

Examining underrepresented student success and engagement in engineering following completion of a bioengineering bridge program

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Abstract

The requirement of high school physics for admission to undergraduate engineering programs can be a barrier for underrepresented students. Students in rural or marginalized communities may lack access to qualified physics instructors. Persistent stereotypes and implicit biases against underrepresented groups, including women, Indigenous peoples, and visible minorities, may discourage these students from studying high school physics. By the time students become aware of engineering as a potential career, it may be too late to fulfill the physics requirement.

In 2019, the University of Calgary (UCalgary) began offering an alternative admissions pathway to first-year engineering for motivated students lacking the physics prerequisite. Students are conditionally admitted to UCalgary based on their high school biology grades in place of the usual physics grade, provided they successfully complete the Bioengineering Summer Institute (BSI), a 4-week summer bridge program. The BSI teaches physics fundamentals through a biology-focused lens. In this study, we investigated BSI student preparedness for their first-year common core courses, and success and retention in engineering as they progressed through their chosen engineering discipline. Additionally, we explored if teaching physics through a bioengineering context benefited student learning and encouraged students to pursue a biomedical engineering (BME) discipline after the common core first-year program.

We conducted a mixed-method research study to examine BSI student performance, engagement and experiences. A longitudinal analysis was conducted on four cohorts of BSI students from 2019-2022. Average student grades in physics and physics-related first-year engineering courses (physics, circuits, statics, programming, and fluids) were compared between BSI and general engineering students. Overall GPA and retention information were collected for students as they progressed through their programs in their respective cohorts. A qualitative survey was distributed to BSI alumni to gain insight into primary reasons for enrolling in the BSI, experiences within the BSI program, preparedness for first-year engineering courses, engagement with BME, and career goals.

Initial results show that BSI students performed slightly below average than their peers. A larger performance gap was observed in 2019, the program's first year with a small cohort, but this gap decreased for subsequent BSI cohorts, suggesting improvements to program delivery. As BSI students progressed through their engineering programs, the performance disparity decreased, with minimal difference in final-year GPAs. While most BSI students completed their engineering degrees, higher rates of attrition were observed within the BSI students. BSI students were three times more likely than general students to enroll in a BME major, and two times more

likely to enroll in a BME minor, although most BSI students did not enroll in any BME disciplines.

The success of the majority of BSI students in their engineering programs is highly encouraging. More work is needed to understand why a larger percentage of BSI students leave engineering, and how these challenges can be addressed. There is also a need to further assess if integrating bioengineering concepts into physics instruction is an effective approach for engaging underrepresented students in engineering.

Introduction

Representation and inclusion of diverse groups within the engineering profession is an ongoing challenge. Low enrollment of underrepresented students in STEM fields often stems from early influences. Implicit biases and stereotypes may prevent teachers, parents, and guidance counselors from encouraging female, Indigenous, and visible minority students to consider engineering as a career option. For instance, interactions with teachers influence girls' participation in physics and their belief in their ability to succeed in the subject [1, 2], but adults rate girls as less capable and less likely to enjoy science [3]. Early discouragement can deter underrepresented students from enrolling in high school prerequisite courses for entering engineering programs. Furthermore, students from underrepresented minority communities may be unaware of STEM prerequisites and graduate from high school lacking these core courses [4].

The requirement for high school physics for undergraduate engineering is a recognized barrier for underrepresented students [5, 6]. In Canada, while there is no notable gender gap for Grade 12 biology and chemistry enrollment, female students enroll in high school physics at much lower rates compared to their male peers. Across all Canadian provinces, only about one-third of students enrolled in Grade 12 physics are female [7]. Students in rural or marginalized communities face additional barriers, as rural high schools often struggle to attract qualified upper-year physics instructors [8].

Summer bridge programs between high school and university have been successful in improving the retention of underrepresented students in STEM fields and enhancing their preparedness for university [9]. In 2019, the University of Calgary (UCalgary) began offering an alternative admissions pathway to engineering for motivated students lacking the physics prerequisite. These students are conditionally admitted to UCalgary based on their high school biology grades, provided they complete the Bioengineering Summer Institute (BSI), a 4-week bioengineering summer bridge program that teaches physics fundamentals with a biology context.

The rationale behind the bioengineering context is that all students applying to the BSI will have taken high school biology, and this background knowledge and interest in biology can be leveraged to teach physics [6]. The bioengineering approach was also developed based on

evidence that underrepresented students are more likely to persist in engineering when they understand how their training can be applied to real-world contexts [10]. Biomedical engineering (BME) may be of greater interest to marginalized students. For instance, BME majors have higher rates of female student enrollment compared to other engineering disciplines, likely due to a perceived greater social impact and inclusivity [11]. The collaborative and transdisciplinary nature of BME may also be more appealing to underrepresented students. Finally, traditional engineering majors such as mechanical or electrical engineering are more associated with stereotypes of white male engineers working in isolation and may therefore be less appealing to underrepresented students [12].

A pilot study of the first BSI cohort found that the program helped develop students' engineering identity and improve their confidence for the transition to university [6]. However, further investigation is needed to assess the BSI's efficacy for preparing students for first-year engineering. Student success and retention within the engineering program, particularly for physics-related courses (e.g., circuits, statics, fluids) must be investigated. Of particular interest is the effectiveness of the BSI's approach of teaching physics through bioengineering concepts.

We conducted a mixed-methods longitudinal study to examine BSI student performance and engagement with BME throughout their engineering degree. Specifically, we investigated student preparedness for first-year engineering and student GPA and retention as they progressed through their engineering degree. We also explored whether teaching physics through a bioengineering context benefited student learning and would encourage students to pursue a BME-related engineering discipline.

Background

The BSI is an intensive 4-week summer bridge program designed to teach physics fundamentals through a bioengineering context. The program runs 5 days per week, with 6 hours of instruction per day. Students are admitted based on their high school biology grades, in lieu of physics grades. All other engineering admission requirements are the same, and students accepted to the BSI must successfully complete the program to enter first-year engineering.

The BSI is open to students from all demographic backgrounds, with no restrictions based on gender or other marginalized identities, however, the goal of the program is to attract students from traditionally underrepresented groups in engineering. BSI student enrollment for each cohort from 2019 to 2023 is summarized in Table 1. The program has grown over the years, with 9 students completing the initial offering in 2019, and expanding to 68 students in 2023.

Table 1: BSI Student Enrollment by Year

Cohort Year	BSI Student Enrollment
2019	9
2020	35
2021	26
2022	45
2023	68

Program Delivery

The BSI curriculum involves a variety of learning methodologies including lectures, labs and hands-on activities, and team-based design challenges. Core physics topics such as kinematics and dynamics, work and power, and electricity and magnetism, are introduced in the context of biomedical engineering. For example, students are first taught the concepts of work and power through traditional physics definitions and equations. They then apply the work and power equations to the heart and cardiac cycle. Similarly, electrical concepts are introduced by making parallels with the circulatory system in the human body. Concepts such as voltage and resistance are related to blood pressure, blood viscosity, and blood vessel diameter. In a hands-on design activity, students work in teams to build an artificial heart prototype using balloons filled with water.

Throughout the BSI program, students are introduced to the engineering mindset and the need for a structured problem-solving approach. The final week consists of a team design challenge intended to integrate physics learnings with engineering design principles. In addition to classroom learning, BSI activities include a campus tour, research lab tours, guest speakers from both industry and academia, and additional workshops including a computer programming workshop to encourage preparedness for first-year university.

Students are evaluated based on physics problem sets and daily quizzes. All assessments are graded on a pass/fail basis to emphasize mastery of foundational concepts and to promote a low-stress environment where mistakes are seen as opportunities for growth.

Methods

We conducted a mixed-methods study combining a longitudinal analysis of BSI student grade point average (GPA) and enrollment with results from a student experience survey. This work was approved by the University of Calgary Research Ethics Board under REB23-1762.

Longitudinal Analysis

A longitudinal analysis was conducted to evaluate the academic performance and retention outcomes of the first five cohorts of BSI students from 2019–2023. We examined mean GPAs in first-year physics and physics-intensive engineering courses (circuits, statics, programming, and fluids). Yearly GPAs and retention were also tracked for each BSI cohort to assess student performance as they progressed through their degree. Outcomes were compared with mean GPAs and retention for general engineering students within the same cohort year. Data on engineering major (e.g., biomedical, electrical, mechanical) and minor enrollment were collected to explore the influence of the BSI program on specialization choices.

Student Experience Survey

A student experience survey was distributed to BSI alumni via Qualtrics to gain insight into primary reasons for enrolling in the BSI, preparedness for first-year engineering, experiences within the BSI program, and interest in BME. The survey included multiple choice, 5-point Likert scale, and open-ended questions. In this paper, the responses to open-ended survey questions were coded based on sentiment (positive/negative/neutral), and themes to assist with explaining the longitudinal data. The open-ended survey questions are summarized in Table 2.

Table 2: Summary of Open-ended Survey Questions

Topic	Survey Question
Reason for Enrolling in the BSI	What was your primary reason for taking the bio entrance pathway into engineering?
Preparedness for Engineering	Do you feel that the BSI and first-year engineering prepared you for upper year physics courses? Why or why not?
Student Experience within BSI	Is there anything else you would like to tell us about your experience in the BSI or in engineering?

Results

The longitudinal analysis was conducted to evaluate the performance of BSI students within their first year of engineering, as they progressed through their engineering degrees, and overall specialization interests.

First-Year Engineering Performance

The mean GPAs of BSI students in first-year physics and physics-intensive engineering courses were compared with the average GPAs of their respective general engineering cohorts from 2019 to 2023. Figure 1 presents the mean GPAs for first-year physics, physics-related engineering first-year courses, and the mean GPAs across all investigated courses (physics, circuits, statics, programming, and fluids).

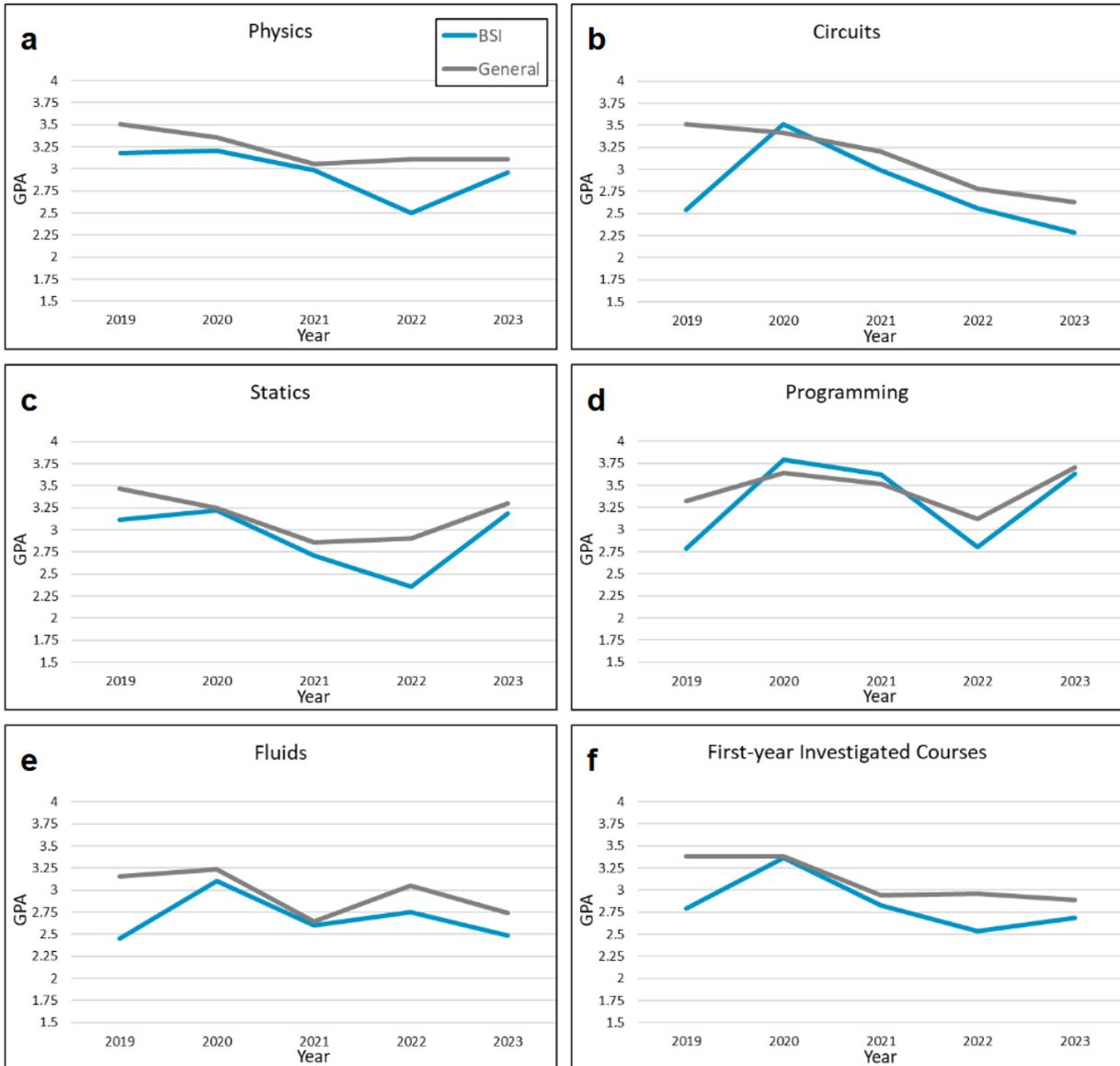


Figure 1: GPAs for BSI students (blue) compared with general engineering students (grey) from 2019-2023 for physics and physics-heavy engineering courses. GPAs for the following first-year courses are shown: a) physics, b) circuits, c) statics, d) programming, e) fluids, f) average of all investigated first-year courses.

Across all first-year courses investigated, BSI students tended to have slightly lower GPA performances than their peers. The difference in performance between the groups varied by the year, with the largest disparities observed in 2019 and 2022. The 2020 BSI cohort performed most similarly to their peers and had slightly higher GPAs in programming and circuits.

Overall Engineering Program Performance

The overall mean GPAs for BSI and general engineering students are compared for all program years in Table 3. The results for the 2019-2021 cohorts are compared graphically in Figure 2. Fourth-year data was unavailable for 2020, as most students in this cohort were completing their engineering internships. The 2022 and 2023 cohorts were omitted from this figure due to the lack of upper-year GPA data, as these students are still progressing through their degrees. As BSI students progressed through their engineering programs, the performance disparities decreased, with minimal difference in final-year GPAs.

Table 3: Mean GPA for BSI vs. General engineering students for 2019-2023 cohorts.

Cohort Year	Program Year	BSI GPA	General GPA
2019	1	2.44	3.17
	2	2.87	3.21
	3	2.65	2.85
	4	2.16	2.13
2020	1	3.10	3.23
	2	2.79	2.92
	3	2.58	2.75
2021	1	2.79	3.01
	2	2.98	2.93
	3	2.41	2.44
2022	1	2.56	2.91
	2	2.43	2.73
2023	1	2.68	2.89

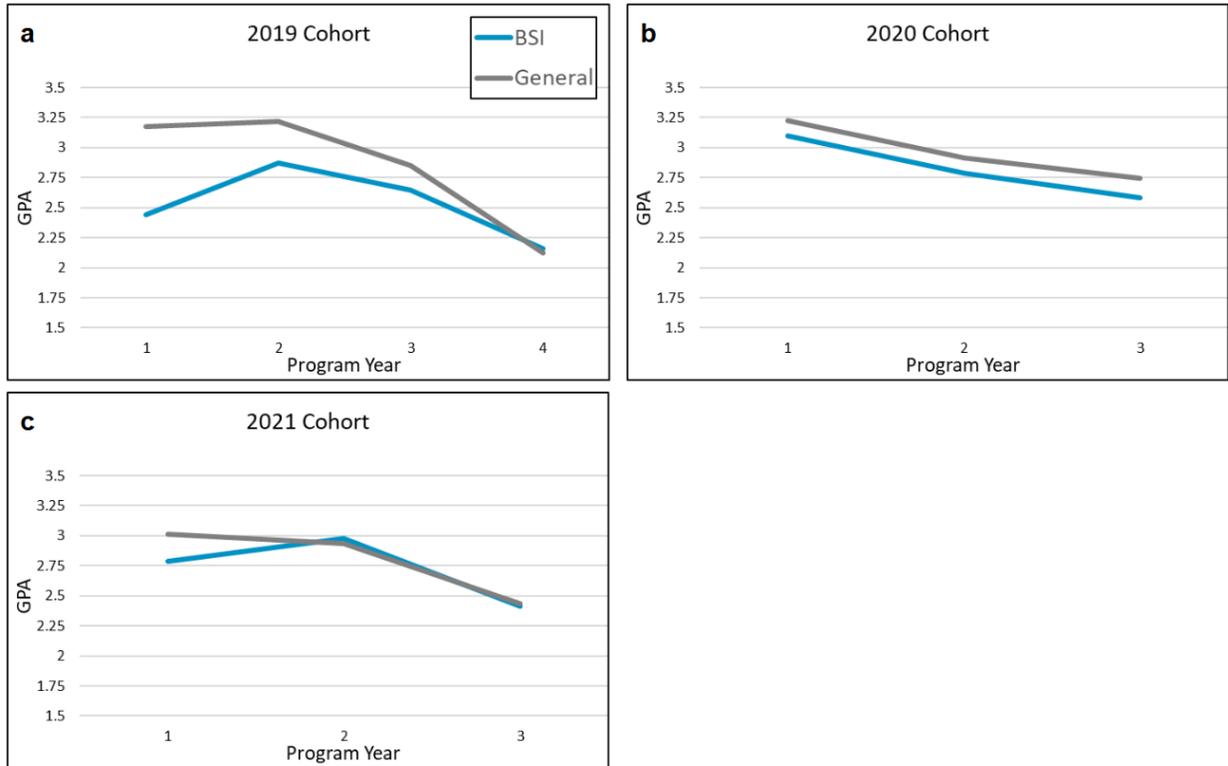


Figure 2: Mean GPAs of BSI students (blue) compared with general engineering students (grey) for each cohort across the four-year engineering program for a) 2019, b) 2020, and c) 2021.

BSI Student Retention

Student enrollment and cumulative percent attrition across all years of the engineering program are shown in Table 4. While most BSI students in cohorts from 2019-2021 successfully completed their engineering degrees, a higher rate of attrition was observed for the BSI students. For instance, in the 2019 and 2020 cohorts, 33.3% and 28.6% of BSI students did not progress to fourth year respectively, compared with 11.2% and 19.2% of general students in the same years.

Table 4: Enrollment and Cumulative % Attrition in Engineering for BSI and General Students

Cohort Year	Program Year	BSI		General	
		Enrollment	% Attrition	Enrollment	% Attrition
2019	1	9	–	792	–
	2	8	11.1	746	5.8
	3	8	11.1	719	9.2
	4	6	33.3	703	11.2
2020	1	35	–	852	–
	2	26	25.7	766	10.1
	3	26	25.7	716	16.0
	4	25	28.6	688	19.2
2021	1	26	–	863	–
	2	23	11.5	791	8.3
	3	20	23.0	756	12.4
2022	1	45	–	965	–
	2	40	11.1	875	9.3
2023	1	68	–	859	–

BME Specializations

Table 5 compares BSI and general student enrollment in the BME major and minor programs. Data is unavailable for the BME major in 2019, as the major program was first offered at UCalgary in 2020. Across all cohorts, BSI students enrolled at higher rates in both the major and minor BME degrees compared to the general student body.

Table 5: BSI student enrollment in BME-related minor vs. general student enrollment

Cohort Year	BME Major Enrollment				BME Minor Enrollment			
	BSI		General		BSI		General	
	No.	%	No.	%	No.	%	No.	%
2019	N/A	N/A	N/A	N/A	4	50.0	121	16.2
2020	6	23.1	38	5.0	4	15.4	51	6.7
2021	3	13.0	57	7.2	3	13.0	44	5.6
2022	5	12.5	38	4.3	3	7.5	29	3.3

Student Experience Survey

A total of $n = 21$ former BSI students completed the student experience survey. Student demographics are reported in Table 6.

Table 6: Summary of Demographics for Student Survey Respondents

	Group	Count	%
Gender Identity	Woman	14	67
	Man	6	29
	Prefer not to disclose	1	5
Student Status	Domestic	20	95
	International	1	5
BSI Cohort Year	2019	0	0
	2020	2	9
	2021	1	4
	2022	7	30
	2023	13	57

16 of the 21 respondents stated that their primary reason for taking the bio pathway into engineering was because they decided to take engineering and didn't have the physics requirements. One student stated that they didn't know engineering required physics courses, and two students performed better in their high school biology course as opposed to their physics

course. One international student noted that they did not have the option to take both physics and biology within their International Baccalaureate program, and were forced to choose only one course, while another student stated that they were simply more interested in biology than physics.

Both authors independently analyze the open-ended responses and thematically coded their interpretation of the results. Table 7 summarizes how the student feedback was coded by sentiment (positive/negative/neutral) and organized into themes.

Table 7: Summary of Coded Responses

Sentiment	Theme	Survey Results
Positive	Friendships and Networking	<p>“making friends who are still my closest friends to this day.”</p> <p>“In COVID, the only major use I found of BSI was connecting me with future colleagues in the program.”</p> <p>“helped me build strong friendships”</p> <p>“develop[ed] lasting friendships with people I’m still close to today.”</p> <p>“I had a really great time at BSI and made some really great friends and memories there!”</p>
	Preparedness for University	<p>“I feel like it greatly prepared me for my first year as well”</p> <p>“I felt like BSI was a great opportunity to get used to being at the university, the larger class sizes and coding in a slower more controlled environment.”</p> <p>“I also feel like it did help me a lot when I got into the more physic [sic] heavy courses.”</p> <p>“I knew nothing about circuits, but after the BSI, I know how to add resistors and how to analyze very basic circuits”</p> <p>“The BSI taught me valuable skills like time management”</p> <p>“Was a good introduction to physics and I am glad I participated.”</p>
	Field Trips and Experiential Learning	<p>“Not only did I learn a bit of physics, but I think the field trips, labs, and guest speakers were amazing.”</p> <p>“The field trips were a highlight of the experience. Visiting places like an MRI lab or the Kinesiology lab was not only fascinating but also deeply motivating.”</p>

	Belonging in Engineering	<p>“The BSI is what made me interested in engineering, especially since it was a last second decision for me.”</p> <p>“It played a significant role in pushing me out of my comfort zone”</p> <p>“These experiences gave me a glimpse of the real-world applications of engineering and reaffirmed that I was on the right path, even if I faced difficulties.”</p>
Negative	Relevance and Depth of Content	<p>“My experience in the BSI program was that it tried to do way too much. If your goal is to be a replacement for high school physics, then do that well.”</p> <p>“Barely an actual focus on physics, more incoherent lectures and very unrelated lectures.”</p> <p>“The only critique I would have was that it did not cover the most relevant content.”</p> <p>“I do not think [sic] coding in Python is a necessary component of the course and should be filled with more topics in electromagnetism physics.”</p> <p>“A lot of things that were covered in first year courses did not have much to do with what was taught in the BSI”</p> <p>“The lab activities were fine, but the lectures were confusing, leaving me unsure how to approach problems.”</p>
	Preparedness for University Physics	<p>“I do not feel as if my understanding was necessarily equivalent to the students that had taken physics in high school.”</p> <p>“While it prepared me somewhat for university, it didn’t help with physics, where I struggled significantly.”</p>
Neutral	Reasons for entering the BSI	<p>“I took the IB program [sic] and in that moment, I preferred [sic] Biology than Physics, so I took Bio instead (in my school, you can only choose between Phys or Bio)”</p> <p>“Was interested in BME engineering and liked bio more than physics, so the BSI felt like a really interesting program”</p> <p>“I did take a physics university transfer course but it was not accepted because it was algebra based rather than calculus based.”</p>

Discussion

BSI Student Experience

A major theme that emerged from the student experience survey was that the BSI enabled students to form friendships with their classmates that persisted throughout their engineering studies. In addition to social preparation, students also mentioned the benefits of becoming familiar with campus space and university expectations. Students highlighted their appreciation of hands-on and experiential learning content such as field trips, labs, and guest speakers as memorable and impactful. The program format allowed students to prepare for taking classes in a university setting, gain a clearer understanding of the engineering profession, and feel confident in their decision to take engineering. This indicates that the BSI program has potential to give underrepresented students peer support and confidence in addition to academic preparation.

Several students expressed concerns that physics content relevant to first-year engineering was not adequately covered or was disorganized. Furthermore, students reported that some learning activities, in particular the Python programming workshop, were not necessary to prepare for first-year engineering and they would have benefited from additional physics content. As introductory Python programming is already a required first-year course without expected prerequisite knowledge, this content has been de-emphasized in subsequent offerings of the BSI. This is also reflected in the GPA data, as there was little disparity between BSI and general student performance in the first-year programming course. Student comments on curriculum content highlight a need to further refine the continual improvement practices of the BSI content to ensure the physics fundamentals taught align as content is updated within the first-year engineering program.

Student experiences within the BSI program varied depending on their cohort year. Students completing the program during the COVID-19 pandemic indicated their learning experience suffered. Students completing more recent iterations of the program likely benefited from improved curriculum design and subsequently gave more positive feedback about the physics content.

First-Year Engineering Performance

BSI students tended to perform slightly below their peers in first-year physics and physics-intensive engineering courses (Figure 1). The largest performance gap between BSI students and their general engineering counterparts was observed in the 2019 cohort. This discrepancy was likely due to challenges associated with the initial implementation of the program, and refinements to the curriculum and teaching strategies likely improved student learning in the subsequent cohorts. Additionally, as the BSI program became more well-known, students with

greater familiarity or interest in BME could have been attracted to apply, resulting in better BSI student performance in first-year engineering over time.

Interestingly, BSI students performed similarly or better than their peers in their first-year courses in 2020, the year most directly impacted by the COVID-19 pandemic. This finding aligns with other observations of increased retention of underrepresented students in engineering during the pandemic years [12, 13]. BSI student performance was much more affected relative to their peers in 2022. This may be due to lingering after-effects of the pandemic, as students in the 2022 cohort would have been in Grade 11 during the height of COVID-19 and may have missed the opportunity to learn foundational skills required for engineering.

Overall Engineering Program Performance

Across all cohorts, as students progressed through their engineering programs, the disparity between BSI and general students continued to decrease (Figure 2). By the final year of their studies, BSI students exhibited minimal differences in GPA compared to general students. This trend suggests that any initial challenges faced by BSI students related to less physics preparation were mitigated over time. Additionally, as BSI students advanced through their program, they may have selected more specialized engineering tracks that aligned better with their strengths and interests.

Higher attrition rates for BSI students may also have contributed to the narrowing of performance disparities. If weaker-performing BSI students left engineering, the remaining cohort students would have been more resilient or better prepared, leading to a perceived better performance over time.

BSI Student Retention

While most BSI students successfully completed their engineering degrees, their attrition rate was higher than that of general engineering students (Table 4). Based on the student experience survey, most BSI students did not feel that they were disadvantaged in their physics training compared with their peers, although some students found their physics learning to be inadequate. Although a higher attrition rate may indicate that some BSI students were not adequately prepared for their engineering programs, there are other potential contributing factors.

Underrepresented students may have faced additional challenges, such as marginalization, lack of representation, and limited peer support and mentorship, contributing to a higher dropout rate. Further investigation is needed into the reasons behind the attrition and specific challenges faced by BSI students to inform future developments to support student success.

BME Specializations

BSI students were more likely to enroll in BME majors or minors compared to their general peers (Table 5). Additionally, the student survey revealed that some high school programs, such as International Baccalaureate (IB) require students to choose between physics and biology, posing a further barrier for students who may be successful in BME. Offering the BSI program can help to mitigate this barrier and encourage more students to pursue BME-related degrees.

Although underrepresented engineering students are more likely to pursue BME disciplines, most BSI students did not pursue a BME specialization. This suggests that many students enrolled in the BSI as a pathway to pursue engineering rather than due to a strong interest in BME. Encouraging underrepresented students to only explore BME could result in missed opportunities for these students to understand how they can contribute to other engineering fields such as civil, mechanical, or electrical engineering, where diversity is also needed.

Limitations

This study has several limitations. The longitudinal data available for this study was missing demographic information, which limited our ability to directly assess the impact of the BSI on specific underrepresented groups. In future work, we plan to assess the data by gender and other marginalized identities to better understand the experiences of underrepresented students.

Participation in the student experience survey was voluntary, and survey results may not have been representative of the experiences of all BSI alumni. There was less representation from students in earlier cohorts of the program, with no responses from students in the 2019 cohort. However, more recent feedback will allow for iterative improvement of the current offering of the BSI.

Conclusion

The success of the majority of BSI students in their engineering programs is highly encouraging, with most students successfully transitioning into and progressing through their engineering programs. Performance disparities between BSI students and their general engineering peers have narrowed since the first BSI offering, suggesting that refinements to the curriculum have improved program effectiveness. The improved academic performance of the BSI cohort in later years of their engineering program suggests that students can overcome any initial gaps in physics knowledge. These findings demonstrate long-term benefits of providing alternative pathways into engineering for underrepresented students. Further analysis is needed to explore specific factors that contributed to the improved performance in subsequent cohorts, including

changes to the BSI's curriculum and teaching methods. Inclusion of the raw data will enable statistical analyses to further evaluate the validity of our findings.

Further investigation is also needed to understand why a larger proportion of BSI students leave engineering and how retention could be improved. Identifying the factors that contribute to attrition will allow for development of methods to support BSI students throughout their academic journey. Given that many BSI students do not pursue a BME-related degree, there is also a need to further assess if integrating bioengineering concepts into physics instruction is the most effective approach for engaging and retaining underrepresented students in engineering.

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