

# Final Assessment Report

## Systems Design Engineering (BASc), Biomedical Engineering (BASc)

### January 2023

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#### Executive Summary

External reviewers found that the Systems Design Engineering (BASc) and Biomedical Engineering (BASc) programs delivered by the Department of Systems Design Engineering were of high quality.

*Our overall assessment is that both the Systems Design Engineering (SYDE) and Biomedical Engineering (BME) undergraduate programs at the University of Waterloo (UW) are of high quality, attract outstanding applicants, provide excellent education, and produce graduates that succeed in both industry and academia.*

A total of seven recommendations were provided by the reviewers, regarding curriculum reviews for both programs, providing greater prominence and autonomy to the Biomedical Engineering program, and increasing the clinical exposure of Biomedical Engineering students. In response, the program created a plan outlining the specific actions proposed to address each recommendation as well as a timeline for implementation. The next cyclical review for this program is scheduled for 2027-28.

#### Enrollment over the past three years

	Systems Design Engineering Honours Co-op	Biomedical Engineering Honours Co-op
2022-2023	519	443
2021-2022	515	413
2020-2021	488	379

Based on Active Students Extract in Quest, December 23, 2022.

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#### Background

In accordance with the University of Waterloo's Institutional Quality Assurance Process (IQAP), this final assessment report provides a synthesis of the external evaluation and the internal response of the Systems Design Engineering (BASc) and Biomedical Engineering (BASc) programs delivered by the Department of Systems Design Engineering. A self-study (Volume I, II, III) was submitted to the Associate Vice-President, Academic on August 16, 2021. The self-study (Volume I) presented the program descriptions and learning outcomes, an analytical assessment of the

programs, including the data collected from a student survey, along with the standard data package prepared by the Office of Institutional Analysis & Planning (IAP). The CVs for each faculty member with a key role in the delivery of the program(s) were included in Volume II of the self-study.

From Volume III, two arm's-length external reviewers were selected by the Associate Vice-President, Academic: Dr. Robert Kearney, Professor of Biological and Biomedical Engineering, McGill University, and Dr. Scott S. H. Tsai, Associate Professor of Biomedical Engineering, Toronto Metropolitan University.

Reviewers appraised the self-study documentation and conducted a virtual site visit to the University from July 4 – 8, 2022. An internal reviewer from the University of Waterloo, Dr. Kesen Ma, Associate Professor of Biology, was selected to accompany the external reviewers. The visit included interviews with the Associate Vice-President, Academic; Dean of the Faculty of Engineering; Faculty Associate Dean of Undergraduate Studies; Chair/Director of the Department, as well as faculty members, staff and current undergraduate students. The site visit team also had an opportunity to view a PowerPoint presentation of the laboratories and other spaces, and meet with representatives from the library, and Co-operative Education.

Following the site visit, the external reviewers submitted a report on their findings, with recommendations. Subsequently, the program responded to each recommendation and outlined a plan for implementation of the recommendations. Finally, the Dean responded to the external reviewers' recommendations, and endorsed the plans outlined by the program.

This final assessment report is based on information extracted, in many cases verbatim, from the self-study, the external reviewers' report, the Program response and the Dean's response.

## **Program Characteristics**

### Systems Design Engineering (BASc)

Systems design covers technical, environmental, socioeconomic, and political aspects of the engineering process, using systems design methodology. The department motto is: "Systems is how we know the World. Design is how we will change it."

Systems Design Engineering (SYDE) strives to provide an educational program for engineering students who want to learn how to address and solve complex and uncertain problems that transcend traditional engineering boundaries. Modern engineering projects comprise elements that cross engineering disciplines (e.g., civil engineering, electrical engineering, mechanical engineering, software engineering) and these elements must be integrated into a functioning whole to meet the needs of users and work effectively within an environment.

Successful completion of the **SYDE** undergraduate program requires the successful completion of: 36 core and compulsory courses, including five Technical Electives (TE), three Complementary Studies electives (CS), and one additional TE or CS (at the discretion of the student).

### Biomedical Engineering (BASc)

The Biomedical Engineering (BME) program is organized around three theme areas: biosignals, biomechanics, and biodevices (refer to the [undergraduate BME calendar](#) for a more detailed description). In upper years, technical electives allow students to gain deeper knowledge in these areas.

The **BME** undergraduate program requires successful completion of 40 core and compulsory courses, including six Technical Electives and three Complementary Studies electives.

### Options and Specializations

In addition to the basic **SYDE / BME** BASc degree, the UW Faculty of Engineering recognizes on diplomas and transcripts the successful completion of selected combinations of courses, designated as “options” or “specializations.” Options recognize a field of study outside the basic engineering degree, while specializations recognize concentration within the engineering program. Currently the SYDE program only offers options, with no specializations available.

The following options (from the 2021-2022 UW Undergraduate Calendar) are common to all UW Engineering students:

1. Artificial Intelligence Engineering Option
2. Biomechanics Option
3. Computer Engineering Option
4. Computing Option
5. Entrepreneurship Option
6. Environmental Engineering Option
7. International Studies in Engineering Option
8. Life Sciences Option
9. Management Sciences Option
10. Mechatronics Option
11. Physical Sciences Option
12. Society, Technology and Values Option
13. Software Engineering Option
14. Statistics Option

## Summary of Strengths, Challenges and Weaknesses based on Self-Study

### Strengths

In 2018, as part of the on-going Strategic Planning exercises conducted by all programs in the Faculty of Engineering, the department conducted an extensive Self-Study. While they believe that there are many aspects of the SYDE program that produce outstanding engineers, they focused on four key strengths: a) engineering design curriculum; b) elective flexibility; c) employability; d) entrepreneurial spirit.

- **Engineering Design Curriculum:** The department's undergraduate students identified the holistic, user-centred approach to problem solving taught in the program as a significant differentiator in the workplace and among their engineering peers. In recent years, industry has also seen a strong push in the direction of user-centred design practice and "design thinking"—two elements that form the backbone of the department's design courses. Their Design Curriculum Committee oversees their eight design-related compulsory courses, and recommends curriculum changes that go to the department's Undergraduate Studies Curriculum Committee (DUGS).
- **Elective Flexibility:** With a strong foundational base established in the first two years of study, SYDE students can then choose from hundreds of technical electives offered on campus. This flexibility fits well with the interdisciplinary philosophy of this program and the students' wide range of technical interests. To track the requisite number of AUs that any given student needs to meet Engineers Canada requirements for graduation, SYDE has a custom-built online "CEAB Planner".
- **Employability:** SYDE has had very high levels of co-op employment, well above the average for UWaterloo engineering students. Even their first-year students have enjoyed consistently high employment rates. More than 50% of their graduating cohorts report that they have secured permanent employment positions before finishing their 4B term; the others find employment within six months of graduation, pursue graduate studies, or launch their own startups.
- **Entrepreneurial Spirit:** While SYDE is a relatively small program (each cohort ~100 students), at the time of its 50<sup>th</sup> anniversary in Fall 2018, their graduates were responsible for approximately 142 startup companies. The department attributes this astounding rate of spinoff activity to the early and repeated exposure that students receive to design and systems thinking, coupled with the University of Waterloo's 100% inventor-owned IP policy, and a well-developed, extremely active startup culture in the Waterloo area.

### Challenges

- Students have limited exposure to the breadth of engineering systems. During their co-op terms they often work in software but are typically not exposed to specific engineering systems that impact societies, such as energy systems, traffic systems, food systems.

- There have been significant COVID and post-COVID faculty resignations and retirements. The large number of sessional teaching in the program is a challenge.
- Our classrooms and lab spaces are not ideal for hands-on learning and the increased size of the cohorts we are now admitting. Ideally, design studio style space should be pursued for 50-student groups (half cohorts).

### **Weaknesses**

- The curriculum is light on systems content. For example, there is an “Introduction to Design” course in first year (and a design course every term), but there is no first-year course “Introduction to Systems.” There are two third-year courses, “Systems Models” (core) and “Complex Systems” (optional) that focus on systems.
- The natural science content in the curriculum should be expanded upon to better meet CEAB requirements.
- The optimization course (now in fourth year) comes too late to be employed by students in their design courses. Note that the department aims to change this with the next revision of the math curriculum.
- The design part of the curriculum should be linked more tightly with the technical content covered in other core courses.

### **Summary of Key Findings from the External Reviewers**

Our overall assessment is that both the Systems Design Engineering (SYDE) and Biomedical Engineering (BME) undergraduate programs at the University of Waterloo (UW) are of high quality, attract outstanding applicants, provide excellent education, and produce graduates that succeed in both industry and academia.

Notably, the students in the program were almost universally praised for their energy, creativity, and initiative—indeed, most of those interviewed in this program review described the quality of the students as one of the strongest features of the program. Another unique attribute of both SYDE and BME programs was the focus on systems thinking and design. While other Canadian university engineering programs also teach these concepts, the UW programs are unique in placing these concepts at the core of the entire curriculum of both programs. Finally, there appears to be a good sense of community and collegiality among the students, support staff, and faculty.

Our assessment found many positives in the programs, and only a handful of areas for potential improvement. Namely, we found that the BME program could be given more opportunities to evolve and grow, especially with respect to new and emerging areas of biomedical engineering. We felt that generally, the BME program played a somewhat secondary role in the department as a whole, and that the program could be featured more prominently, both externally (i.e., in department webpages) and internally (i.e., with newer BME-focused faculty members taking more responsibilities to guide the evolution of the program). We found that the undergraduate BME students would benefit from more clinical exposure, perhaps by increasing collaborations

with clinicians or having clinicians co-supervise some of the capstone projects. We also noted some issues in both the SYDE and BME curricula: the breadth and depth of mathematics training, the workload of laboratory courses, the alignment and timing of lab and lecture contents, and the flexibility of when students can take technical electives. We identified a need for a critical evaluation of the undergraduate curricula to look for possible ways to reduce the overall workload in the programs. Finally, while students in the programs were almost universally praised for their quality and dedication, it was also noted that an updated recruitment and student selection approach could bring to the programs more students that are passionate about engineering. These findings form the basis of our recommendations for what are already outstanding programs in SYDE and BME.

### **Program Response to External Reviewers' Recommendations**

**1. Provide the BME program more autonomy and prominence.** We recognize the origins of the BME program and how it was planned from the beginning to be a systems-thinking focused take on BME. This approach has led to a very successful BME program. However, the BME program is growing with more recently hired faculty. The program should be given the flexibility to evolve and expand from the original program design to cover a wider range of biomedical engineering in terms of both recruitment and teaching. This could be addressed by increasing the number and diversity of BME related specializations and the recruitment of the faculty needed to teach them. The program website should also be updated to indicate which faculty members are “core” to the BME program (not just faculty members that conduct research in BME) and clearly indicate that the BME program is in the Department of Systems Design Engineering. (The current BME program website does not indicate that it is part of the department.)

#### **Program Response**

The experience we have gained from teaching eight cohorts of the BME program has highlighted the need to revise the curriculum, and we agree with the reviewers' recommendation that some changes are needed. Upcoming curriculum renewals will be conducted separately for BME and SYDE, allowing each program to achieve excellence in its own right.

Overlapping courses will no longer be required for efficiency as they were at the onset of the new BME program. The values of systems thinking and design will remain for both programs, and will be implemented independently and in ways that best fit the curriculum and vision of each program. Three new BME specializations, that may not have been discussed during the visit, will also be available to students as of Fall 2023. Additionally, our recently hired faculty will be developing technical electives that will further diversify our offerings. Two new faculty hires are expected within the next 2 years.

Website overhaul will be undertaken in Fall 2022-Winter 2023, with an emphasis on clarifying BME as a distinct program from SYDE within the department that has the same name.

Additionally, faculty members who teach, or having taught BME courses will be identified on the website, as well as members of the BME program committee.

### **Dean's Response**

I support the department's proposed actions to address this recommendation.

**2. Increase the clinical exposure of BME students.** We found that the students would benefit from more interactions with clinical personnel. We found that there are many possible routes to increase such interactions. For example, McMaster University's medical school has a satellite campus in Waterloo, there are pharmacy and optometry schools on campus, and there are several large hospitals nearby. However, there currently does not appear to be a lot of interactions between BME program students and these entities. One mechanism could be to invite clinicians from these entities to propose BME capstone projects and serve as co-supervisors to ensure that the projects focus on real clinical problems.

### **Program Response**

We agree with the reviewers' recommendation that more clinical exposure would be beneficial to our students. Several pilot studies are ongoing in our design courses in which the medical community is involved. Waterloo Region clinicians and health-care providers are invited to speak in our design courses, and to present problem space for capstone projects. Third year BME students are being connected to medical students on a voluntary basis. As we learn from these experiences, we aim to develop a sustainable and long-lasting approach to these interactions and connections. One such approach may be to develop a field course which would be core to the BME curriculum. Increasing the number of co-op jobs in healthcare facilities would also create further opportunities for BME students; this may require additional student funding, as these jobs may not always pay at the same levels as industry opportunities, which may reduce student interest in these opportunities due to financial reasons.

Through the support of a donation, a clinician-in-residence program, whereby a health care provider would spend one day a week in our program (providing consultations with design teams, intervention in BME courses, etc.), is also being created.

### **Dean's Response**

I support the department's proposed actions to address this recommendation.

**3. A critical curriculum review should be conducted for the BME and SYDE programs.** We believe that there are a number of minor adjustments to the curricula that would improve the programs. First, a critical curriculum review should be conducted to examine ways to reduce the overall workload while still meeting the requirements for accreditation. Secondly, the relation between workload and credit weight of the laboratory courses should be reviewed. We are told that some laboratory courses with 0.25 weight had a workload similar to that of a 0.5 weight lecture course. In addition, the topics of the lab sessions should be presented in an order that roughly corresponds

to the order of the lectures so that students are exposed to some of the theory before they see the labs. We were informed that these issues were being addressed. Nevertheless, the curriculum review should confirm that the workload of courses is consistent with their weight. Finally, the mathematics content of the third courses should be reviewed to see if it can be modified to reduce the load while still fulfilling the program requirements.

### **Program Response**

Both the SYDE and BME Program committees will conduct formal curriculum reviews, taking into account these recommendations, over the next 1-2 years with continuing evaluation of effectiveness. The reviews will be done with the intention of updating learning outcomes and meeting CEAB requirements, with the simultaneous goal of reducing “busy” student workloads. This effort is in line with a faculty-level initiative in Waterloo Engineering.

We will also include consideration of the following:

- Re-design and updating of lab experiences to optimize the overall workload of the labs and improve alignment with the 0.25 weight allotted to the lab courses.
- Removal of third year math course (SYDE 311). The math curriculum committee has already revised the curriculum to remove the content from this course that is no longer needed in the curriculum and move content that is needed into our other math courses. This has been done for all our math courses, and therefore there is no net increase in material. It is instead an update to the needed concepts.
- The SYDE program committee has already met, and it agreed to move the optimization course to third year for better alignment with design courses. As this will create an opening in fourth year, we are considering an additional required systems course in fourth year to enhance the systems content in the curriculum.
- We are taking steps to add more simulation modeling methods to our SYDE curriculum
- Efforts in BME will include the clinical experience mentioned above.

### **Dean’s Response**

This recommendation aligns well with a current Faculty of Engineering initiative to look at ways of reducing the intensity of student workload throughout all the undergraduate engineering programs via what we have called a “curriculum diet”.

**4. Review the Role of Software in the Program.** A frequently expressed concern was that students were more interested in software development than in the technical areas that were central to SYDE and BME. To some extent this may be result of co-op program where the software companies offer the most attractive salaries and job opportunities. The Department should decide whether to embrace this trend or attempt to ensure its graduates leave with a more rounded engineering approach. If the decision is to embrace software, then the curriculum should be reviewed to provide stronger training in the area.



One suggestion we heard was to replace some of the “classical” math topics with discrete math. If a more rounded approach is selected – the preference of the reviewers – then several steps are possible. Thus, as we suggest below, the Department should find ways of admitting students with a real interest and passion for systems engineering rather than simply accepting the students with the best marks.

The program should also be modified to provide students with more “hands-on” experience in the course work, to require capstone projects to have both hardware and software components, and to encourage/require students to have a range of experience in their co-op terms.

### **Program Response**

It is our intention to remain unique and distinct from software engineering, and to continue to emphasize core biomedical and systems engineering concepts in our curricula. We plan to improve communication of the SYDE and BME programs to incoming students through our website and outreach, with the goal of ensuring an understanding that these programs are distinct from software engineering, and improving awareness of the various possible career paths.

While our current admissions procedure allows us to accept students based on more than their grades, we do agree that this process could be modified to enable improved selection of candidates that are more aligned with SYDE and BME program goals (see “Review of Admissions criteria” below).

With respect to the capstone design course, we plan to review incorporation of systems design and biomedical engineering aspects in capstone projects. In our curriculum review, we will consider improving the exposure of students to systems integration and physical systems, to allow for more diverse components in our capstone projects. We will also assess the viability of establishing different sections for capstone design courses with the goal of establishing an improved faculty-to-student ratio, which would allow better capacity to advise a broader range of student projects.

It is important to recognize that there is a need for software solutions to address healthcare needs both in industry and hospitals. The BME curriculum should offer courses to support our students following that path by ensuring they have the skills to develop robust engineering solutions; this can be best achieved through a specialization.

### **Dean’s Response**

I support the department’s proposed actions to address this recommendation.

**5. Increase the Flexibility of Electives.** Students should be given the flexibility to take more technical elective courses before the fourth year, so that they can be exposed to a range of specialized topics before having to decide on a specialization.

**Program Response**

As we look toward renewing our curriculum, we are considering the potential for flexible streaming in third year. This could consist of allowing students to pick two electives from sets of electives representing different specializations. This concept aligns with a faculty-level initiative to improve flexibility in engineering curricula. For example, by allowing some courses that are offered across departments to be taken according to a more flexible schedule, we could allow space for increased electives in third year.

**Dean's Response**

I support the department's proposed actions to address this recommendation.

**6. Review Admissions Criteria.** The department should consider whether the current recruitment approach is bringing in the type of students that best suit the SYDE and BME programs. Current students are universally praised for being excellent academically, but not all appear to be genuinely committed to engineering. It might be useful to ask applicants to include a portfolio in their applications and interview a short list of the most qualified students. Any such steps should be designed to ensure equity. Care must be taken to ensure that any changes, for example the addition of a portfolio, do not inadvertently work to the advantage groups of students (e.g., students who already have many opportunities to engage in extracurricular activities because of socioeconomic advantages) that are already in a favorable position to gain entry into the programs.

**Program Response**

We will evaluate the feasibility and effectiveness of a two-stage process to specifically assess the candidate's ability to demonstrate their interest and goals in pursuing engineering and design. We are also considering how to incorporate equity in this process.

**Dean's Response**

Currently admissions is conducted centrally across the faculty. We have already initiated discussions around the way we admit students with an aim to find students who are truly passionate about a career in SYDE or BME.

**7. Library Resources.** The reviewers were favorably impressed by the library's contributions to the BME program in particular. However, from our discussions with the librarian, we feel that the library would benefit from additional financial resources to expand its collections in the biomedical/medical areas to better support BME students.

**Program Response**

Resources for BME library content are being requested at this time in the new BME Graduate Program proposal.

**Dean's Response**

I support the department's proposed actions to address this recommendation.

**Recommendations Not Selected for Implementation**

None.

**Implementation Plan**

	<b>Recommendations</b>	<b>Proposed Actions</b>	<b>Responsibility for Leading and Resourcing (if applicable) the Actions</b>	<b>Timeline for addressing Recommendations</b>
1.	<b>Provide the BME program more autonomy and prominence</b>	(1) Independent curriculum review and renewal. (2) New BME technical electives by new faculty hires (3) Two new faculty hires (4) BME website revisions	(1,2) BME director with program committee (3) BME director and SYDE chair (4) BME director and Communication & Outreach Officer	(1,2,3) 2023-2024 Fall 2022  Websites changes have been undertaken as have other actions.
2.	<b>Increase the clinical exposure of BME students</b>	(1) Formalize involvement from healthcare providers and clinicians in design courses (2) Clinician-in-residence	BME director and program committee BME director and SYDE chair	2023-2024
3.	<b>A critical curriculum review should be conducted for the BME and SYDE programs</b>	(1) Re-design and updating of lab experiences (2) Removal of third year math course and move optimization course (3) Renewal of SYDE curriculum	(1,2) ACUG and program committee (3) ACUG, SYDE chair and program committee	(1,2) 2023 (3) Begin in 2023 with continuing evaluation of effectiveness of program content and curriculum for each program.
4.	<b>Review the Role of Software in the Program</b>	(1) Improve outreach materials (2) Review curriculum to improve flow of skills to capstone	(1) ACUG and Communication & Outreach Officer	(1) 2023-2024 (2) Begin in 2023 with continuing evaluation of

			(2) ACUG, Program committee and SYDE chair, BME Director	effectiveness of program content and curriculum.
5.	<b>Increase the Flexibility of Electives</b>	(1) Consider flexible streaming of elective groupings (3) Continue BME specialization development	(1,2) ACUG, BME Director and program committee	(1) 2023-2024
6.	<b>Review Admissions Criteria</b>	(1) Evaluate feasibility of 2-stage admissions process	ACUG and SYDE chair, BME director	(1) 2023-2024
7.	<b>Library Resources</b>	(1) Funding requested through the new BME graduate program proposal	BME director and SYDE chair	2023

The Department Chair/Director, in consultation with the Dean of the Faculty shall be responsible for the Implementation Plan.

Date of next program review \_\_\_\_\_

2027-2028

Date

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**Signatures of Approval**

*Lan Huan Fall*

*Nov 30/23*

Chair/Director

Date

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AFIW Administrative Dean/Head (*For AFIW programs only*)

Date

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Faculty Dean

Date

**Note:** AFIW programs fall under the Faculty of ARTS; however, the Dean does not have fiscal control nor authority over staffing and administration of the program.

*Dan De Vidi*

July 24, 2023

Associate Vice-President, Academic  
(For undergraduate and augmented programs)

Date