (senior year) of students feeling confident in LO 1 is met or exceeded in all junior classes except for BMEN 354. In course evaluations students identified the class as very challenging and were struggling with some of the concepts. During the course reviews the Assessment Committee discussed switching to a different textbook since the Spring 2018 textbook, despite being more biologically connected than the alternative, seemed more appropriate for a graduate class than an undergraduate class. A different Biotransport textbook was chosen for the Spring 2019 offering. Course review grades for Spring 2019 improved to a grade of B and student confidence levels rose from 35.5% to 60%. The Assessment Committee will continue to monitor attainment of student outcomes for BMEN 354 as well as student evaluations of this class.

In senior year, student confidence in their ability to identify, formulate and solve complex engineering problems improved significantly. At the end of their senior capstone design sequence, 90.4% (class of 2018) and 92.2% (class of 2019) of graduating seniors expressed high confidence levels in LO 1. The overall steadily increasing level of confidence of students throughout the curriculum indicates how students are consistently improving their skillsets and confidence in their ability to identify, formulate and solve complex engineering problems as they advance through their major.

As a direct measurement of student attainment of LO 1, the ability to identify, formulate and solve complex engineering problems by applying engineering, science and mathematics concepts, project grades on an open-ended reactor design as assigned during the senior class BMEN 391 have been collected and are summarized in Table 1.3. The criterion of at least 85% of students receiving a grade of A or B in this assignment has not been met in the Fall 2017 offering (78%). However, the following two years, 100% of students received a grade of A or B in the same assignment, suggesting improvement. The instructor noted during the Fall 2017 course review that lectures explaining commonly encountered problems during the project, previously not part of the lecture outline, will be incorporated in future offerings since some students seemed to struggle with the project. This change may have contributed to the stark improvement from Fall 2017 compared to the following two offerings that included the added help. The instructor also noted that some of the deductions in the final report grades were due to poor technical writing rather than the formulation and solving of engineering concepts. With the new implementation of the laboratory sequence that started in Fall 2019, future senior classes (starting Fall 2020) should have been exposed to more technical writing practice.

In summary, the Program has met most of the criteria for LO 1. Some adjustments had to be made to BMEN 240, BMEN 354, and BMEN 391. For BMEN 354 and BMEN 391 these adjustments seem to have increased students' ability to identify, express and solve complex engineering problems for the respective assignments. BMEN 240 has only been offered once since the implementation of the new curriculum. The Assessment Committee will evaluate if an increased integration of engineering concepts with the biology lectures has increased student competency in the respective course outcomes during their next course review (August 2020). As of Fall 2020, BMEN 211 will be discontinued in favor of a senior-level modeling and simulation course.

The Program will continue to assess course outcomes and student confidence in BMEN 240, BMEN 354, BMEN 391 and the other core courses, including the newly created BMEN 411, to be able to react to student deficiencies in LO 1.

Learning Outcome 2.

Ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

Measures and Criteria

Two courses within the curriculum, BMEN 427 and 428, Biomedical Engineering Design I and II, provide the capstone design experience. In these courses, students will work in groups to design a biomedical device or process to meet a wide range of specified criteria and constraints. Additionally, smaller design projects are incorporated in increasing complexity throughout the Biomedical Engineering curriculum: BMEN 290 Thermodynamics of Biomolecular Systems (sophomore level), BMEN 354 Biotransport (junior level), and BMEN 391 Kinetics in Biomolecular Systems (senior level). This enables students to experience progressively higher levels of engineering design as they advance through the curriculum. Performance on design projects will be evaluated separately from other course assignments in the form of a composite grade for the design project, allowing assessment on the students' ability to apply engineering design while considering various constraints in regards to public health, safety, and welfare, as well as economic, global, cultural, social and environmental factors.

Attainment of LO 2 will be evaluated both qualitatively and quantitatively in the manner described below.

Qualitative Assessment:

The Assessment Committee in close cooperation with each course instructor determines students' attainment of LO 2 based on student performance in the design projects embedded in BMEN 290 (sophomore year), BMEN 354 (junior year) and BMEN 391 (senior year). For this, instructors are asked to submit their design project assignment as well as information on students' main deficiencies and competencies. The same process applies to the year-long capstone design sequence in senior year, BMEN 427 and BMEN 428, though assessment of LO 2 may be spread out over several assignments and projects in these courses. Additionally, instructors are asked to explain all changes they made to the course including the design project if applicable and recommend changes for the next course offering. Upon review, the Assessment Committee meets with the respective instructor for further discussion and feedback. The Committee then assesses how well this LO was attained in the respective course and assigns a letter grade according to the following system:

A: Learning/course outcome is not only attained but exceeded; little to no room for increasing student performance or confidence

B: Learning/course outcome is comfortably attained; improvements that could raise the level of student performance or confidence are still perceived

C: Learning/course outcome is attained, but this attainment is marginal; improvements that could raise the level of student performance and confidence are obvious

F: Learning/course outcome is not attained; major improvement is required to raise student performance and confidence to acceptable levels

Student will be exposed to progressively complex engineering design projects in BMEN 290, BMEN 354, and BMEN 391, before embarking on a year-long design experience in the capstone design sequence BMEN 427/ BMEN 428. Hence, attainment of LO 2 is expected to improve as students progress through the curriculum. BMEN 290 (sophomore year) is expected to receive a qualitative grading of a grade of C or higher in respect to the design project, whereas courses in junior and senior year (BMEN 354 and BMEN 391) are expected to receive a grade of A or B. Likewise, students' ability to apply engineering design while meeting requirements and constraints must receive a grade of B or A in the senior design sequence BMEN 427 and BMEN 428.

In addition to the annual course review process, attainment of LO 2 is also assessed via feedback from students as collected during the student course evaluations at the end of the five courses mentioned above:

BMEN 290, BMEN 354, BMEN 391, BMEN 427, and BMEN 428. Open ended questions in these five courses will be examined by the assessment coordinator for qualitative student feedback in regard to LO 2 and discussed with the course instructor during the course review meeting.

Quantitative Assessment:

Course evaluations administered at the end of BMEN 290, BMEN 354, and BMEN 391 will determine the level of confidence that students have with respect to their ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. This will be accomplished with closed ended questions to be answered using a Likert scale. Students are expected to increasingly gain confidence in this area as they advance through the curriculum. At least 70% of students must report high levels of confidence in their engineering design abilities in BMEN 290, (sophomore year), at least 75% of students in BMEN 354 (junior year), and at least 80% in BMEN 391 (senior year).

In addition, an on-line exiting survey of graduating seniors, administered annually, determines the level of confidence that students have with respect to LO 2 upon graduation. At least 85% of graduating seniors must respond that they have a high or very high level of confidence in their ability to design a biomedical device or process.

Direct Quantitative Assessment for LO 2:

Students are exposed to smaller design projects throughout their curriculum, culminating in the senior design capstone design sequence during their final year in which students are designing a biomedical process or product while adhering to a wide range of technical, medical, social, environmental, ethical (global) and economic criteria and constraints. This learning experience closes with the final design report that students must hand in at the end of the semester in which they summarize their entire design process including objectives and constraints and present their final prototype. Student performance in this final design report is assessed and the average score and grade are recorded. At least 90% of all students are expected to receive a grade of A or B in this final design assignment.

Methods

Five primary assessment tools are employed to assess that students are meeting the criteria for individual learning outcomes (LOs), two qualitative ones (1, 2) and three quantitative ones (3, 4, 5).

(1) Qualitatively, attainment of learning outcomes in applicable courses (Table II) is assessed by the Assessment Committee in the form of annual course reviews. The Assessment Committee is comprised of the Assessment Coordinator, the Director of the Biomedical Engineering Program, the Undergraduate Director of the Biomedical Engineering Program as well as members of the Undergraduate Committee of the Program. The instructor of a course is asked to prepare a course review document detailing which student assessments in the course connects to the respective LO and provide information on average student performance in these student assessments. For this, the instructor is asked to reflect in writing on students' key competencies and deficiencies for each individual course outcome connected to the respective LO. Lastly, the instructor is asked to reflect on the success of changes to the course compared to the previous offering, if applicable, and to recommend changes to the upcoming course offering. The Assessment Committee together with the respective course instructor reviews all materials and assigns a letter grade (A, B, C, F) for each course outcome supporting the respective LO according to the following system:

A: Course/Learning outcome is not only attained but exceeded; little to no room for increasing student performance or confidence

B: Course/Learning outcome is comfortably attained; improvements that could raise the level of student performance or confidence are still perceived

C: Course/Learning outcome is attained, but this attainment is marginal; improvements that could raise the

level of student performance and confidence are obvious

F: Course/Learning outcome is not attained; major improvement is required to raise student performance and confidence to acceptable levels

The course reviews, including outcomes from the Assessment Committee discussions, are then compiled by the Assessment Coordinator, and filed in the Main Biomedical Engineering Office with access to all faculty. Letter grades below B will result in more in-depth follow-up communication or meetings with the instructor to discuss possible options for improvement of learning outcome attainment. Since course reviews are held twice a year just before the start of the Fall and Spring semester, respectively, to discuss the respective previous year's Fall and Spring classes, qualitative assessment will end with Spring 2019 courses for this assessment period. This timing ensures that feedback about each course is handed to the instructor of a class just as they are preparing for their upcoming class when feedback is most critical.

(2) Student comments as collected in course evaluations at the end of each course offering are reviewed by the Assessment Coordinator and may provide additional qualitative feedback on each LO connected to the respective courses (see Table II). The Assessment Coordinator is present for all course review meetings, where qualitative student feedback in relation to LOs 1 to 7 for individual classes will be discussed in detail.

(3) Quantitatively, student attainment of individual LOs is assessed by probing students for confidence in the respective LO on a closed ended questionnaire at the end of each course connected to the respective LO (Table II) using a Likert scale. Student confidence is reported in % students who display "high or very high" levels of confidence in this student outcome and is expected to rise for each LO as students advance from freshman to senior year.

(4) Additionally, at the end of each spring semester, student exit interviews are conducted for students that graduate in May or during the upcoming Summer or Fall semesters. The Director of the Program will conduct these interviews; the Assessment Coordinator is present to take notes. Students are asked to assess the outcomes of their education including LOs 1 to 7. Student responses to both closed ended questions to be answered using a Likert scale and open-ended questions are collected in each of these areas and compiled by the Chair of the Assessment Committee. The compiled data is distributed to the Assessment Committee and the Assessment Coordinator and discussed at a designated meeting of the Assessment Committee for the purpose of listing student strengths and weaknesses and formulating action items for improvement of learning outcomes and program goals. Discussion comments and action items will be documented by the Chair of the Assessment Committee and filed in the Biomedical Engineering Office. Generally, 85% or more of graduating seniors are expected to show high or very high levels of confidence in each of the seven LOs.

For each LO a specific assignment that assesses and exemplifies the respective LO has been chosen as a direct assessment of whether the Program is achieving the attainment of this LO. All assignments chosen are assignments handed to upperclassmen as they near graduation. Generally, at least 80% of students are expected to receive a grade of B or higher in the respective indicator assignment.

Results

Biomedical Engineering core courses that contain a graded design component include BMEN 290, BMEN 354, BMEN 391, and the senior capstone design sequence BMEN 427 / BMEN 428. Attainment of course outcomes connected to LO 2, the ability to apply engineering design to produce solutions that meet specified needs, as assessed in yearly course reviews for these classes is summarized in Table 2.1. In the sophomore class BMEN 290, the design course outcome received a grade of B in both course offerings, meeting the qualitative criterion for LO 2 of receiving a grade of C or higher. In junior and senior year, all course outcomes connected to LO 2 (engineering design) are expected to receive a grade of B or higher. This criterion was met for all junior and senior-level course offerings except the Spring 2018 offering of BMEN 354.

Student confidence regarding LO 2 as collected by student course evaluations in all courses containing a design project and collected in an exit survey for graduating seniors is reported in Table 2.2. A general upward trend throughout the curriculum is noticeable. However, the criterion of 70% of students with high confidence in sophomore year, 75% of students with high confidence in junior year, 80% of students with

high confidence in senior year and 85% of graduating seniors with high confidence in their ability to apply engineering design has only been met in five out of eleven surveys.

No class in the Biomedical Engineering curriculum has a higher exposure to design concepts as the senior capstone design class. For their design prototype students must meet customer and cultural demands, perform a risk analysis, stay within a budget, and consider safety, environmental and public health and ethical questions. Students hand in their final design report at the end of this experience in BMEN 428. The grades for this report are collected and the percentage of students receiving a grade of A or B for each year is reported in Table 2.3, serving as a direct measure of students' ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. In Spring 2018, 100% of students received a grade of B or higher for their design solutions; in Spring 2019, 92% of students received a grade of B or higher for their projects.

Tables for LO 2

Use of Results

All course offerings have met their course review criterion (grade of C or higher for sophomore year, grade of B or higher for junior and senior year) except for the Spring 2018 offering of BMEN 354 Biotransport (Table 2.1). This outcome falls in line with previous results for LO 1, where students seem to have struggled with general engineering concepts in this class. Regarding the design project, the instructor noted that students were lacking background knowledge in the field of fluid mechanics. The Assessment Committee suggested a brief review of mass and heat transfer concepts in the beginning of future course offerings and/or offer tutoring sessions. In the following course offering of Spring 2019 student's ability to scale and design transport systems had improved and was graded with a grade of B, meeting the criterion. Student confidence levels regarding LO 2 in BMEN 354 were the lowest reported in the curriculum sequence (54.9% for Spring 2018; 61.7% for Spring 2019, Table 2.2). Improvements made after Spring 2018 have led to an increase in student confidence in the following course offering; but the criterion of 75% percent students feeling very confident in this LO was not met again in the Spring of 2019. During the Spring 2019 course review the Assessment Committee examined the design project and troubleshoot possible shortcomings. The instructor of the 2020 course offering has been advised to be more clear about the goals and objectives of the design project and to define clear constraints. The Assessment Committee is advised to closely monitor development of student attainment in the design course outcome as well as student confidence in LO 2 for BMEN 354.

In the capstone senior design sequence where designing engineering solutions has the highest impact in the curriculum all respective course outcomes have received a grade of either A or B, meeting the qualitative assessment criterion. Particular attention was paid to the final design report students submit at the end of BMEN 428. In this report students present their final prototype of their design solution to a real-life biomedical engineering problem. Students work in groups throughout their senior year designing either a device or process that fulfills a medical need, satisfying customer demands, as well as meeting other (e.g., societal, environmental and economic) constraints. In Spring 2018, 100% of students received a grade of B or higher for their design solutions; in Spring 2019, 92% of students received a grade of B or higher (Table 2.3). In both years, the criterion of 90% or more of students receiving a grade of A or B in their final design report was met.

However, both indirect as well as direct assessment indicate that there is opportunity for improvement within LO 2. Student confidence levels, despite showing a temporal upward trend from sophomore year, when students are first exposed to small design projects, to graduation was below the expected levels for five out of eleven recorded surveys. Upon graduation, 71.2% of seniors felt very confident in their ability to design apply engineering design with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors in May of 2018. In 2019, this percentage had increased to 86.3% of students. Within open-ended questions and discussions during their senior exit interviews, students noted a big learning curve in this LO during their senior capstone design sequence BMEN 427 and BMEN 428. Some students however wished for more help during their first semester of senior design (BMEN 427), a comment that has been brought forward to the instructor of the course. The Assessment Committee suggested incorporating some additional lectures at the beginning of the BMEN 427 semester reiterating some concepts of the design process such as the difference between goals and

objectives and the creation of Gantt charts and decision matrices. Additionally, students undergoing the new curriculum will now be eased into the concept of a research proposal and experiment design through the addition of BMEN 382. The first students who will have undergone this new sequence are set to graduate May 2021.

Instructors of courses that incorporate a design project, BMEN 290, BMEN 354, BMEN 391 and BMEN 427/428 have been made aware of the low levels of student confidence and have been directed to provide more help or tutoring opportunities for struggling students. The Assessment Committee will continue to monitor both student confidence in LO 2 and student performance, both quantitatively and qualitatively, in all course outcomes connected to this LO to identify shortcomings and help students improve their ability to design engineering solutions with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

Learning Outcome 3.

Ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions.

Measures and Criteria

Students learn how to design and execute experiments in various biomedical engineering areas, and practice collection, analysis, and reporting of experimental data during the laboratory sequence BMEN 381 and BMEN 382. Student performance in these courses will be evaluated in the form of data analysis projects and/or laboratory reports or tests. Further opportunities for conducting, analyzing, and interpreting biomedical measurements will be acquired during the capstone design experience, BMEN 427 and BMEN 428.

Students' ability to develop and conduct appropriate experimentation, analyze, and interpret data, and use engineering judgement to draw conclusions will be assessed both qualitatively and quantitatively in the manner described below.

Qualitative Assessment:

The Assessment Committee in close cooperation with each course instructor determines students' attainment of this LO based on student performance in assignments and projects that involve the development of experiments, as well as analysis and/or interpretation of data. Instructors for BMEN 381, BMEN 382, BMEN 427 and BMEN 428 are asked to disclose assignments addressing this LO and reflect in writing on key student competencies and key deficiencies related to these assignments. The Assessment Committee then meets with the respective instructor and evaluates the students' attainment of this LO for each course according to the following system:

A: Learning/course outcome is not only attained but exceeded; little to no room for increasing student performance or confidence

B: Learning/course outcome is comfortably attained; improvements that could raise the level of student performance or confidence are still perceived

C: Learning/course outcome is attained, but this attainment is marginal; improvements that could raise the level of student performance and confidence are obvious

F: Learning/course outcome is not attained; major improvement is required to raise student performance and confidence to acceptable levels

Course evaluations must receive a grade of B or higher in BMEN 381, BMEN 382, BMEN 427, and BMEN 428 to pass the qualitative assessment of LO 3.

In addition to the annual course review process by the Assessment Committee, students' perceived confidence in this LO is also assessed via feedback from students within course evaluations at the end of BMEN 381, BMEN 382, BMEN 427, and BMEN 428. Open ended questions in these four courses will be

examined by the assessment coordinator for qualitative student feedback on their ability to develop and conduct appropriate experimentation, as well as analyzing and interpreting data.

Quantitative Assessment:

In the Fall of 2017, the Biomedical Engineering Program implemented a new curriculum which included a new laboratory sequence to enhance students' laboratory skills important for Biomedical Engineering practice. This laboratory sequence consists of the two 2-credit hour laboratory focused classes BMEN 381 and BMEN 382, typically undertaken during junior year. Course evaluations administered at the end of BMEN 381, BMEN 382 determine the level of confidence that students have with respect to their ability to develop and conduct appropriate experimentation, as well as analyze and interpret data. This will be accomplished with closed ended questions to be answered using a Likert scale. At least 80% of students in junior year must report high confidence in this area. Due to the implementation of the curriculum in Fall 2017, BMEN 381 was first offered to the junior class in the Fall semester of 2019 and BMEN 382 was first offered in the Spring semester of 2020, falling outside of this assessment period. Hence, BMEN 382 cannot be used for the quantitative assessment of LO 3 during this assessment cycle. To substitute for BMEN 381/382 prior to Fall 2019, BMEN 361 Bioinstrumentation, a junior Biomedical Engineering core class from the old curriculum that contained a laboratory component within its syllabus was assessed for student attainment of laboratory and experiment design-related course outcomes. Both BMEN 381 and BMEN 382 will contribute to the qualitative and quantitative assessment of LO 3 during the next assessment period: Fall 2020 to Fall 2022 assessment.

Later in the curriculum, students are again exposed to experiment design as well as interpretation and analysis of data during their capstone design sequence in senior year, further increasing their knowledge and practice in this LO. An on-line exit survey of graduating seniors, administered annually, determines the level of confidence that students have with respect to experiment design and data analysis/ interpretation upon graduation. At least 85% of graduating seniors must respond that they have a high or very high level of confidence in LO 3.

Direct Quantitative Assessment for LO 3:

Students undergo a two-semester laboratory sequence in their junior year: BMEN 381 in the Fall semester and BMEN 382 in the Spring semester. In these two classes students focus on designing experiments to prove a research hypothesis and learn how to interpret and analyze collected data to prove or disprove this hypothesis. Final grades for both classes are collected and averaged for each student; 80% of students are expected to receive an overall final grade of B or higher in their junior laboratory sequence to pass LO 3.

Methods

Five primary assessment tools are employed to assess that students are meeting the criteria for individual learning outcomes (LOs), two qualitative ones (1, 2) and three quantitative ones (3, 4, 5).

(1) Qualitatively, attainment of learning outcomes in applicable courses (Table II) is assessed by the Assessment Committee in the form of annual course reviews. The Assessment Committee is comprised of the Assessment Coordinator, the Director of the Biomedical Engineering Program, the Undergraduate Director of the Biomedical Engineering Program as well as members of the Undergraduate Committee of the Program. The instructor of a course is asked to prepare a course review document detailing which student assessments in the course connects to the respective LO and provide information on average student performance in these student assessments. For this, the instructor is asked to reflect in writing on students' key competencies and deficiencies for each individual course outcome connected to the respective LO. Lastly, the instructor is asked to reflect on the success of changes to the course compared to the previous offering, if applicable, and to recommend changes to the upcoming course offering. The Assessment Committee together with the respective course instructor reviews all materials and assigns a letter grade (A, B, C, F) for each course outcome supporting the respective LO according to the following system:

A: Course/Learning outcome is not only attained but exceeded; little to no room for increasing student performance or confidence

B: Course/Learning outcome is comfortably attained; improvements that could raise the level of student performance or confidence are still perceived

C: Course/Learning outcome is attained, but this attainment is marginal; improvements that could raise the level of student performance and confidence are obvious

F: Course/Learning outcome is not attained; major improvement is required to raise student performance and confidence to acceptable levels

The course reviews, including outcomes from the Assessment Committee discussions, are then compiled by the Assessment Coordinator, and filed in the Main Biomedical Engineering Office with access to all faculty. Letter grades below B will result in more in-depth follow-up communication or meetings with the instructor to discuss possible options for improvement of learning outcome attainment. Since course reviews are held twice a year just before the start of the Fall and Spring semester, respectively, to discuss the respective previous year's Fall and Spring classes, qualitative assessment will end with Spring 2019 courses for this assessment period. This timing ensures that feedback about each course is handed to the instructor of a class just as they are preparing for their upcoming class when feedback is most critical.

(2) Student comments as collected in course evaluations at the end of each course offering are reviewed by the Assessment Coordinator and may provide additional qualitative feedback on each LO connected to the respective courses (see Table II). The Assessment Coordinator is present for all course review meetings, where qualitative student feedback in relation to LOs 1 to 7 for individual classes will be discussed in detail.

(3) Quantitatively, student attainment of individual LOs is assessed by probing students for confidence in the respective LO on a closed ended questionnaire at the end of each course connected to the respective LO (Table II) using a Likert scale. Student confidence is reported in % students who display "high or very high" levels of confidence in this student outcome and is expected to rise for each LO as students advance from freshman to senior year.

(4) Additionally, at the end of each spring semester, student exit interviews are conducted for students that graduate in May or during the upcoming Summer or Fall semesters. The Director of the Program will conduct these interviews; the Assessment Coordinator is present to take notes. Students are asked to assess the outcomes of their education including LOs 1 to 7. Student responses to both closed ended questions to be answered using a Likert scale and open-ended questions are collected in each of these areas and compiled by the Chair of the Assessment Committee. The compiled data is distributed to the Assessment Committee and the Assessment Coordinator and discussed at a designated meeting of the Assessment Committee for the purpose of listing student strengths and weaknesses and formulating action items for improvement of learning outcomes and program goals. Discussion comments and action items will be documented by the Chair of the Assessment Committee and filed in the Biomedical Engineering Office. Generally, 85% or more of graduating seniors are expected to show high or very high levels of confidence in each of the seven LOs.

(5) For each LO a specific assignment that assesses and exemplifies the respective LO has been chosen as a direct assessment of whether the Program is achieving the attainment of this LO. All assignments chosen are assignments handed to upperclassmen as they near graduation. Generally, at least 80% of students are expected to receive a grade of B or higher in the respective indicator assignment.

Results

Due to the implementation of a new curriculum in Fall 2017, BMEN 381 was first offered to the junior class in the Fall semester of 2019 and BMEN 382 was first offered in the Spring semester of 2020, falling outside of this assessment period. Hence, BMEN 381 and BMEN 382 cannot be used for the qualitative assessment of LO 3 and BMEN 382 cannot be used for quantitative assessment of LO 3 during this assessment cycle. Both BMEN 381 and BMEN 382 will contribute to the qualitative and quantitative assessment of LO 3 during the next assessment period: Fall 2020 to Fall 2022 assessment. To substitute for BMEN 381/ 382 prior to Fall 2019, BMEN 361 Bioinstrumentation, a junior Biomedical Engineering core class from the old curriculum that contained a laboratory component within its syllabus was assessed for student attainment of laboratory and experiment design-related course outcomes. BMEN 361 was last

offered in Spring 2019 before being discontinued. During BMEN 361, students were required to take part in six laboratory classes. These laboratory sessions included graded homework, quizzes, notebook documentations, as well as laboratory reports similar to assessments in BMEN 381 and BMEN 382. Attainment of course outcomes connected to students' ability to develop and conduct experimentation, as well as data interpretation and analysis, of BMEN 361 as well as BMEN 427/ BMEN 428 was assessed in the yearly course reviews and is summarized in Table 3.1. The qualitative criterion of receiving a grade of B or higher was consistently achieved in all junior-level course outcomes connected to LO 3 as well as in the senior-level courses of BMEN 427 and BMEN 428.

Student confidence regarding LO 3 as collected by student course evaluations in BMEN 361 (Spring 2018 and Spring 2019), BMEN 381 (Fall 2019) is summarized in Table 3.2. Graduating seniors' (Spring 2018 and Spring 2019) confidence in their ability to develop and conduct experimentation and subsequent data analysis and interpretation, as collected in an exit survey, is also listed in Table 3.2. Student confidence levels have consistently exceeded 85% for all surveys.

Table 3.3 shows the percentage of students who received a grade of B or higher as their final laboratory grade in BMEN 361 and BMEN 381. The direct criterion of at least 80% of students receiving a grade of B or higher on their final cumulative laboratory experience in junior year was achieved for all course offerings.

Tables for LO 3

Use of Results

The program consistently achieved its qualitative criterion of receiving a grade of B or higher in all course outcomes connected to LO 3 (Table 3.1). The criterion of at least 80% of students feeling confident or very confident in their ability to conduct appropriate experimentation, analyze, and interpret data, and use engineering judgement to draw conclusions was exceeded in all course offerings hands-on laboratory experiences. Graduating seniors also express high confidence in this area (Table 3.2).

The direct criterion of at least 80% of students receiving a grade of B or higher on their final cumulative laboratory experience in junior year (BMEN 361 prior to Fall 2019, BMEN 381 after implementation of the new curriculum) was achieved for all course offerings (Table 3.3). However, in Spring 2018 (BMEN 361), this percentage was only barely met. Unlike BMEN 381 which is mainly focused on experimental skills, BMEN 361 is a lecture-based class that – despite a strong laboratory component – only dedicates a part of its class content to hands-on experiments, which may explain the lower grade scores. Within open-ended questions in their course evaluations in BMEN 361 and 381 as well as during senior exit interviews, some students identified the laboratory experiences and practice of technical reports as one of the strengths of the program; other students noted some disappointment with the technological delivery of the labs, lack of facilities and lack of time dedicated to experiment design and data analysis. These comments are particularly abundant in the senior exit surveys of Spring 2018 and 2019. These students still underwent the old curriculum, prior to implementation of the junior-year lab sequence BMEN 381/ BMEN 382. In 2017 the Program implemented a new curriculum which now includes a two-semester long, four credit hour independent laboratory sequence (BMEN 381 and BMEN 382) instead of singular laboratory exercises embedded in certain sophomore (e.g., BMEN 260, now discontinued) and junior-level (e.g., BMEN 361) core classes. The new laboratory sequence allows for a higher number of laboratory exercises, a higher focus on experiment design, and a more structured environment in which students learn proper preparation of laboratory notebooks and reports as well as approaches for statistical data analysis, increasing students' ability to not only design experiments, but also analyze and interpret data. To accommodate for this increase in laboratory focus, the Biomedical Engineering Program underwent an extension of their lab facilities in the summer of 2018 and acquired new computers to support student workstations. The first students who have undergone the new laboratory sequence will be graduating in May of 2021. Additionally, the first course reviews of BMEN 381 and BMEN 382 will take place in August of 2020 (BMEN 381) and January of 2021 (BMEN 382), respectively. Future senior exit interviews and course reviews will provide feedback on whether student ability and confidence in experiment design and data interpretation/ analysis will have improved with the implementation of the new laboratory sequence. The Program will continue to assess student attainment of this learning outcome to evaluate the impact the implemented changes in

laboratory administration have on the students' ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions. Particular attention will be paid to comparing direct assessment, student confidence, and open-ended feedback prior to the implementation of BMEN 381 and BMEN 382 and afterwards.

Learning Outcome 4.

Ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Measures and Criteria

Students will be first introduced to scientific literature searching techniques during BMEN 101 Introduction to Biomedical Engineering. This skill is further strengthened in BMEN 303 where students independently investigate a medical technology, following it from conception to market. Other classes especially in the later part of the curriculum namely BMEN 354, BMEN 363, and BMEN 391 also require students to individually research various topics in biomedical engineering mostly within independent projects. Furthermore, the capstone design sequence, BMEN 427 and BMEN 428, will require a considerable amount of independent learning. Independent, open ended projects in each of these courses will be graded separately and attainment of students' ability to acquire and apply new knowledge will be assessed both qualitatively and quantitatively in the manner described below.

Qualitative Assessment:

The Assessment Committee in close cooperation with the course instructors for BMEN 101, BMEN 303, BMEN 354, BMEN 363, BMEN 391, BMEN 427, and BMEN 428 determines students' ability to acquire and apply new knowledge based on student performance in projects that require a high level of independent research and learning. Each course instructor is asked to reflect in writing on key student competencies and key deficiencies in regard to this LO. Together with the respective course instructor, the Assessment Committee then assesses the students' ability to acquire and apply new knowledge using appropriate learning strategies in all eight courses according to the following system:

A: Learning/course outcome is not only attained but exceeded; little to no room for increasing student performance or confidence

B: Learning/course outcome is comfortably attained; improvements that could raise the level of student performance or confidence are still perceived

C: Learning/course outcome is attained, but this attainment is marginal; improvements that could raise the level of student performance and confidence are obvious

F: Learning/course outcome is not attained; major improvement is required to raise student performance and confidence to acceptable levels

In the freshman-level class BMEN 101, students' ability to acquire and apply new knowledge using appropriate learning strategies such as literature search and independent learnings skills are assessed through open-ended project assignments and should receive a grade of C or higher. The junior-level classes BMEN 303, BMEN 354, and BMEN 391 must receive a grade of B or A to meet this LO. The junior-level class of BMEN 363 was first offered in Spring 2020 and will not contribute to the Fall 2017 – Fall 2019 assessment cycle. In senior year (BMEN 427 and BMEN 428) students' ability to acquire and apply new knowledge as proven in independent project work must be assessed with a grade of B or A.

In addition to the annual course review process, students' perceived ability to acquire and apply new knowledge as needed is assessed via feedback from students within course evaluations at the end of BMEN 101, BMEN 211, BMEN 303, BMEN 354, BMEN 391, BMEN 427, and BMEN 428. Open ended questions in these eight courses will be examined by the assessment coordinator for qualitative student feedback regarding independent learning.

Quantitative Assessment:

Course evaluations administered at the end of BMEN 101, BMEN 303, BMEN 354, BMEN 391, BMEN 427, and BMEN 428 will determine the level of confidence that students have with respect to their ability to acquire and apply new knowledge for project assignments. This will be accomplished with closed ended questions to be answered using a Likert scale. Students are expected to increasingly gain confidence in this area as they advance from freshman to senior year. At least 70% of students must report high levels of confidence in their ability to acquire and apply new knowledge in BMEN 101 (freshman year) and at least 80% of students are expected to show high or very high levels of confidence in this LO in BMEN 303, BMEN 354, and BMEN 391 (junior year). During senior year (BMEN 427 and BMEN 428) and upon graduation (senior exit survey) student confidence in their ability to acquire and apply new knowledge using appropriate independent learning strategies must always remain above 85%.

Direct Quantitative Assessment for LO 4:

Each student group is working on a highly individualized and open-ended design project in their senior design capstone sequence BMEN 427 and BMEN 428. In this project, students try to solve an unaddressed need or market gap in the medical or biological field, which requires them to do an intensive background research and independently learn new concepts and techniques as students are designing and constructing a new prototype. To track their literature research, independent learning and acquisition of new tools, students are asked to keep a detailed journal of their progress throughout the design sequence. This journal is then graded by the instructors of the class throughout the semester. At least 90% of all students are expected to receive a final cumulative journal grade of B or A to pass LO 4, the ability to acquire and apply new knowledge.

Methods

Five primary assessment tools are employed to assess that students are meeting the criteria for individual learning outcomes (LOs), two qualitative ones (1, 2) and three quantitative ones (3, 4, 5).

(1) Qualitatively, attainment of learning outcomes in applicable courses (Table II) is assessed by the Assessment Committee in the form of annual course reviews. The Assessment Committee is comprised of the Assessment Coordinator, the Director of the Biomedical Engineering Program, the Undergraduate Director of the Biomedical Engineering Program as well as members of the Undergraduate Committee of the Program. The instructor of a course is asked to prepare a course review document detailing which student assessments in the course connects to the respective LO and provide information on average student performance in these student assessments. For this, the instructor is asked to reflect in writing on students' key competencies and deficiencies for each individual course outcome connected to the respective LO. Lastly, the instructor is asked to reflect on the success of changes to the course compared to the previous offering, if applicable, and to recommend changes to the upcoming course offering. The Assessment Committee together with the respective course instructor reviews all materials and assigns a letter grade (A, B, C, F) for each course outcome supporting the respective LO according to the following system:

A: Course/Learning outcome is not only attained but exceeded; little to no room for increasing student performance or confidence

B: Course/Learning outcome is comfortably attained; improvements that could raise the level of student performance or confidence are still perceived

C: Course/Learning outcome is attained, but this attainment is marginal; improvements that could raise the level of student performance and confidence are obvious

F: Course/Learning outcome is not attained; major improvement is required to raise student performance and confidence to acceptable levels

The course reviews, including outcomes from the Assessment Committee discussions, are then compiled

by the Assessment Coordinator, and filed in the Main Biomedical Engineering Office with access to all faculty. Letter grades below B will result in more in-depth follow-up communication or meetings with the instructor to discuss possible options for improvement of learning outcome attainment. Since course reviews are held twice a year just before the start of the Fall and Spring semester, respectively, to discuss the respective previous year's Fall and Spring classes, qualitative assessment will end with Spring 2019 courses for this assessment period. This timing ensures that feedback about each course is handed to the instructor of a class just as they are preparing for their upcoming class when feedback is most critical.

(2) Student comments as collected in course evaluations at the end of each course offering are reviewed by the Assessment Coordinator and may provide additional qualitative feedback on each LO connected to the respective courses (see Table II). The Assessment Coordinator is present for all course review meetings, where qualitative student feedback in relation to LOs 1 to 7 for individual classes will be discussed in detail.

(3) Quantitatively, student attainment of individual LOs is assessed by probing students for confidence in the respective LO on a closed ended questionnaire at the end of each course connected to the respective LO (Table II) using a Likert scale. Student confidence is reported in % students who display "high or very high" levels of confidence in this student outcome and is expected to rise for each LO as students advance from freshman to senior year.

(4) Additionally, at the end of each spring semester, student exit interviews are conducted for students that graduate in May or during the upcoming Summer or Fall semesters. The Director of the Program will conduct these interviews; the Assessment Coordinator is present to take notes. Students are asked to assess the outcomes of their education including LOs 1 to 7. Student responses to both closed-ended questions to be answered using a Likert scale and open-ended questions are collected in each of these areas and compiled by the Chair of the Assessment Committee. The compiled data is distributed to the Assessment Committee and the Assessment Coordinator and discussed at a designated meeting of the Assessment Committee for the purpose of listing student strengths and weaknesses and formulating action items for improvement of learning outcomes and program goals. Discussion comments and action items will be documented by the Chair of the Assessment Committee and filed in the Biomedical Engineering Office. Generally, 85% or more of graduating seniors are expected to show high or very high levels of confidence in each of the seven LOs.

(5) For each LO a specific assignment that assesses and exemplifies the respective LO has been chosen as a direct assessment of whether the Program is achieving the attainment of this LO. All assignments chosen are assignments handed to upperclassmen as they near graduation. Generally, at least 80% of students are expected to receive a grade of B or higher in the respective indicator assignment.

Results

The junior-level class of BMEN 363 was first offered in Spring 2020 and will not contribute to the Fall 2017 – Fall 2019 assessment cycle, leaving six Biomedical Engineering core classes for this cycle's assessment of LO 4, the ability to acquire and apply new knowledge as needed, using appropriate learning strategies: BMEN 101, BMEN 303, BMEN 354, BMEN 391, BMEN 427, and BMEN 428. Attainment of course outcomes connected to LO 4, as assessed in yearly course reviews, is summarized in Table 4.1. The criterion of receiving a course review grade of B or higher was consistently achieved in all course outcomes connected to LO 4 from freshman to senior year, except for the Spring 2018 offering of BMEN 354.

Student confidence regarding LO 4 as collected through student course evaluations in all applicable courses and during an exit survey for graduating seniors is reported in Table 4.2. The criterion of at least 70% of students reporting high levels of confidence in their ability to acquire and apply new knowledge in BMEN 101 (freshman year) and at least 80% of students reporting high or very high levels of confidence in this LO for BMEN 303, and BMEN 391 (junior year) was exceeded for all course offerings. During senior year (BMEN 427 and BMEN 428) and upon graduation (senior exit survey) student confidence in their ability to acquire and apply new knowledge using appropriate independent learning strategies remained consistently above 90%, meeting the criterion of 85% students expressing high or very high confidence in LO 4.

Journals kept during their capstone senior design journey detail each student's learning experience throughout the project. Final cumulative journal grades are used as direct assessment of students' ability to

acquire new knowledge and are listed in Table 4.3. Ninety-six percent (96%) and 98% of students received a cumulative final grade of A or B for their journals in Spring 2018 and Spring 2019, respectively, meeting the direct assessment criterion of 90% of students receiving a grade of B or higher.

Tables for LO 4

Use of Results

The criterion of receiving a course review grade of B or higher was consistently achieved in all course outcomes connected to LO 4 from freshman to senior year, except for the Spring 2018 offering of BMEN 354 (Table 4.1). For this course outcome student performance as judged by the instructor and students themselves was analyzed regarding the open-ended design project of a dialysis unit. This project requires students to not only research the topic and learn about dialysis, but also to expand and apply their previously acquired fluid / mass transport knowledge to a real-life biological system and perform necessary calculations and scale-up design using a software program of their choice. Some students expressed frustration with the project and struggled with the execution. These results are consistent with overall poor performance and student satisfaction in this course offering, possibly due to students being overwhelmed with the graduate-level textbook and overall challenging material in the class. Students did not seem to succeed in keeping up with the material and some students were not able to independently complete the open-ended project assignment. Following Spring 2018, a new textbook has been chosen and review lectures on fluid mechanics have been embedded in the lecture outline. The instructor was also encouraged to increase office hours and / or peer tutoring in this course. In Spring of 2019, student evaluations and performance had improved, and the course outcome was reviewed with a grade of B. The Assessment Committee together with the instructor of this course will continue to monitor student attainment of this course outcome in BMEN 354. All other course outcomes across different courses at different stages within the curriculum varied between a grade of A or B, with every course at least receiving one A during the two-year assessment timeframe. This suggests that there is no persistent issue within any class that needs to be addressed in regard to strengthening students' ability to acquire and apply new knowledge.

Throughout the curriculum students are challenged with independent open-ended projects. However, independent learning is of most importance during their final year as students work on their individual senior design project. Each student is required to document their project and learning experience in a journal. Ninety-six percent (96%) and 98% of students received a cumulative final grade of A or B for their journals in Spring 2018 and Spring 2019, respectively, meeting the direct assessment criterion of 90% and confirming that they are able to adjust to independent project challenges through the acquisition and application of new knowledge and effective learning strategies (Table 4.3).

Students perceive themselves to be very confident in their ability to acquire new knowledge throughout the curriculum (Table 4.2). This may be attributed to the high amount of open-ended homework and project assignments in the courses listed. During senior exit interviews graduating seniors mentioned the positive effect that the amount and variety of open-ended projects and research assignments had on their independent learning skills. Students mentioned this as a strength of the Program and expressed that their skills in acquiring new knowledge makes them feel very prepared for graduate studies and/or future employment.

The Program will continue to assign open-ended projects that require a high amount of independent learning throughout the curriculum and assess students' performance in these assignments directly and indirectly so that future deficiencies can be identified and addressed and the high level of student competency and confidence in this learning outcome can continue.

Goal 2.

"Graduates will advance their careers by engaging in teamwork, effective communication, and continued learning to expand their professional development and technical understanding."

Goal 2 refers primarily to the professional skills, experiences, perspectives, and learning capabilities that will be instilled within graduates. These attributes prepare graduates to respond to an interdisciplinary, global, and continually evolving workplace in a manner that reflects social responsibility.

Table I - Curriculum

Table II - Curriculum Map of Learning Outcomes

Curriculum

The curriculum for the BS in Biomedical Engineering is summarized in the major map presented in Table I. This curriculum was revised based upon data gathered from faculty and students and implemented beginning in Fall 2017. Biomedical Engineering courses are related to the Learning Outcomes as depicted in Table II, indicating the emphasis of each course for the respective LO. Learning Outcomes of the Biomedical Engineering B.S. Program are derived directly from the prescribed Engineering Accreditation Commission of ABET student outcomes to ensure that consistency is maintained between the two accreditation bodies throughout the process of assessment, evaluation, and curriculum improvements.

Technical electives can be fulfilled with mathematics, biology, chemistry, or engineering courses chosen from an approved list.

Engineering electives can be fulfilled with engineering or computing courses chosen from an approved list.

Biomedical engineering electives are chosen from an approved list of courses from biomedical and other engineering disciplines. A complete list of all approved electives can be found in the Biomedical Engineering bulletin: http://bulletin.sc.edu/preview_program.php?catoid=88&poid=5718&returnto=2551

Required courses in general education meet requirements defined by the University.

Learning Outcome 1.

Ability to communicate effectively with a range of audiences.

Measures and Criteria

In the capstone design sequence, BMEN 427 and 428, students are required to communicate to a range of audiences, including their peers, teaching assistants, faculty panels, and their industry sponsors through written reports, poster presentations, journal entries and oral presentations. Written reports and oral presentations will also have a strong focus in BMEN 101 and BMEN 303, respectively. Lastly, students will be trained in technical writing and data presentation and their technical communication skills will be assessed through several professional papers and technical reports during their year-long lab sequence, BMEN 381 and BMEN 382, typically undertaken in junior year. Written reports and oral presentations in each of these courses will be graded separately, allowing assessment on the students' communication skills.

Attainment of LO 5 will be evaluated both qualitatively and quantitatively in the manner described below.

Qualitative Assessment:

The Assessment Committee in close cooperation with each course instructor determines students' attainment of LO 5 based on student performance in written reports, papers, and oral presentations embedded in BMEN 101 (freshman year), BMEN 303, BMEN 381, and BMEN 382 (junior year), as well as the capstone design sequence BMEN 427 and BMEN 428 (senior year). For this, instructors are required to disclose examples of their assessment of students' communication skills (written essays /reports, poster or oral presentations) as part of an extensive course review document as described in "Methods". Course instructors are also required to reflect in writing on key student competencies and key deficiencies regarding students' communication skills. Additionally, instructors are asked to explain all changes they made to the course including communication-based assignments and recommend changes for the next course offering. Upon review, the Assessment Committee meets with the respective instructor for further discussion and feedback. The Committee then assesses the students' ability to communicate to a wide range of audiences in the six courses mentioned above and assigns letter grades for student communication skills in all six courses according to the following system:

A: Learning/course outcome is not only attained but exceeded; little to no room for increasing student performance or confidence

B: Learning/course outcome is comfortably attained; improvements that could raise the level of student

performance or confidence are still perceived

C: Learning/course outcome is attained, but this attainment is marginal; improvements that could raise the level of student performance and confidence are obvious

F: Learning/course outcome is not attained; major improvement is required to raise student performance and confidence to acceptable levels

In the freshman-level class BMEN 101 students' ability to communicate effectively should receive a grade of C or higher for this LO; in the junior-level seminar class BMEN 303 and the laboratory sequence BMEN 381 / BMEN 382 students' should receive a grade of B or higher. Lastly, students' ability to communicate effectively should receive a grade of A or B in the capstone senior design sequence BMEN 427/ 428, where communication is assessed intensively to both a variety of audiences and using numerous different media (posters, oral reports, journals, oral presentations etc.).

In addition to the annual course review process, attainment of this LO is also assessed via feedback from students as collected during the student course evaluations at the end of BMEN 101, BMEN 303, BMEN 381, BMEN 382, BMEN 427, and BMEN 428. Open ended questions in these six courses will be examined by the assessment coordinator for qualitative student feedback regarding students' communication skills and discussed with the course instructor during the course review meeting.

Quantitative Assessment:

Course evaluations administered at the end of BMEN 101, BMEN 303, BMEN 381, BMEN 382, BMEN 427, and BMEN 428 determine the level of confidence that students have with respect to their ability to communicate with a range of audiences. This will be accomplished with closed ended questions to be answered using a Likert scale. Students are expected to increasingly gain confidence in this LO as they advance from freshman to senior year. At least 70% of students must report high levels of confidence in their ability to communicate effectively in BMEN 101 (freshman year) and at least 80% of students in BMEN 303 (junior year) are expected to show high or very high levels of confidence in their communication skills. During senior year (BMEN 427 and BMEN 428) and upon graduation (senior exit survey) student confidence in their ability to effectively present material in a variety of different formats to a range of audiences must always remain above 85%.

Direct Quantitative Assessment for LO 5:

In BMEN 428, at the end of their senior design sequence, students present their final design prototype to a faculty panel, as well as their sponsors and peers in an oral presentation, summarizing and justifying both their design process and well as their final product. The instructor, with the help of the teaching assistants and a faculty panel, scores these presentations; scores are tallied up and averaged. At least 85% of students are expected to receive a grade of A or B to pass this direct assessment for LO 5.

Methods

Five primary assessment tools are employed to assess that students are meeting the criteria for individual learning outcomes (LOs), two qualitative ones (1, 2) and three quantitative ones (3, 4, 5).

(1) Qualitatively, attainment of learning outcomes in applicable courses (Table II) is assessed by the Assessment Committee in the form of annual course reviews. The Assessment Committee is comprised of the Assessment Coordinator, the Director of the Biomedical Engineering Program, the Undergraduate Director of the Biomedical Engineering Program as well as members of the Undergraduate Committee of the Program. The instructor of a course is asked to prepare a course review document detailing which student assessments in the course connects to the respective LO and provide information on average student performance in these student assessments. For this, the instructor is asked to reflect in writing on students' key competencies and deficiencies for each individual course outcome connected to the

respective LO. Lastly, the instructor is asked to reflect on the success of changes to the course compared to the previous offering, if applicable, and to recommend changes to the upcoming course offering. The Assessment Committee together with the respective course instructor reviews all materials and assigns a letter grade (A, B, C, F) for each course outcome supporting the respective LO according to the following system:

A: Course/Learning outcome is not only attained but exceeded; little to no room for increasing student performance or confidence

B: Course/Learning outcome is comfortably attained; improvements that could raise the level of student performance or confidence are still perceived

C: Course/Learning outcome is attained, but this attainment is marginal; improvements that could raise the level of student performance and confidence are obvious

F: Course/Learning outcome is not attained; major improvement is required to raise student performance and confidence to acceptable levels

The course reviews, including outcomes from the Assessment Committee discussions, are then compiled by the Assessment Coordinator, and filed in the Main Biomedical Engineering Office with access to all faculty. Letter grades below B will result in more in-depth follow-up communication or meetings with the instructor to discuss possible options for improvement of learning outcome attainment. Since course reviews are held twice a year just before the start of the Fall and Spring semester, respectively, to discuss the respective previous year's Fall and Spring classes, qualitative assessment will end with Spring 2019 courses for this assessment period. This timing ensures that feedback about each course is handed to the instructor of a class just as they are preparing for their upcoming class when feedback is most critical.

(2) Student comments as collected in course evaluations at the end of each course offering are reviewed by the Assessment Coordinator and may provide additional qualitative feedback on each LO connected to the respective courses (see Table II). The Assessment Coordinator is present for all course review meetings, where qualitative student feedback in relation to LOs 1 to 7 for individual classes will be discussed in detail.

(3) Quantitatively, student attainment of individual LOs is assessed by probing students for confidence in the respective LO on a closed ended questionnaire at the end of each course connected to the respective LO (Table II) using a Likert scale. Student confidence is reported in % students who display "high or very high" levels of confidence in this student outcome and is expected to rise for each LO as students advance from freshman to senior year.

(4) Additionally, at the end of each spring semester, student exit interviews are conducted for students that graduate in May or during the upcoming Summer or Fall semesters. The Director of the Program will conduct these interviews; the Assessment Coordinator is present to take notes. Students are asked to assess the outcomes of their education including LOs 1 to 7. Student responses to both closed ended questions to be answered using a Likert scale and open-ended questions are collected in each of these areas and compiled by the Chair of the Assessment Committee. The compiled data is distributed to the Assessment Committee and the Assessment Coordinator and discussed at a designated meeting of the Assessment Committee for the purpose of listing student strengths and weaknesses and formulating action items for improvement of learning outcomes and program goals. Discussion comments and action items will be documented by the Chair of the Assessment Committee and filed in the Biomedical Engineering Office. Generally, 85% or more of graduating seniors are expected to show high or very high levels of confidence in each of the seven LOs.

(5) For each LO a specific assignment that assesses and exemplifies the respective LO has been chosen as a direct assessment of whether the Program is achieving the attainment of this LO. All assignments chosen are assignments handed to upperclassmen as they near graduation. Generally, at least 80% of students are expected to receive a grade of B or higher in the respective indicator assignment.

Results

Due to the implementation of a new curriculum in Fall 2017, BMEN 381 was first offered to the junior class

in the Fall semester of 2019 and BMEN 382 was first offered in the Spring semester of 2020. Hence, BMEN 381/ 382 will not contribute to the Fall 2017 – Fall 2019 assessment of LO 5, leaving BMEN 101, BMEN 303, BMEN 427, and BMEN 428 to be assessed for students' ability to communicate effectively. Assessments of communication skills in these classes spans a variety of both oral and written formats including but not limited to technical reports, literature reviews, design projects and outlines, market or ethics studies, poster presentations, proposals, journal entries and meeting minutes, as well as oral presentation, both individual as well as group presentations. Attainment of course outcomes connected to LO 5, the ability to communicate effectively with a range of audiences, as assessed in yearly course reviews in presentation and report-heavy classes BMEN 101, BMEN 303, and BMEN 427/ BMEN 428 is summarized in Table 5.1. The criterion of a grade of B or higher was achieved in all course offerings except the Fall 2017 offering of BMEN 427.

Student confidence regarding LO 5 as collected by student course evaluations in BMEN 101, BMEN 303, BMEN 427, BMEN 427 as well as the first offering of BMEN 381 (Fall 2019) consistently exceeded the respective minimum percentages (70% for freshman year, 80% for junior year, 85% for senior year) for all course offerings (Table 5.2). Table 5.2 also includes quantitative student confidence results of graduating seniors as compiled from senior exit surveys. Ninety-six percent of seniors who graduated May 2018 expressed high or very high confidence in their ability to communicate effectively with a range of audiences. For graduates of May 2019, this percentage was 98. In both years, the quantitative criterion of 85% of graduates expressing high or very high confidence in LO 5 was exceeded. In open-ended senior exit interviews, graduates expressed that they feel very comfortable communicating in both written and oral form e.g., writing up reports or presenting in front of an audience.

Table 5.3 shows the percentage of students in BMEN 428 who received a grade of B or higher in their final design presentation held at the end of the semester open to all faculty, students, project sponsors and the public. In their final design presentation, 100% of students received a grade of A or B in both years confirming their growth in LO 5 (Table 5.3).

Tables for LO 5

Use of Results

Attainment of students' ability to communicate in written and/or oral form was reviewed as described in Methods in BMEN 101, BMEN 303, as well as the senior design sequence BMEN 427/ BMEN 428 and graded with a grade of A or B in all course offerings except the Fall 2017 offering of BMEN 427 when students ability to communicate effectively was rated with a grade of C (Table 5.1). In BMEN 427 students are tested in their ability to communicate effectively through journal entries, a project proposal, update reports, oral presentations and a group poster presentation. During the Fall 2017 course review of this course outcome in BMEN 427, the instructor noted that most of the communication deficiencies were poor technical writing and a poor performance of some student groups in their proposal assignment. Students noted that despite a range of required literature reviews and other reports, this was their first proposal assignment in the curriculum. Following this criticism, instructors of BMEN 361 (Spring 2018 and 2019) have implemented a short proposal assignment and students undergoing the new curriculum will be exposed to a proposal assignment in BMEN 382 (first offering Spring 2020). Additionally, technical writing is now introduced and practiced within the laboratory sequence of the new curriculum (BMEN 381 and 382) implemented in Fall 2017. Students who will have first undergone this laboratory sequence are set to graduate in May of 2021. It will be interesting to see if technical writing skills will have improved within the average student population and the Assessment Committee will continue to monitor students' ability to report technically as well as other communication skills (oral, poster presentations etc.). Within the senior design sequence, students improved their ability to communicate effectively from a C (Fall 2017) to a grade of B (Spring 2018) as assessed during course reviews, most likely to the increased exposure to a range of reports and presentations in BMEN 427. The following year, students were assessed to be much more competent in LO 7 in their senior year; their ability to "demonstrate the art of clear communication in written journals, reports and oral presentations" was graded with a grade of A in both semesters by the Assessment Committee. (Table 5.1, last row).

In their final design presentation that students hold in front of faculty, their peers, industrial and academic project sponsors as well as their instructors, 100% of students received a grade of A or B in both years confirming their growth in LO 7 (Table 5.3).

During senior exit interviews, many students identified their acquired ability to effectively communicate in both written and oral form as a strength of the program and attributed it to the variety and frequency of reports, research papers, poster and oral presentations implemented in various core courses throughout the Biomedical Engineering curriculum.

With the exception of a missed criterion in BMEN 427 due to a lack of technical writing proficiency, the Program has met all benchmarks in regard to LO 7 and student confidence in their ability to communicate was very high throughout the curriculum in all examined course offerings (Table 5.2). Students' exposure to technical writing and written reports was increased with the implementation of a laboratory sequence in junior year, which started in the Fall of 2019. The Program will continue to monitor all aspects of students' ability to communicate with a range of audiences in a variety of forms, both oral and written, and adjustments will continue to be put in place if further shortcomings are identified.

Learning Outcome 2.

Ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.

Measures and Criteria

Students are introduced to professional and ethical responsibility during the freshman-level course BMEN 101 Introduction to Biomedical Engineering. Skills relating to this LO are then further strengthened in BMEN 303 Professional Development and Ethics in BME. In addition, students are expected to apply these responsibilities when performing independent research, conducting experiments, or implementing engineering design within the year-long capstone design sequence BMEN 427 and BMEN 428 in senior year. Student performance on assignments and projects related to professional, social and ethical responsibility is reviewed for each of these classes, and attainment of this LO is evaluated both qualitatively and quantitatively in the manner described below.

Qualitative Assessment:

The Assessment Committee in close cooperation with each course instructor determines students' ability to recognize ethical and professional responsibility in engineering situations based on student performance in written reports, assignments, and/or oral presentations that emphasize professionalism and/or include an ethics component in the following courses: BMEN 101 (freshman year), BMEN 303 (junior year), and BMEN 427 / BMEN 428 (senior year). Instructors are asked to submit information on student performance in reports, papers, posters, and presentations that emphasize engineering ethics and professionalism. Within this document, instructors are required to reflect in writing on key student competencies and key deficiencies regarding this LO. The Assessment Committee then, with feedback from each course instructor, assesses the students' ability to recognize ethical and professional responsibilities in all four courses according to the following system:

A: Learning/course outcome is not only attained but exceeded; little to no room for increasing student performance or confidence

B: Learning/course outcome is comfortably attained; improvements that could raise the level of student performance or confidence are still perceived

C: Learning/course outcome is attained, but this attainment is marginal; improvements that could raise the level of student performance and confidence are obvious

F: Learning/course outcome is not attained; major improvement is required to raise student performance and confidence to acceptable levels

In the freshman-level class BMEN 101 students' ability to recognize and practice professional and ethical responsibilities should receive a grade of C or higher as determined by the Assessment Committee. The

junior-level seminar class BMEN 303, which has a higher focus on this LO, must receive a grade of B or A to meet this LO. Likewise, in senior year students' ability to recognize and demonstrate professional and ethical responsibility and to consider the impact of engineering solutions in global, economic, environmental, and societal contexts should be assessed with a grade of B or A.

In addition to the annual course review process, students' perceived ability to exercise professional and ethical responsibility is also assessed via feedback from students as collected during the student course evaluations at the end of BMEN 101, BMEN 303, BMEN 427, and BMEN 428. Open ended questions in these four courses will be examined by the assessment coordinator for qualitative student feedback regarding this LO.

Quantitative Assessment:

Course evaluations administered at the end of BMEN 101, BMEN 303, BMEN 427, and BMEN 428 determines the level of confidence that students have with respect to their ability to recognize ethical and professional responsibilities in engineering situations. This is accomplished with closed-ended questions to be answered using a Likert scale. Students are expected to increasingly gain confidence in this area as they advance from freshman to senior year. At least 70% of students must report high levels of confidence in their ability to exercise professional and ethical responsibility in BMEN 101 (freshman year) and at least 80% of students are expected to show high or very high levels of confidence in this LO in BMEN 303 (junior year). During senior year (BMEN 427 and BMEN 428) and upon graduation (senior exit survey) student confidence in their ability to recognize ethical and professional responsibilities in engineering situations and their ability to consider the impact of engineering solutions in global, economic, environmental, and societal contexts must remain above 85% at all times.

Direct Quantitative Assessment for LO 6:

Students work on a semester-long analysis of a patented medical device or process and its ethical, economic, societal and global implication in the junior-level class BMEN 303 Professional Development and Ethics in BME. Projects are presented in oral and written form and are graded by the instructor. At least 80% of students are expected to receive a grade of A or B in this project to pass this direct assessment for LO 6.

Methods

Five primary assessment tools are employed to assess that students are meeting the criteria for individual learning outcomes (LOs), two qualitative ones (1, 2) and three quantitative ones (3, 4, 5).

(1) Qualitatively, attainment of learning outcomes in applicable courses (Table II) is assessed by the Assessment Committee in the form of annual course reviews. The Assessment Committee is comprised of the Assessment Coordinator, the Director of the Biomedical Engineering Program, the Undergraduate Director of the Biomedical Engineering Program as well as members of the Undergraduate Committee of the Program. The instructor of a course is asked to prepare a course review document detailing which student assessments in the course connects to the respective LO and provide information on average student performance in these student assessments. For this, the instructor is asked to reflect in writing on students' key competencies and deficiencies for each individual course outcome connected to the respective LO. Lastly, the instructor is asked to reflect on the success of changes to the course compared to the previous offering, if applicable, and to recommend changes to the upcoming course offering. The Assessment Committee together with the respective course instructor reviews all materials and assigns a letter grade (A, B, C, F) for each course outcome supporting the respective LO according to the following system:

A: Course/Learning outcome is not only attained but exceeded; little to no room for increasing student performance or confidence

B: Course/Learning outcome is comfortably attained; improvements that could raise the level of student performance or confidence are still perceived

C: Course/Learning outcome is attained, but this attainment is marginal; improvements that could raise the level of student performance and confidence are obvious

F: Course/Learning outcome is not attained; major improvement is required to raise student performance and confidence to acceptable levels

The course reviews, including outcomes from the Assessment Committee discussions, are then compiled by the Assessment Coordinator, and filed in the Main Biomedical Engineering Office with access to all faculty. Letter grades below B will result in more in-depth follow-up communication or meetings with the instructor to discuss possible options for improvement of learning outcome attainment. Since course reviews are held twice a year just before the start of the Fall and Spring semester, respectively, to discuss the respective previous year's Fall and Spring classes, qualitative assessment will end with Spring 2019 courses for this assessment period. This timing ensures that feedback about each course is handed to the instructor of a class just as they are preparing for their upcoming class when feedback is most critical.

(2) Student comments as collected in course evaluations at the end of each course offering are reviewed by the Assessment Coordinator and may provide additional qualitative feedback on each LO connected to the respective courses (see Table II). The Assessment Coordinator is present for all course review meetings, where qualitative student feedback in relation to LOs 1 to 7 for individual classes will be discussed in detail.

(3) Quantitatively, student attainment of individual LOs is assessed by probing students for confidence in the respective LO on a closed ended questionnaire at the end of each course connected to the respective LO (Table II) using a Likert scale. Student confidence is reported in % students who display "high or very high" levels of confidence in this student outcome and is expected to rise for each LO as students advance from freshman to senior year.

(4) Additionally, at the end of each spring semester, student exit interviews are conducted for students that graduate in May or during the upcoming Summer or Fall semesters. The Director of the Program will conduct these interviews; the Assessment Coordinator is present to take notes. Students are asked to assess the outcomes of their education including LOs 1 to 7. Student responses to both closed ended questions to be answered using a Likert scale and open-ended questions are collected in each of these areas and compiled by the Chair of the Assessment Committee. The compiled data is distributed to the Assessment Committee and the Assessment Coordinator and discussed at a designated meeting of the Assessment Committee for the purpose of listing student strengths and weaknesses and formulating action items for improvement of learning outcomes and program goals. Discussion comments and action items will be documented by the Chair of the Assessment Committee and filed in the Biomedical Engineering Office. Generally, 85% or more of graduating seniors are expected to show high or very high levels of confidence in each of the seven LOs.

(5) For each LO a specific assignment that assesses and exemplifies the respective LO has been chosen as a direct assessment of whether the Program is achieving the attainment of this LO. All assignments chosen are assignments handed to upperclassmen as they near graduation. Generally, at least 80% of students are expected to receive a grade of B or higher in the respective indicator assignment.

Results

Biomedical Engineering core courses that demand a high level of professional and soft skills, discuss bioethical issues and require students to consider global, economic, environmental and societal issues include BMEN 101, BMEN 303, and the senior capstone design sequence BMEN 427 / BMEN 428.

Four course outcomes across these four Biomedical Engineering core courses assess students' competency in regard to LO 6:

- Ability to define ethics in global, economic, environmental, and societal contexts, with examples from biomedical engineering (BMEN 101)
- Ability to analyze biomedical engineering technology by considering scientific advancements as well

- as ethical, global, economic, environmental, and societal issues. (BMEN 303)
- Ability to critically consider ethical issues in biomedicine. (BMEN 302)
- Ability to apply ethics, public health, safety and welfare assessments, as well as global, societal, and environmental impact evaluations to engineering designs. (BMEN 427 and BMEN 428)

Examples of assessment for all course outcomes include project work, homework, in-class assignments and blackboard or oral discussions.

Attainment of all four course outcomes was assessed during course reviews and graded with a grade of A in all course offerings except for the Fall 2018 offering of BMEN 427 and the Spring 2019 offering of BMEN 428 (continuation of BMEN 427 of Fall 2018) when the respective course outcomes was rated with a grade of B (Table 6.1). The criterion of receiving an assessment grade of B or higher was achieved in all LO 6-related course outcomes.

The high scores regarding professional and ethical responsibility is mirrored in the high student confidence throughout the curriculum in this LO. Students perceive themselves to be very knowledgeable in their ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts in all course offerings in freshman and junior year (Table 6.2). As observed with the qualitative assessment scores summarized in Table 6.1, student confidence decreased slightly in the last semester, BMEN 428. Here, the percentage of students who feel high or very high confidence in LO 6 decreased to below the required 85% for the Spring 2019 offering. Unfortunately, evaluation results for Spring 2018 were not recorded for this LO due to low student response. Upon graduation, 82.7% and 86.3% of students (May 2018 and May 2019, respectively) felt very confident in their ability to recognize ethical and professional responsibility in engineering solutions, missing the criterion of 85% in 2018 but meeting it in 2019 (Table 6.2).

In BMEN 303 students undergo a semester-long study of the history and implications of a medical invention on society requiring students to consider all aspects related to LO 6: economics, ethical considerations during the clinical trials and after marketing, professional responsibility, global and environmental benefits and concerns. Hence, this project has been chosen as a direct measure of students' competency in LO 6. In both years, 100 % of students received a grade of B or higher in their project, exceeding the criterion of 80 % (Table 6.3).

Tables for LO 6

Use of Results

The criteria for LO 6 are met in most offerings for all three categories: qualitative, quantitative indirect and quantitative direct assessment. The criterion of receiving an assessment grade of B or higher was achieved in all LO 6-related course outcomes for all course offerings during the assessment period (Table 6.1) and students performed well in their BMEN 303 projects (Table 6.3). Additionally, students displayed high student confidence throughout most of the curriculum (Table 6.2). However, a drop in student confidence can be observed in the very last semester (Table 6.2, Spring 2019 offering of BMEN 428). Overall, BMEN 428 shows lower qualitative assessment for LO 6 (Table 6.1) as well as lower student confidence levels (Table 6.2).

No negative student comments were observed during open-ended course evaluations in any of the courses connected to LO 6 or senior exit interviews throughout the assessment period and instructors of BMEN 101, BMEN 303, and BMEN 427/ BMEN 428 did not express any concerns in regard to students' ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts. The drop in student confidence as observed in BMEN 428 may be due to a higher stress level in regard to this LO as students are writing up their projects and subjected to stricter rubrics and higher expectations of the instructor in regard to ethical and professional responsibilities prior to finalizing the senior design project. The instructor of BMEN 428 has been notified of the lower than expected student confidence levels. Only one course offering in the senior design sequence of BMEN 427/ BMEN 428 has displayed a percentage of lower than 80% of students feeling very confident in LO 6 (Spring 2019 offering of BMEN 428; no data available for Spring of 2018). The Assessment Committee will continue to monitor student performance and confidence in this LO in the senior design sequence to see if this result is part of

an overall trend or only an outlier.

In summary, the Program will continue to stress professional and ethical responsibility throughout the curriculum and have students practice informed judgement considering societal, environmental and global issues in freshman, junior and senior year. The Assessment Coordinator will monitor instructor and student feedback as observed during course reviews, course evaluations and senior exit interviews for comments in this area to be able to react to possible deficiencies.

Learning Outcome 3.

Ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.

Measures and Criteria

Students will be required to work in teams during semester-long projects in BMEN 101 (freshman year) and BMEN 303 (junior year), as well as in the laboratory course sequence BMEN 381 and BMEN 382 (junior year). In addition, student group work will be an intricate part of the capstone design sequence, BMEN 427 and BMEN 428 (senior year). Students' ability to work effectively in these team projects will be assessed both qualitatively and quantitatively in the manner described below.

Qualitative Assessment:

Instructors for BMEN 101, BMEN 303, BMEN 381, BMEN 382, BMEN 427 and BMEN 428 are asked to submit information on the how well students worked in teams and reflect in writing on key student competencies and key deficiencies in regard to student team work. The Assessment Committee then meets with the respective instructor and evaluates the students' attainment of this LO for each course according to the following system:

A: Learning/course outcome is not only attained but exceeded; little to no room for increasing student performance or confidence

B: Learning/course outcome is comfortably attained; improvements that could raise the level of student performance or confidence are still perceived

C: Learning/course outcome is attained, but this attainment is marginal; improvements that could raise the level of student performance and confidence are obvious

F: Learning/course outcome is not attained; major improvement is required to raise student performance and confidence to acceptable levels

In the freshman-level class BMEN 101 students' team-work abilities should receive a grade of C or higher; junior-level classes BMEN 303, BMEN 381 and BMEN 382 must receive a grade of B or A to meet this LO. Likewise, in the teamwork focused capstone design sequence BMEN 427 and BMEN 428 (senior year), students' ability to work effectively and collaboratively in groups and meet goals must remain at a grade level of A or B.

In addition to the annual course review process by the Assessment Committee, students' perceived ability to function effectively on a team, establish goals, plan tasks, and meet objectives is also assessed via feedback from students as collected during the student course evaluations at the end of BMEN 101, BMEN 303, BMEN 381, BMEN 382, BMEN 427, and BMEN 428. Open ended questions in these seven courses will be examined by the assessment coordinator for qualitative student feedback in regard to student teamwork.

Quantitative Assessment:

Course evaluations administered at the end of BMEN 101, BMEN 303, BMEN 381, BMEN 382, BMEN 427, and BMEN 428 determine the level of confidence that students have with respect to their ability to work effectively in teams, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives. This will be accomplished with closed-ended questions to be answered using a Likert scale. Students are expected to increasingly gain confidence in their teamwork ability as they are exposed to more and more teamwork challenges throughout the curriculum. At least 70% of students must report high levels of confidence in their ability to work effectively in teams in freshman year (BMEN 101) at least 80% of students in junior year (BMEN 303, BMEN 381, and BMEN 382), and at least 85% of students must report high confidence in their team work skills in senior year (BMEN 427 and BMEN 428).

In addition, an on-line exit survey of graduating seniors, administered annually, determines the level of confidence that students have with respect to teamwork skills upon graduation. At least 85% of graduating seniors must respond that they have a high or very high level of confidence in their ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.

Direct Quantitative Assessment for LO 7:

Biomedical Engineering students are exposed to a high level of group work during their capstone senior design sequence. During this experience students work in teams of 3 to 5 members on a year-long design project setting their own individual timetables, tasks, as well as objectives and goals. Team members are asked to evaluate each other on a regular basis on their commitment to common objectives and timelines as well as ability to effectively function in a group environment throughout their one-year journey (BMEN 427 and BMEN 428) in regular peer evaluations. These peer evaluations are point-score evaluations that are filled out anonymously by each student for each group member. The scores each student receives from all group members throughout their senior design year is recorded and averaged for the direct assessment of LO 7. At least 90% of all students are expected to receive an average grade of A or B over the course of both semesters from their group to pass the requirements for LO 7.

Methods

Five primary assessment tools are employed to assess that students are meeting the criteria for individual learning outcomes (LOs), two qualitative ones (1, 2) and three quantitative ones (3, 4, 5).

(1) Qualitatively, attainment of learning outcomes in applicable courses (Table II) is assessed by the Assessment Committee in the form of annual course reviews. The Assessment Committee is comprised of the Assessment Coordinator, the Director of the Biomedical Engineering Program, the Undergraduate Director of the Biomedical Engineering Program as well as members of the Undergraduate Committee of the Program. The instructor of a course is asked to prepare a course review document detailing which student assessments in the course connects to the respective LO and provide information on average student performance in these student assessments. For this, the instructor is asked to reflect in writing on students' key competencies and deficiencies for each individual course outcome connected to the respective LO. Lastly, the instructor is asked to reflect on the success of changes to the course compared to the previous offering, if applicable, and to recommend changes to the upcoming course offering. The Assessment Committee together with the respective course instructor reviews all materials and assigns a letter grade (A, B, C, F) for each course outcome supporting the respective LO according to the following system:

A: Course/Learning outcome is not only attained but exceeded; little to no room for increasing student performance or confidence

B: Course/Learning outcome is comfortably attained; improvements that could raise the level of student performance or confidence are still perceived

C: Course/Learning outcome is attained, but this attainment is marginal; improvements that could raise the level of student performance and confidence are obvious

F: Course/Learning outcome is not attained; major improvement is required to raise student performance and confidence to acceptable levels

The course reviews, including outcomes from the Assessment Committee discussions, are then compiled by the Assessment Coordinator, and filed in the Main Biomedical Engineering Office with access to all faculty. Letter grades below B will result in more in-depth follow-up communication or meetings with the instructor to discuss possible options for improvement of learning outcome attainment. Since course reviews are held twice a year just before the start of the Fall and Spring semester, respectively, to discuss the respective previous year's Fall and Spring classes, qualitative assessment will end with Spring 2019 courses for this assessment period. This timing ensures that feedback about each course is handed to the instructor of a class just as they are preparing for their upcoming class when feedback is most critical.

(2) Student comments as collected in course evaluations at the end of each course offering are reviewed by the Assessment Coordinator and may provide additional qualitative feedback on each LO connected to the respective courses (see Table II). The Assessment Coordinator is present for all course review meetings, where qualitative student feedback in relation to LOs 1 to 7 for individual classes will be discussed in detail.

(3) Quantitatively, student attainment of individual LOs is assessed by probing students for confidence in the respective LO on a closed ended questionnaire at the end of each course connected to the respective LO (Table II) using a Likert scale. Student confidence is reported in % students who display "high or very high" levels of confidence in this student outcome and is expected to rise for each LO as students advance from freshman to senior year.

(4) Additionally, at the end of each spring semester, student exit interviews are conducted for students that graduate in May or during the upcoming Summer or Fall semesters. The Director of the Program will conduct these interviews; the Assessment Coordinator is present to take notes. Students are asked to assess the outcomes of their education including LOs 1 to 7. Student responses to both closed ended questions to be answered using a Likert scale and open-ended questions are collected in each of these areas and compiled by the Chair of the Assessment Committee. The compiled data is distributed to the Assessment Committee and the Assessment Coordinator and discussed at a designated meeting of the Assessment Committee for the purpose of listing student strengths and weaknesses and formulating action items for improvement of learning outcomes and program goals. Discussion comments and action items will be documented by the Chair of the Assessment Committee and filed in the Biomedical Engineering Office. Generally, 85% or more of graduating seniors are expected to show high or very high levels of confidence in each of the seven LOs.

(5) For each LO a specific assignment that assesses and exemplifies the respective LO has been chosen as a direct assessment of whether the Program is achieving the attainment of this LO. All assignments chosen are assignments handed to upperclassmen as they near graduation. Generally, at least 80% of students are expected to receive a grade of B or higher in the respective indicator assignment.

Results

Due to the implementation of a new curriculum in Fall 2017, BMEN 381 was first offered to the junior class in the Fall semester of 2019 and BMEN 382 was first offered in the Spring semester of 2020. Hence, BMEN 381/ 382 will not contribute to the Fall 2017 – Fall 2019 assessment of LO 7, leaving BMEN 101, BMEN 303, BMEN 427, and BMEN 428 to be assessed for students' ability to work effectively in a team environment. However, the Fall 2019 offering of BMEN 381 will contribute to student confidence evaluations. The laboratory sequence in junior year, BMEN 381 and BMEN 382, will contribute in full to the next assessment period of Fall 2020 to Fall 2022. Table 7.1 shows assessment of all course outcomes that are connected to LO 7 either directly or through project teamwork. Additionally, instructors are probed on how effectively students functioned in a team environment during those assignments as part of the course review process. Both competencies as well as deficiencies of students in regard to teamwork are discussed during the assessment meetings. All course outcomes related to LO 7 received an assessment grade of A or B, with the direct course outcome "Ability to demonstrate the principles of teamwork and project management with emphasis on consensus decision making, organizing, planning, and scheduling" of BMEN 427 and BMEN 428 receiving a grade of A in all four course offerings.

In BMEN 427 and BMEN 428 students were also directly graded on their ability to work in teams through the implementation of peer evaluations. Each student scored each of their team members using a rubric that includes aspects such as dependability, percentage of contribution, communication as well as an open-ended comment section. Peer evaluations are collected repeatedly throughout the senior capstone design sequence (BMEN 427/ BMEN 428). Table 7.3 shows the percentage of students who received a grade of B or higher on their teamwork skills as assessed in those peer evaluations. Ninety-six (96) percent of students received a grade of B or higher in the first assessment year (Fall 2017/ Spring 2018), and 98% of students received a grade of B or higher in the second assessment year (Fall 2018/ Spring 2019) for their teamwork skills, exceeding the requirement of 90%.

Assessment also evaluated student confidence in teamwork skills following individual courses via supplemental questions included within course evaluations. This assessment was specifically conducted following each of the courses where teamwork is central to the class (Table 7.2), BMEN 101, BMEN 303, and the capstone design sequence BMEN 427/ BMEN 428. These courses are spaced throughout the curriculum and therefore allow for temporal assessment of student improvement in this learning outcome. During the assessment period of Fall 2017 to Fall 2019) on average 92% of freshmen (students enrolled in BMEN 101), 98% of juniors (students enrolled in BMEN 303 and BMEN 381), and 92% of seniors (students enrolled in BMEN 427 and BMEN 428) express confidence in their teamwork skills. These results show a consistently high student confidence in teamwork skills from the freshman to the junior level, exceeding the criterion of 70% student confidence in freshman year, 80% student confidence in junior year, and 85% student confidence in senior year, respectively. Due to the consistently high level, a temporal trend is not noticeable. Among graduating seniors, 94.2% and 100% reported feeling confident in their ability to function in teams in May of 2018 and 2019, respectively, meeting the criterion for 85% student confidence in this learning outcome.

Tables for LO 7

Use of Results

The criteria for LO 7 are exceeded in all aspects. In senior exit open-ended questions and interview discussions, many graduating seniors identified their acquired teamwork skills to be a strength of the program. This is also confirmed in the assessment of course outcomes connected to teamwork projects (Table 7.1) as well as high student satisfaction in this learning outcome as assessed by course evaluations (Table 7.2). Instructors of BMEN 101, BMEN 303, and BMEN 427/ BMEN 428 expressed high student group functionality and efficiency during course reviews, and student confidence was consistently above the desired criterion throughout the course of the curriculum. During the senior capstone design sequence where effective group work is paramount to the progress and success of the coursework, more than 95% of students received a grade of B or higher by their peers in an anonymous peer evaluation for both assessment years (Table 7.3). Group work will continue to be emphasized and monitored throughout the Biomedical Engineering curriculum, so that performance will continue to meet the specified criteria with respect to this learning outcome.