Engineering Education: Does Our Training Reflect Student Employment Trajectories?

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Abstract – *Departmental/disciplinary differences aside, newly graduated engineers can be considered to have one of four general and non-exclusive initial employment trajectories: operations, technological innovation, research, and teaching. Survey data from engineering students at the University of Saskatchewan will describe the proportions of students focused on these employment trajectories by year of study, and by discipline. An important implication of this classification is that the desired graduate attributes of these four employment trajectories require divergent knowledge and skills, aside from technical competence. Operations engineers need training in hazard assessment, economics, optimization, schematics, controls, constrained design, and quality control. Technology Innovators require training in creativity, abstract thinking, taking initiative, open-ended design, technical graphics, prototyping, and market research. Research engineers need training in experimental design, statistics, the scientific method, programming, instrumentation, and data analytics. Teaching engineers require training in pedagogy, communications, curriculum design, and social-media tools. All Canadian engineering schools train for Operations. Most have an option/certificate/specialization for Technological Innovation. Some have a minor emphasis on training for the Research stream. Very few systematically prepare for the Teaching role. Are we losing some good engineers by lack of curricular support for these latter three aspirations? Equally important, are sufficient numbers of engineers being prepared in each trajectory? These questions will also be addressed in this study, as data reflecting on the personality characteristics of student respondents was collected and analyzed while looking at their employment trajectories. The potential implications of this type of analysis on attrition and retention, innovation in Canada, and more effective teaching of STEM, will be discussed.*

Keywords: employment trajectory, operations, teaching, undergraduate engineering, technological innovation, pedagogy, research

1. INTRODUCTION

Engineering is a profession marked by strong common bonds and by disciplinary diversity. Engineers are known for their technical knowledge and skills, and for their abilities in design. However, specializations in different sectors of technology (e.g. mechanical, electrical, civil and chemical) are often so disparate that only the most basic knowledge and skills ultimately bind engineers together. We teach engineering students a common foundation of content which includes basic sciences, mathematics, humanities, and design. After that, students are taught increasingly specialized content specific to their chosen discipline. These disciplinary "silos" are virtually universal [4], and are also quite functional insofar as they allow, for example, mechanical engineering students to be taught mechanical engineering by mechanical engineers. However the silos pose challenges for training, such as design [7] or real problems [4] that cut across disciplines. But what if we have been missing another way of looking at our profession, namely a categorization that cuts across these disciplines in a different way that both binds and divides our calling? And what if this new perspective had important implications for *how* we teach engineering?

This paper proposes a new way of looking at engineering education based on what we call "employment trajectories". *What kind of work do you want to do when you graduate from engineering?* The answers to this question exhibit patterns that manifest across disciplines and are not discipline dependent. Instead, the patterns are characterized by more generic types of activities that one aspires to undertake and that everyone can relate to.

We propose four trajectory archetypes: technological innovation (TI), operations/production, research, and teaching. What is most striking about these archetypes is how little they overlap and how different their training requirements are. Operations/production work can include maintenance and optimization of operations, hazard assessment and implementation of safety protocols, project management, plant and process design, and consulting. As such, these engineers need training in hazard assessment, economics, optimization, schematics, controls, project and business management, constrained design, and quality control. Technological innovation includes activities such as the development of new products and processes, less constrained design, and entrepreneurship. These engineers require training in creativity, initiative-taking, open-ended design, technical graphics, prototyping, entrepreneurship, and market research. Research engineers engage in the pursuit of new knowledge (the groundwork for innovation), as well as in standards testing, evaluation, and development. They need training in experimental design, statistics, data analytics, the scientific method, programming, and instrumentation. Finally, teachers engage in all types of activities associated with training, teaching and learning facilitation, in both academics and industry. They need training in pedagogy, curriculum design, communications, and social-media technology.

This study grew out of the collective experience of the authors who had the good fortune of working and studying at different institutions with very different engineering cultures. We recognized that these cultures were different, but we had difficulty describing how they were different. Conceptualizing the differences through an employment trajectories perspective provided a promising taxonomy for description. This paper describes our initial work to explore the potential applicability of this perspective through a pilot survey study [3], which was conducted at the University of Saskatchewan this past Winter term, including what we found thus far and some of the implications.

2. METHODS

A survey was distributed to all undergraduate engineering students at the University of Saskatchewan during the Winter 2015 term. The data was then compiled and analyzed. Ethics clearance was secured from the University of Saskatchewan Research Ethics Board.

An electronic version of the survey was managed using FluidSurveys™ with a solicitation distributed via email by the College's Engineering Student Centre. A paper version was also distributed to selected 1st, 2nd, 3rd and 4th year cross-disciplinary classes e.g. Engineering in Society (GE 449). Survey questions examined positive academic experiences, personality characteristics, employment expectations/aspirations/preferences, and demographic details. The two modalities (paper and electronic) were employed to help secure adequate numbers of responses for significance testing and to see whether, and how, modality mattered in terms of response characteristics.

The first page of the survey gathered information on a variety of personality characteristics to see if certain personality characteristics corresponded with certain employment trajectory aspirations and preferences. Twenty-four word pairs were presented, such as "cooperative/independent", and respondents rated where they fell on that spectrum using a 7-point scale.

The second page asked a number of open-ended questions such as: what do you think you'll be doing as an engineer when you graduate, what would you like to be doing, what were/are some of your favourite courses and academic experiences, as well as where would you like to work when you graduate, and why? The answers to these questions would be used to help determine whether we had the right employment trajectories identified and/or whether we missed something, prior to biasing the respondents with our pre-determined categories.

The third page directly addressed the proposed employment trajectory categories. Respondents were asked to rank their preference for four proposed trajectories from first to fourth, followed by scoring each trajectory on a 10-point scale in terms of how much they would want that kind of a job after graduation. These are fundamentally different types of questions as ranking forces distinctions while the 10-point scale allows for similarity in ratings across the trajectories. Analysis examined the extent to which the two questions showed convergent construct validity [13]. Notably, we also asked if there was another type of job that they would want to rank that had not been offered as a choice.

The last page contained demographic questions such as year of study, program of study, age, gender and high school origin (urban, rural, or international). These questions allow us to determine whether the trajectory preferences vary by these demographic variables.

The full data analysis plan incorporates a mixed methods approach. The results presented in this paper cover the first and most basic level, necessitated by time constraints and space limitations for this publication. Further analyses will involve more inferential statistics. The personality data, trajectory rankings and scorings, and all demographic data has been analyzed using Excel™ and SPSS™. Rigorous grounded theory analysis and coding of the responses to the open-ended questions will occur in subsequent analysis. However, a preliminary review of the qualitative data has shown some clear and obvious trends and these will be reported in the Results section. In general, we will look for recurring themes and words to create emergent groups of answers.

This is a pilot study examining a heretofore unstudied way of characterizing engineering students. As such, the statistical validity and reliability of the survey metrics have only been initially explored with any interpretations being tentative. The findings from this pilot study will inform further development of the survey instrument.

3. RESULTS

A total of 335 surveys were collected (108 online, 227 on paper). Eight (paper) responses were unusable and approximately 55 were incomplete and were used whenever it was possible to do so. With approximately 1750 undergraduate engineering students in the College of

Engineering at the time of the study, the response rate was approximately 20%.

In terms of gender, 23% of respondents were female and 77% were male, which was representative of the percentages in the College (24% and 76%, respectively).

The mean age of participants was 21.29 with a standard deviation of 2.72. The peak age was 20 (approximately 25% of the total) with ages 18, 19, 21, 22 and 23-29 each providing about 15% of the final total. The oldest 5 respondents were between the ages of 30 and 35. These percentages are fairly representative of the College population. Just over 60% of the students were of urban origin (communities with a population > 10,000), while 30% reported rural roots. The remaining 9% reported international high schooling.

In terms of academic programs, we offered 11 choices including first-year (i.e. prior to division by discipline) and "undeclared". The nine true programs, with their full College enrollments and sample sizes shown in brackets, include electrical (121; 6), computer (59; 11), biological (11; 6), chemical (279; 49), civil (260; 46), environmental (66; 21), mechanical (292; 90), geological (113; 20), and engineering physics (49; 14). Figure 1 shows the demographic break-out of the survey respondents by program where the "other" category encompasses undeclared, computer, electrical, engineering physics, and biological. In absolute numbers, mechanical, chemical, and civil were the biggest responders but on a "percentage of program enrollment" basis, biological and environmental were well represented at 55% and 32%, respectively. Mechanical (31%), engineering physics (29%), and computer (19%) were also well represented.

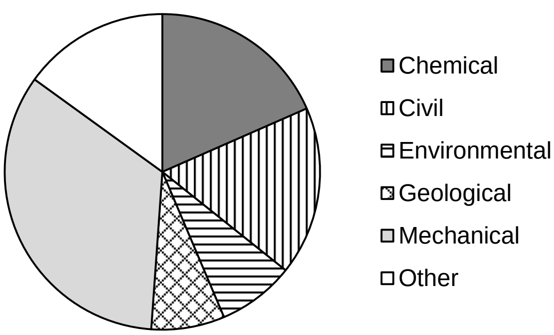

Fig. 1. Proportion of respondents by program

Students could identify their "year" as 1, 2, 3, 4, or 5+. Figure 2 shows the response distribution. For the purposes of subsequent analyses, years 4 and 5+ were combined. First-year was the least well represented at about 12%.

Although this is the first time that this survey has been conducted, we did ask whether a student's prioritization of the offered employment trajectories had changed since starting school. Approximately one third said "yes". We will soon evaluate the comments detailing those changes.

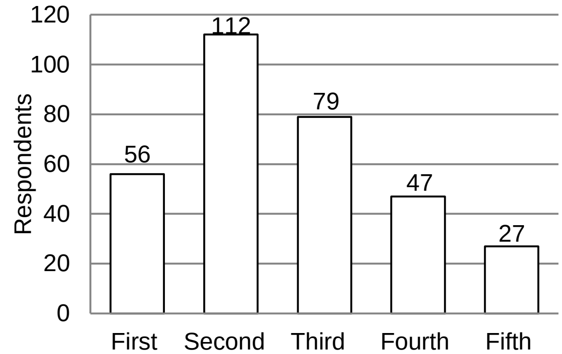

Fig. 2. Number of respondents by year

The next set of results pertain to the ranking of the four employment trajectories. A ranking of 1 represents the type of job <u>most</u> wanted, while 4 represents the <u>least</u> wanted. Figure 3 shows the ranking data by percentage, in a stacked bar graph format. Notably, over 50% of the respondents ranked technological innovation (TI) as #1, while approximately 50% of respondents ranked teaching as #4. Conversely and surprisingly, over 50% of respondents did <u>not</u> rank teaching as #4. Indeed, 5% ranked it as their top employment trajectory preference!

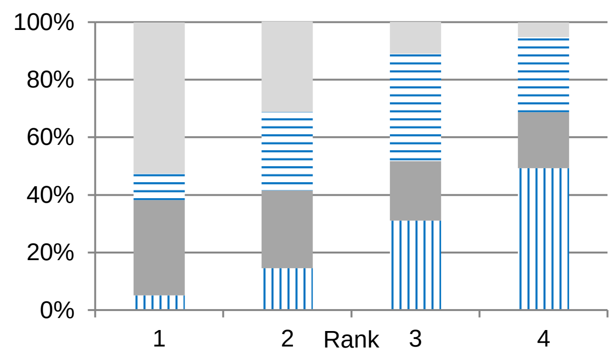

Fig. 3. Employment trajectory rankings
(light solid = TI, horizontal lines = research, dark solid = operations/production, vertical lines = teaching)

Using the same legend schema as Figure 3, Figures 4, 5 and 6 show stacked percentage <u>first-place</u> rankings by year, program and high school origin, respectively. Note i) the increasing preference for operations and decreasing preference for research, by year, ii) the dramatic differences between engineering physics (EP) and the other disciplines especially with respect to research, and iii) the stronger preference for operations by rural students. There were no significant differences in first-place rankings by gender.

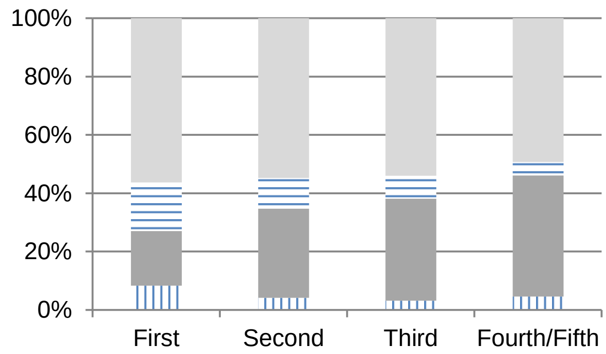

Fig. 4. Employment trajectory #1 rankings by year (same legend colours/patterns as Fig. 3)

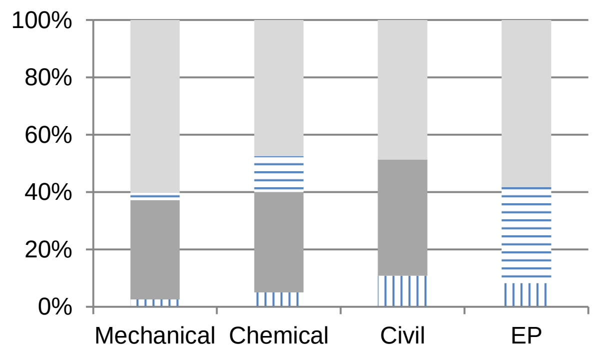

Fig. 5. Employment trajectory #1 rankings by program (same legend colours/patterns as Fig. 3)

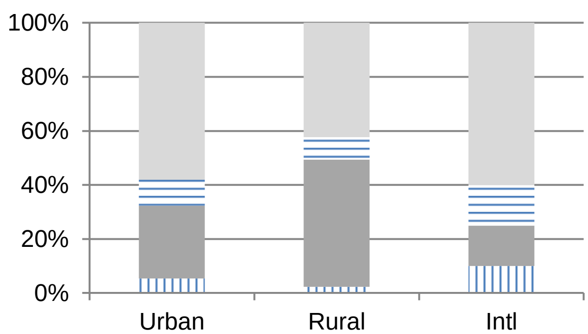

Fig. 6. Employment trajectory #1 rankings by high school (same legend colours/patterns as Fig. 3)

The next set of results pertain to the scores of the four employment trajectories on 10-point scales. A score of 1 represented the type of job <u>least</u> wanted, while 10 represented the <u>most</u> wanted. Figure 7 shows the scoring data by percentage, in a stacked bar graph format. Note that for all of the scoring Figures (7-11), the 10-point scale has been reduced to a 4-point scale and has been inverted to facilitate comparison with the earlier ranking data. More specifically, the lowest scores of 1-3 = 4, scores of 4-6 = 3, scores of 7-8 = 2 and top scores of 9-10 = 1. Also note that for the rankings, we had the same number of respondents for all 4 ranks because it was a forced choice. With the scores columns, each column represents a unique total.

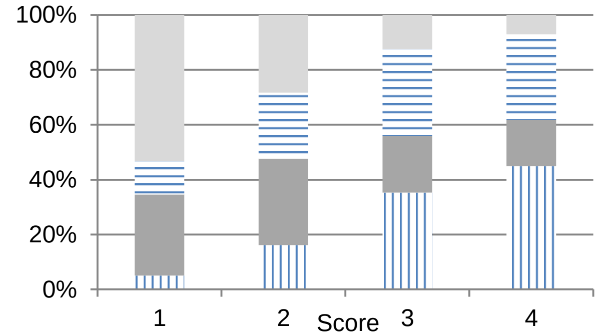

Fig. 7. Employment trajectory scores (same legend colours/patterns as Fig. 3)

One can note that Figures 3 and 7 are qualitatively very similar, suggesting a level of convergent validity based on using two very different ways of probing the same fundamental concepts.

Using the same legend schema as Figure 3, Figures 8, 9 and 10 show stacked percentage <u>top-score</u> rankings by year, program and high school origin, respectively.

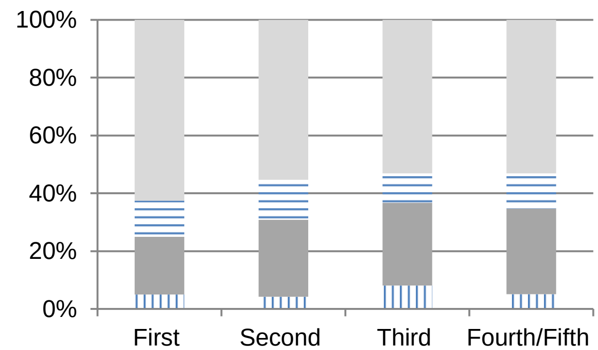

Fig. 8. Employment trajectory top scores by year (same legend colours/patterns as Fig. 3)

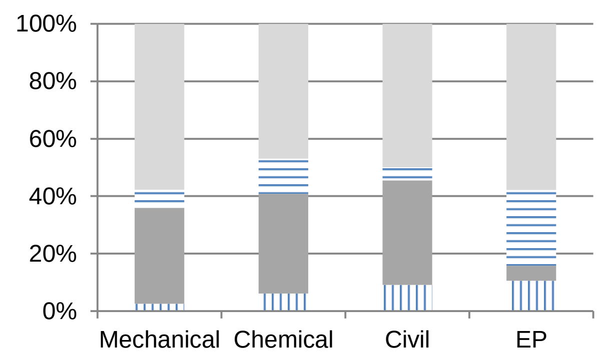

Fig. 9. Employment trajectory top scores by program (same legend colours/patterns as Fig. 3)

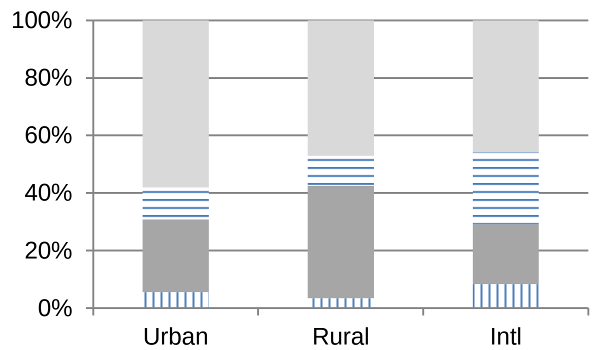

Fig. 10. Employment trajectory top scores by high school (same legend colours/patterns as Fig. 3)

Compared to Figures 4-6, Figures 8-10 show a smaller increase in preference for operations over 4 years, with research figuring more prominently. For Mechanical and Civil, research also fares better at the expense of operations. With high school origin, there is a marked increase in internationally trained preference for operations and research, at the expense of TI. There were also minor differences by gender (not shown), as males were slightly more inclined to TI and research and less so to operations.

The possibility of archetypal "vector patterns" in the trajectory scores was also explored. That is, if someone scored TI highly, were there characteristic patterns to the scores of the other trajectories? Figure 11 shows these results where averages of scores were taken for those that scored each of the trajectories highly i.e. a 9 or 10. As an example of what Figure 11 shows, if someone scored operations highly (dark line), they typically scored research quite low. Similarly, scoring research highly (dotted line), typically correlated with a low operations score. Note that standard deviations varied from about 0.5 to 3.0.

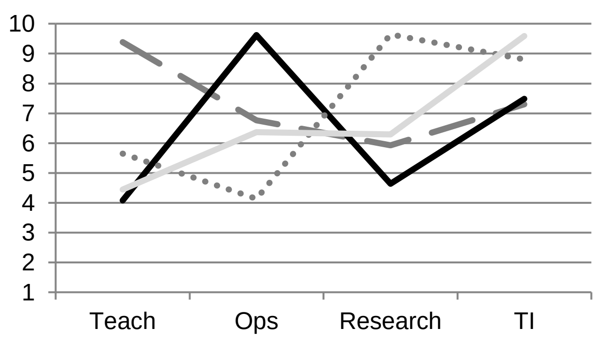

Fig. 11. Employment trajectory high score vectors (light solid = TI, dotted = research, dark solid = operations/production, dashed = teaching)

Two basic patterns are apparent in Figure 11. If you most preferred teaching or TI, all other preferences were scored relatively low, on average. If you most preferred operations or research, then TI was a strong second and the others were scored low. Looking at it another way, one could say that all trajectories were strongly liked or disliked, except TI which was more consistently preferred to a lesser or greater extent.

Additional employment trajectory categories that respondents mentioned wanting to rank/score included project management and consulting. This finding will be referred to in the Discussion.

Lastly, the personality characteristics have been only partially analyzed. As an example of these findings, we looked at those respondents that rated themselves most cautious or risk taking, and examined their other response data. A greater proportion of risk takers were from first year and/or chemical engineering and ranked research or teaching last more often than cautious students. A greater proportion of cautious students were female. In another word pair (independent/cooperative), a greater proportion of independent students were from urban high schools and tended to rank TI first in the trajectory rankings. With the feeler/thinker word pair, there were 139 respondents who rated themselves at the thinker end of the spectrum, while only 13 rated themselves at the feeler end. At the feeler end, the gender split was 50/50. At the thinker end, 86% were male. In terms of trajectory rankings, the thinkers were not dissimilar to the general population of respondents, but <u>none</u> of the feelers ranked research first or second, and teaching was a popular choice (17% 1st and 33% 2nd) suggesting a potential direction for further research with personalities and trajectories.

4. DISCUSSION

There are many potential implications stemming from this line of research. From a pedagogical perspective, the most important implications may apply to the engineering curriculum, as the different trajectories require different forms of instruction and preparation. All Canadian engineering schools train for operations. Most have an option, certificate, or specialization for technological innovation. Some have a minor emphasis on training for true research. Very few systematically prepare engineers for teaching. Are we losing some good engineers due to a lack of curricular support for these latter aspirations? This study's survey instrument, applied over a series of years, may be able to shed some light on this question.

In a very similar way, we may be able to track changes in the diversity of the student population over the time they spend in school, where in this case "diversity" means the diversity of personality characteristics and career aspirations as well as ethnicity and gender. Across a variety of variables, there were no statistical differences between female and male respondents (except for the "thinker/feeler" word pair) although further analyses are needed to examine the patterns more exhaustively. In addition to thinker/feeler [11], gender differences in other personality types are well-established beyond engineering schools [2, 5]. The finding of no other gender difference raises questions such as, is this because the system selects women who think like men, or because it trains or encourages them to do so?

We did note a number of variables that seemed to change by year, program, age and/or high school origin (urban, rural, and international). For example, the results for the word pair "spontaneous/methodical" varied by high school origin and by year. More data, over multiple years, will help clarify whether these trends are persistent in Saskatchewan and/or elsewhere in Canada. If such trends are persistent, they would create a new potential use for the results. If we can establish validity and reliability in these measurement tools, they may be able to show behavioural changes during the time that students are in school that are related to some of the harder-to-measure graduate attributes. For instance, in more traditional engineering schools, is student self-perception of being an innovative thinker atrophying in our students? This type of survey tool may be able to help assess this type of question.

A rigorous evaluation of the open-ended (qualitative) responses has not yet been completed. However, two persistent patterns were readily evident during cursory review that suggest "missing activities" in the employment trajectory framework. In the first case, we often saw references to wanting to "make money", "earn prestige", "help society" and "change society". These motivations speak to another potential level of differentiation that may encompass the range of needs in Maslow's hierarchy [8], the well documented range of career motivations including job autonomy and altruism [6], and self-determination theory's extrinsic and intrinsic motivations [10]. An interesting question is whether these motivations exist equally across the employment trajectories such that someone motivated by money is interested in both operations and research, or if these motivations vary by career trajectory with a specific motivation such as helping society or prestige being more closely associated with a specific trajectory such as technological innovation or research. We plan to include questioning in the next version of the survey instrument asking "what is your ultimate personal objective in pursuing engineering?" with the aim of identifying their priorities across "making money", "earning prestige", "helping society", etc.

In the second case, consulting and project management appeared fairly frequently as activities that some students expect to or want to engage in. Within our proposed framework, these activities would not qualify as new categories. Rather, we would include them as examples under the operations category. They could also fall within some of the other categories, but only in more specialized and/or more senior managerial capacities which students would likely be less familiar with and/or which would fall outside of the scope of these questions.

That issue of familiarity raises a concern about measurement validity that we will address more directly in future iterations. When 100 students say that they are all keen on TI, are they all thinking about the same concept? We attempted to address that concern in two ways with this pilot study. We asked open-ended "naïve" questions first, so as to gather unbiased data: this data will be examined as part of further analyses. Then, when we did introduce the trajectory categories, we provided a list of examples of the types of activities that we were assuming to be associated with the categories to provide common definitions based on our conceptualizations.

Assuming these trajectory categories are valid and that we can and should address them in our engineering curricula, would increasing focus on these trajectories enhance student motivation to persist and excel in school? If we introduced a 4th year elective on teaching STEM, might that encourage some engineers to go into the teaching profession that otherwise would not? Such an outcome would most certainly help our profession in the long term. And what if we introduced a senior elective in "research techniques in engineering" that could allow students to see whether graduate work might be something they would want to pursue? And what if we allowed students to identify and develop their own design problems in senior capstone courses, allowing them to try entrepreneurship in a relatively safe environment? Many schools already do this, with great success e.g. [9, 14]. And finally, what if we had industry-supplied and co-supervised design projects in operations/production that would allow students to see what the real world is like in industry? These approaches could help motivate all of our students, not just one or two sets of them [1].

The irony in all of this is that we already have obvious silos in engineering, namely our disciplines. What we may not have recognized is that we have equally powerful silos in our employment trajectories. They just have not been previously identified as such. When we have talked about this study with our peers and colleagues in academia and industry, the typical response has been "Well, of course real engineers want to work in [a specific trajectory]". The interesting thing has been that whether a given person says "technological innovation" or "operations/production" to complete that sentence, they are equally sure of their statement, as if there was no other sensible thing to say. These appear to be very visceral perspectives.

5. CONCLUSIONS AND FUTURE WORK

Initial results from this pilot study are very promising in terms of revealing a new way of looking at educating engineers. Our four proposed employment trajectories have held up well in terms of covering the field of possibilities, at least at this level of vocational activity.

In terms of the picture one can draw from University of Saskatchewan engineering students, they seem to be much more oriented towards technological innovation than was expected. These preferences also appear to change based on program of study, gender, year of study, high school origin, and age.

In terms of short-term future work, much analysis of the pilot data still remains to be completed including cross-tabulating several variables, coding qualitative responses, and examining potential differences in response rates and characteristics between paper and online submissions.

After that, the survey instrument should be refined and improved with an eye to verifying validity and reliability in the measurements. The survey will continue to be applied at the University of Saskatchewan over at least the next few years, to establish some longitudinal results by cohort. We are also considering modifying the surveys to include respondent identification so that individuals can be tracked over the years that they are in the College. This would create a much more powerful tool for assessing changes in preferred employment trajectories and the reasons for those changes. Finally, we are very eager to conduct this survey at other institutions to see to what extent different engineering schools have different "personalities" (compositions of employment trajectory preferences) and if patterns within disciplinary programs are consistent across different institutions.

On a more detailed level, several improvements to the survey instrument are planned for future iterations. For example, we will shorten the survey to enhance completion rates by removing personality word pairs and open-ended questions that this pilot study has identified as redundant or no longer necessary. We will also investigate the feasibility of completing the survey using mobile apps. And we will look at framing the trajectory scoring question using a 7-point graphical format similar to the personality word pairs.

Additional questions to the survey may provide further insights. We could ask about previous co-op, summer, or internship employment experiences, to see how those experiences have shaped aspirations. Given government priorities and Canadian demographics [12], identifying Aboriginal students and their preferred career trajectories may also be worthwhile. We are also considering asking about program satisfaction. If we know a program is strongly operations-oriented, for instance, can we see any dissatisfaction among those students who are more entrepreneurially-oriented, or vice versa? And could changes in satisfaction level be tracked after implementing changes in curriculum? As noted earlier, we may also want to include questions pertaining to the more fundamental level of motivations for choosing engineering e.g. money, prestige, helping society, and changing society.

Clearly, we are at the beginning of a potentially productive line of research with important implications for engineering education. If your school is interested in participating in an expanded study, we welcome any collaborators and invite schools to contact us.

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