Work in Progress: Are We on Track with Tracks?

Dr. Jennifer R Amos, University of Illinois, Urbana-Champaign

Dr Amos joined the Bioengineering Department at the University of Illinois in 2009 and is currently a Teaching Associate Professor in Bioengineering and an Adjunct Associate Professor in Educational Psychology. She received her B.S. in Chemical Engineering at Texas Tech and Ph.D. in Chemical Engineering from University of South Carolina. She completed a Fulbright Program at Ecole Centrale de Lille in France to benchmark and help create a new hybrid masters program combining medicine and engineering and also has led multiple curricular initiative in Bioengineering and the College of Engineering on several NSF funded projects.

Gabriella R Dupont, University of Illinois, Urbana-Champaign

I am a MEng student in Bioengineering, with a BS, Bioengineering, both from University of Illinois, Urbana-Champaign. I am interested in biomechanics and how curriculum structure affects education outcomes.

Are we on Track with Tracks?

It is challenging to achieve technical depth in an undergraduate Bioengineering curriculum due to the implicit breadth of multidisciplinary technical content underlying the field. Moreover, institution-specific requirements can have a dominating impact on the depth/breadth balance and how they are attained. As a primary example, many large engineering schools were forced to make challenging, required curricular alterations when state legislatures required a reduction of hours while maintaining ABET engineering hours for accreditation. These changes necessitated reduction of the requirements for fundamental science and traditional engineering courses from other departments to make room for courses with heavy design content, societal context, and integrated communication skills.

Due to these changes, the curriculum has become increasingly rigid, which limits students' opportunities to deeply explore technical content. To ensure depth, many programs create tracks which align the educational focus with faculty research interests; however, they further add to curricular rigidity, as they are often composed of courses largely outside of our department. When speaking with peer institutions, it became clear that many institutions experience these challenges, and in particular, the debate over the benefit of technical tracks appears to be ongoing. Beyond challenges to students, technical tracks present difficulties for administrators, as maintaining relevance to modern bioengineering practice requires continual assessment and forecasting due to the rapid changes in the field and can never comprehensively satisfy all technical needs in bioengineering industries. Managing the content of the tracks is further problematic due to pre-requisite strings that often extend outside of the home department. In a time when minors, certificates, and other methods of credentialing are widely available, one wonders how relevant tracks are for an engineering discipline. To this end, a benchmarking study was conducted of top Bioengineering/Biomedical program curricula to determine trends in track and elective offerings across programs and analysis of program tracks was performed to determine the benefit of these. The program took these data and used the information to propose a new philosophy for creating undergraduate tracks for bioengineering programs.

Materials and Methods

The US News & World Reports publishes an annual top 20 "Biomedical Undergraduate Rankings" of schools with doctoral programs [1]. This list represents the perceived top programs as ranked by department heads across BME programs in the nation. With that list of schools, three qualities of each program were considered as metrics of curriculum breadth and depth: track or concentration offerings, curriculum structure, and curriculum flexibility. All the information about the qualities of each program was gathered through public use websites and files found on the programs website.

To compare curriculum structures, core curriculum requirements (engineering and general education) and the BME curriculum requirements, along with electives for all three categories were tabulated. Required courses were sorted into general descriptions including, but not limited to, math, physics, mechanical engineering, and molecular and cellular engineering. Curriculum flexibility was calculated based on general education and BME electives. To normalize the data, percent of total credit hours or total number of courses was used to calculate the percentage of the curriculum that is flexible (elective) versus required over total hours. After this quantitative score for flexibility was determined, a qualitative analysis of the tracks was performed looking at diversity of track offerings. The same analyses were repeated for the Top 20 Mechanical [2] and Electrical Engineering [3] programs as a comparison.

For the internal study of tracks in the local program, data on track membership over the past 10 years was analyzed for enrollment, as well as diversity of courses available in the tracks. A diversity score was calculated for each track by counting how many of each mechanics, electrical, programming, cell, and materials science classes were in each track offering and computing the standard deviation of each track, where high numbers meant less diversity in courses.

In addition, faculty, alumni and current student surveys were collected through an online survey system asking a variety of questions about importance of skills, topics, ranking of courses and preference of topics, as well as career alignment with track area. The survey was sent to 400 people and a 34% response rate was achieved with an even gender split amongst participants. The survey of both faculty and students covered topics or themes in bioengineering and asked to rank the themes by level of interest.

Results for Curriculum Top 20 Comparison

After analysis of core curriculum, all required courses, trends appeared in both preparatory courses and engineering courses across the top 20. All curricula require general chemistry, calculus-based physics, three calculus courses, differential equations, molecular/cellular biology and a computing course. Beyond those courses, there was diversion in requirements for linear algebra, organic chemistry, biochemistry, and modeling or numerical analysis. Table 1 shows a

Table 1: Required Courses in BME Curricula

Core Prep Courses	**Notes**
General Chemistry	2 semesters
Physics	2 semesters
Calculus	3 semesters
Differential Equations	1 semester
Cell/Molecular Biology	1 semester
Computing	1 semester
Linear Algebra	58%, 1 semester
Organic Chemistry	47%, 1 semester
Biochemistry	22%, 1 semester
Modeling, Numerical Analysis	50%, 1 semester

Table 2: Engineering Courses in BME Curricula

Engineering courses:	Notes
Intro	1 semester
Fundamental	1 semester
Electrical	44%, 1 semester
Mechanics	1 semester
Materials	75%, 1 semester
Design	2 semesters
Thermodynamics	67%, 1 semester
Transport	1 semester
Physiology	1 semester
Statistics	75%, 1 semester

breakdown of general preparatory course and engineering courses in BME curricula.

Table 3 shows the trends in engineering course. In core required courses, all curricula required in introductory course, conservation/problem solving course, mechanics, design (all 2 semesters), transport, and physiology, but requirements were not common for circuits/electrical courses, materials science, thermodynamics, and statistics. Overall, there is 89% conservation of required course content across all curricula studied.

Table 3: Track breakdown by name for the top 20 BME programs

Track Category	No. of Schools offering track
Imaging/Bioelectrical	8
Biomechanics	7
Computational	7
Cell and Tissue	6
Devices/instruments	4
Materials	4
Therapeutics	3
Systems Biology	3
Neuroengineering	2

Of the top twenty schools, eight (47%) do not have required tracks, but the other schools had relatively consistent trends in the track topics, a full breakdown is shown in Table 3. Imaging or Bioelectrical was the most common track across the top 20, followed closely by Biomechanics, which aligns with the maturity of these research areas. Computationally focused tracks were offered in as many programs as Biomechanics, which was a surprising trend. Newer research areas, such as therapeutics, systems biology, and neuroengineering were not common track areas.

Another important factor in curricula for students is the percentage of electives. After the core basic science, math, and engineering courses, curricula tended to have electives but how they were offered varied by school. BME Schools range from 20%-45% flexibility, with an average of 32% flexibility in electives. We wondered if this flexibility in curriculum was normal or common to other more traditional curricula. To compare this perceived flexibility and breadth versus breadth perception in BME programs, the Top 20 as ranked by US News & World Reports for Electrical Engineering (EE) and Mechanical Engineering (ME), as shown in Table 4. Looking at the trends, it seems that BME curricula are similar to ME curricula in terms of flexibility, depth/breadth ratio, and conservation of course content across curricula, but show less programs with defined tracks than both EE and ME curricula. From these data, it appears that having tracks is common across engineering curricula and BME is similar to other engineering disciplines. This conclusion led us to focus on other aspects of the tracks that might contribute to the perceived lack of satisfaction by students.

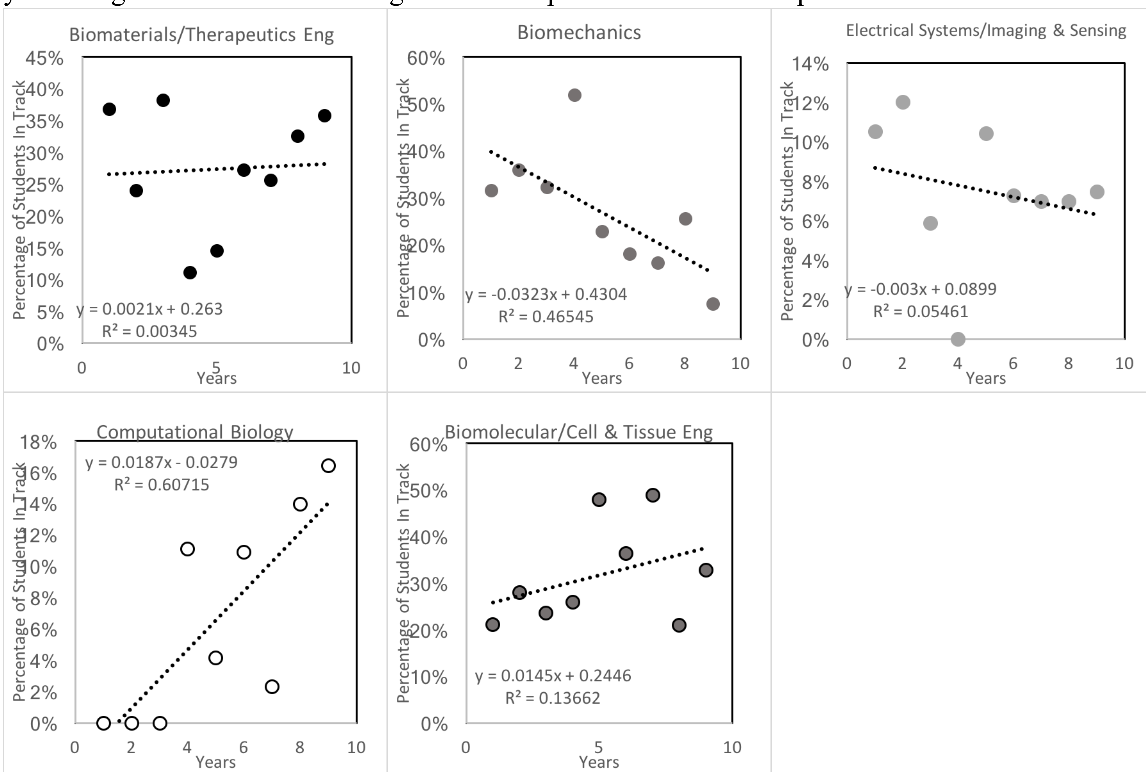
Table 4: Comparing top 20 programs for BME, EE, and ME

	Average $\frac{\text{elective hours}}{\text{total hours}}$	Average Depth hours	Average Breadth hours	Average $\frac{\text{Depth}}{\text{Breadth}}$	Average $\frac{\text{Lab hours}}{\text{Total Hours}}$	% of Top 20 with tracks	% conserved across top 20
BIOE	32%	12.7	10.6	1.18	10%	53%	89%
EE	47%	21.3	14.7	1.44	9%	62%	93%
ME	31%	13.4	13.2	1.05	8%	77%	85%

Results from Program Tracks

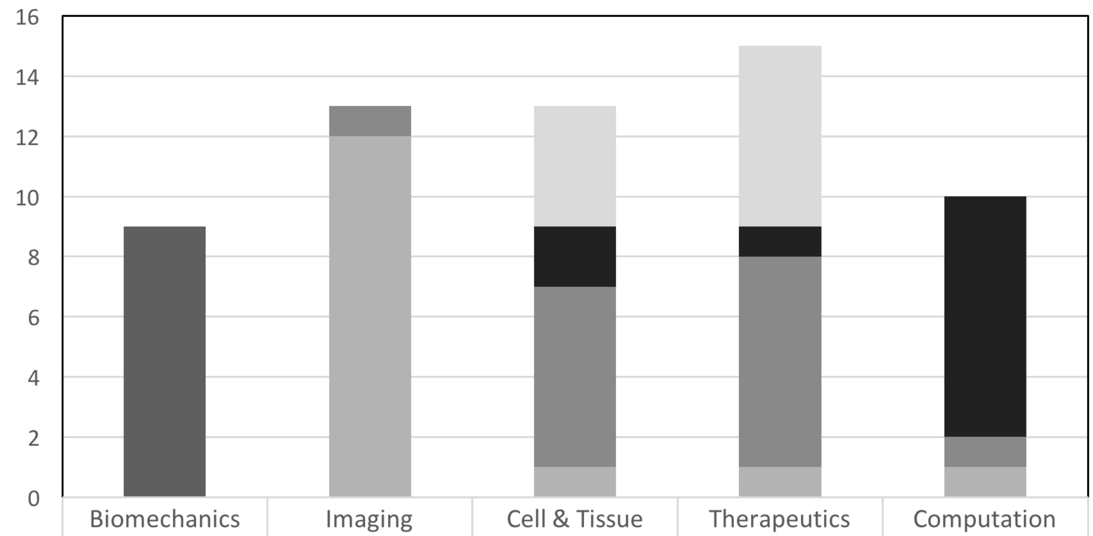
In addition to looking at national trends in tracks, several studies of program tracks were done to look at diversity of courses, perceived benefit and popularity of tracks. In order to explore track trends over the years, archival enrollment data was analyzed to follow track at the time of graduation over the past 10 years and all counts were converted to percent enrollment to normalize these data. The trend for biomechanics is negative, computation has seen strong growth and others have remained mostly neutral.

Figure 1: Track trends over the past 10 years. Each graph shows percent of student enrolled for each year in a given track. A linear regression was performed with R^2 is presented for each track.



To see what differences there are among tracks besides field of study, the team attempted to quantify diversity of track by counting how many of each Mechanical, Electrical, Computational, Cell, and Materials Science classes were in each track offering and took standard deviation of each result, giving a Diversity Score, where high numbers meant less diversity in courses. Results were Biomechanics: 3.6, Imaging: 4.7, Cell & Tissue: 2.15, Therapeutics: 2.89, Computation: 3.03, showing that the older tracks, Imaging and Biomechanics, has less diversity than other tracks, Figure 2.

Figure 2: Diversity of discipline represented in each track: Biomechanics, Imaging & Sensing, Cell & Tissue, Therapeutics, and Computational Biology. M=Mechanical, E=Electrical, C=Cell, P=programming, MS=Materials Science

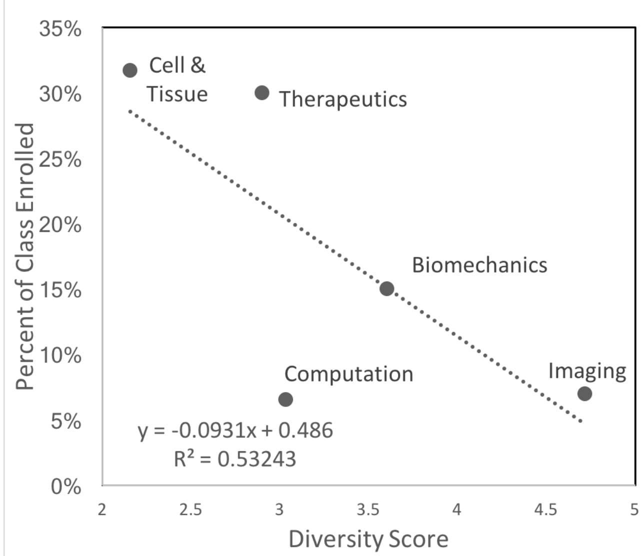


	Biomechanics	Imaging	Cell & Tissue	Therapeutics	Computation
MS	0	0	4	6	0
P	0	0	2	1	8
C	0	1	6	7	1
E	0	12	1	1	1
M	9	0	0	0	0

M E C P MS

In an attempt to see the correlation between popularity and diversity, the data were plotted with a regression fit. Cell and Tissue and Therapeutics tracks had the highest diversity and popularity, while Imaging and Biomechanics had a low diversity score and popularity. The computational track was an outlier with a medium diversity score and high popularity, but the overall trend, Figure 3, suggests that a correlation exists which shows a trend that student enrollment in track decreases as track diversity decreases, meaning that students may prefer more diverse track offerings.

Figure 3: Correlation between Diversity Score for each track and Popularity of track.

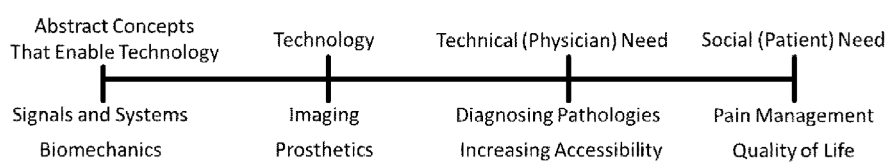


To summarize, BME top 20 programs have similar trends in curriculum and tracks which are not unique to BME programs as compared to ME and EE. In studying our own track offerings, higher diversity in disciplinary courses may lead to increased popularity in the tracks.

Challenging Traditional Tracks

Traditional engineering tracks are structured around scientific or mathematical concepts (e.g., signals and systems, biomechanics) or technologies (e.g., imaging, prosthetics), Figure 4. By focusing on social or technical needs, we can more easily help students understand the cultural relevance of their engineering studies, providing opportunities for students to develop identities as engineers [4]. To this end, faculty were challenged to create tracks that would rearrange courses based on the needs that drove the creation of the technology or concepts. These need-

Figure 4: Representative spectrum of track topics from traditional, uni-disciplinary tracks to need or challenge-based tracks.

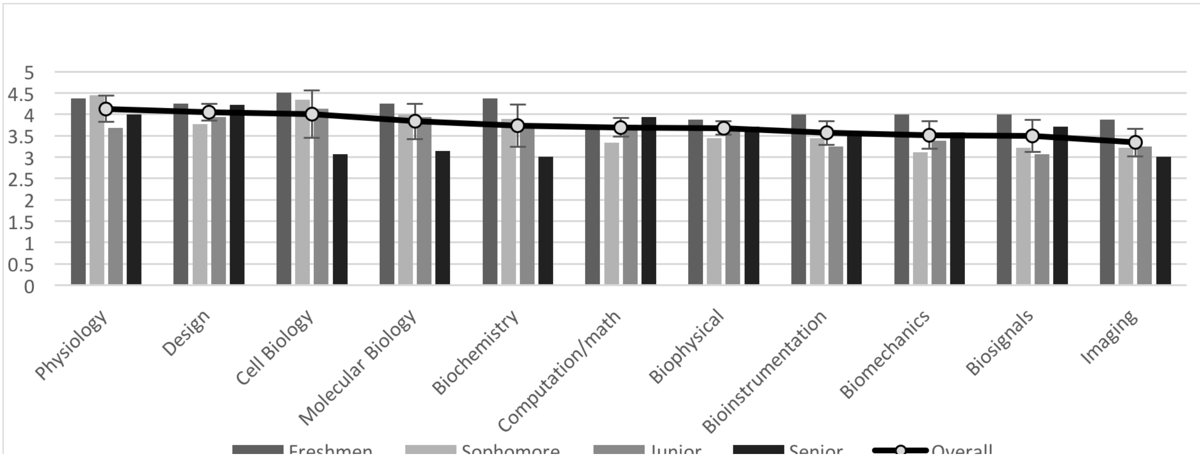


focused tracks will facilitate the alignment between medical and engineering practice, which can in turn motivate students towards careers at this interface.

These needs-driven tracks emphasize long-term challenges which transcend individual courses, enabling students to develop a holistic vision for their education and develop deep technical expertise in a chosen track, supporting relatedness and competence beliefs. These multi-term tracks remove artificial restraints to solve problems by the end of a term, promoting growth mindsets that learn from early failures. These tracks also integrate and enhance clinical experiences. Further, these multi-year tracks will provide opportunities for senior students to mentor junior students, developing leadership and communication skills.

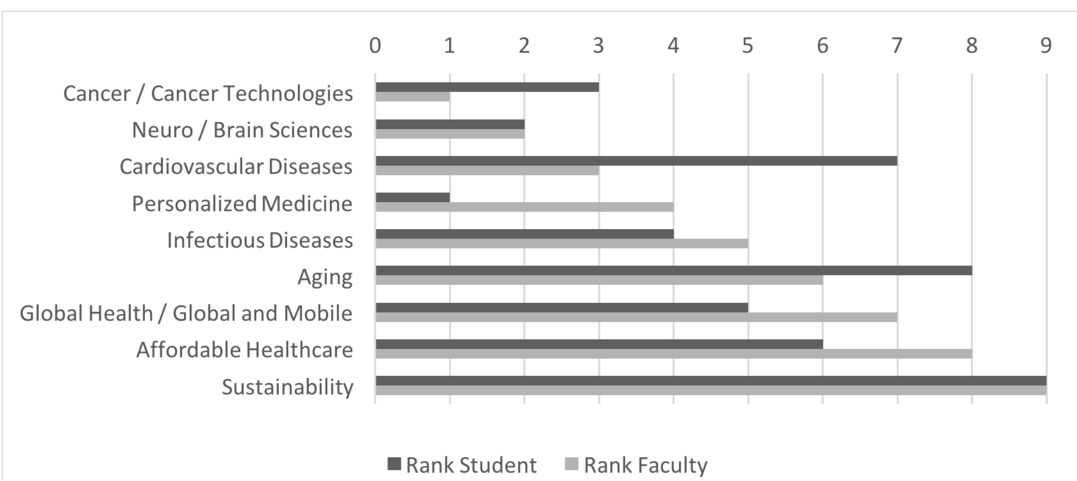
To start this process, students and were surveyed to answer questions about importance of traditional topics, which should be included across curriculum and each track area. In general, all areas were ranked as important with some significant differences between students early in the curriculum and graduating seniors in terms of Cell Biology, Molecular Biology, Biochemistry, and Imaging. Figure 5 displays the result from this survey from both students and faculty.

Figure 5: Results from the student and faculty ranking survey to form the track areas. Faculty and students rated the importance of subject area inclusion in the tracks from 1=not important to 5=most important.



Another topic of the student and faculty survey was the ranking of challenge areas proposed as tracks. The faculty and students were given a list of nine areas and asked to rank them in order of preference, with 1 being the highest rank (most preferred) and 9 being the lowest rank (least desirable) as shown in Figure 6. The research team then compared the average faculty and student ranking into top areas of alignment. The emerging winners for both lists were cancer, cardiovascular, neuroengineering, and infectious diseases and immune diseases (IDID). Cancer and neuroengineering were clearly popular with both groups, but the other two selections were

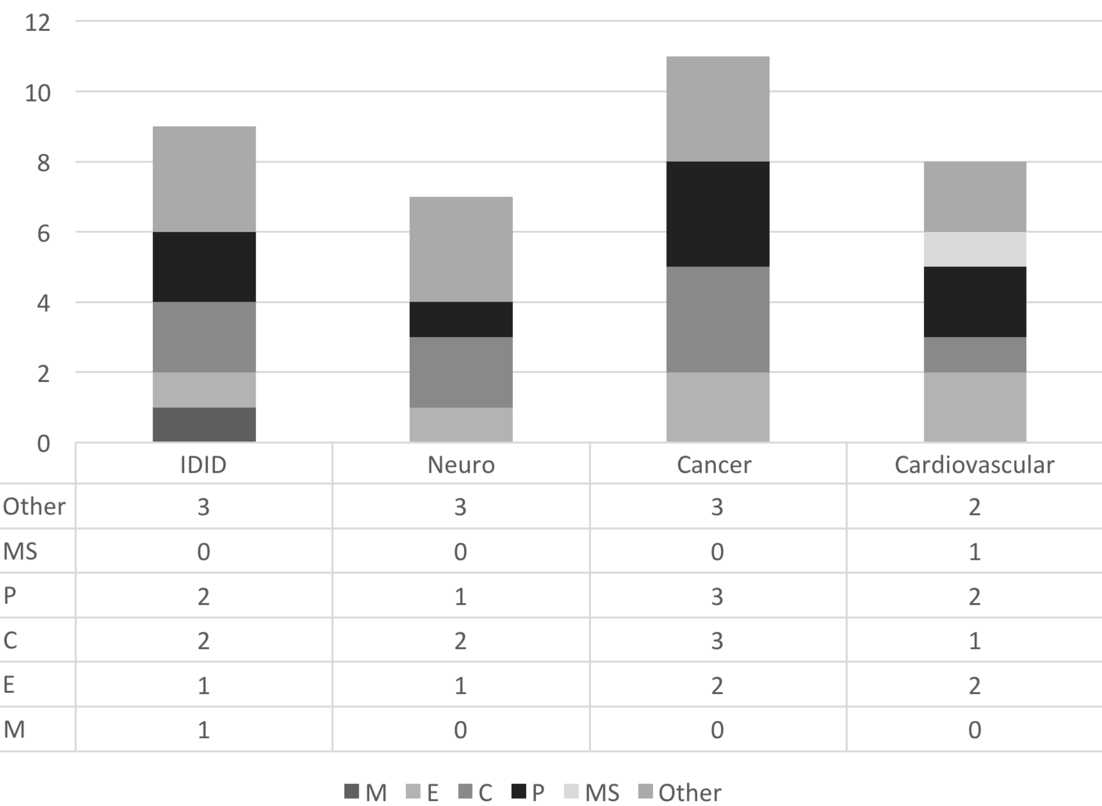
Figure 6: Results from the student and faculty ranking survey to form the track areas. Faculty and students ranked track areas for preference from 1 being the highest rank (most preferred) and 9 being the lowest rank (least desirable).



defined through discussion amongst the faculty. IDID emerged by combining infectious disease with global health as well as aspects of affordable healthcare. While cardiovascular wasn't the next highest student rank after infectious disease, we believe that personalized medicine is a cross-cutting theme reflected in all tracks, so the next best application theme with faculty support was cardiovascular. Faculty then formed into communities of practice and prepared list of outcomes, needs for courses, outside of class experiences. Faculty were then told to choose courses for their track, either existing courses on campus, or ones that they would want to create.

The resulting tracks were analyzed for the same diversity score as before and the proposed tracks were much more diverse in terms of the variety of disciplines represented in each track, Figure 7.

Figure 7: Diversity of discipline represented in each proposed track: IDID (Infectious Disease and Immune Diseases), Neuroengineering, Cancer, and Cardiovascular. M=Mechanical, E=Electrical, C=Cell, P=programming, MS=Materials Science, other=non-engineering



	IDID	Neuro	Cancer	Cardiovascular
Other	3	3	3	2
MS	0	0	0	1
P	2	1	3	2
C	2	2	3	1
E	1	1	2	2
M	1	0	0	0

Future direction

Tracks may be more beneficial to students if they can more accurately represent the breadth of knowledge needed to solve many of the grand challenges that face society. In each track, students must learn how to discover and understand social needs to design appropriate technologies or decide which needs should be addressed. The applications for bioengineering, particularly clinical needs, cannot be fully understood without an understanding of the contextual factors that create those needs. For students to gain the most from clinical experiences, they need to be trained in ethnography and problem identification; these techniques help bridge the gap between design and the social context [5, 6].

Acknowledgments

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