

An evidence-informed approach to course development: incorporating insights from working engineers on the skills that enable graduate school success

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Introduction

Attention is being paid to the importance of educating graduate engineering students for both research careers and opportunities in industry, acknowledging that graduates are increasingly making the choice to pursue careers outside academia. Understanding the skills that enable success both within and outside academia can help us provide more relevant and effective programming at the graduate level [1] [2] [3] [4] [5] [6] [7] [8]. Research in this area acknowledges the value of transferable (non-technical skills) to students during their graduate degree, as well as during their transition to industry. Often these skills can be most effectively delivered through formalized graduate student training. In this paper we will share data gathered from alumni interviews conducted by students in a Research Methods and Project Execution course at the University of Toronto, and discuss how we have applied this directly to course development. These alumni interviews, conducted from winter 2020 to its most recent iteration in fall 2024, yield valuable insights into the skills and mindsets that alumni identify as enabling graduate school success, and their transferability to professional contexts. This paper will first introduce the course and the function of the alumni interview assignment within this course context; next, it will describe the data analysis methods and results; and lastly, it will discuss how this data has informed the course design.

Developing Research Methods and Project Execution

Research Methods and Project Execution was launched in 2017 to provide Chemical Engineering graduate students at the University of Toronto with consistent instruction on transferable or transdisciplinary skills including project management, research skills and teamwork within research environments.

Without access to professional and graduate research skills training, our graduate students were finding varying levels of success in navigating their graduate school experience, as well as situating themselves professionally as they looked towards graduation. The trend to increase graduate-level enrolment recognizes the value of advanced graduate research skills both within academia and outside of academia in a variety of industry sectors. These skills include critical thinking, experimental design, problem framing and inquiry, project management, quantitative decision making, team skills and communication. The appropriate and equitable delivery of these advanced training skills within our graduate programs is therefore a critical aspect of our curriculum, which will impact time to degree completion and overall completion rates.

Research Methods and Project Execution was developed based on input from stakeholders to understand how and what current graduate students were being trained in and how this aligned with the needs of professional contexts. In 2016, we undertook a study to understand how graduate training in Chemical Engineering was helping students to develop these skills for their research thesis, as well as their career success within and outside academia. Through a survey of Chemical Engineering graduate alumni, meetings with graduate supervisors, and focus groups

with current graduate students we learnt that research skill training was not equitable: respondents reported that training was highly variable, supervisor dependent, and typically delivered via peer mentorship from senior graduate students. While the value of peer-to-peer learning is reflected in the literature and is central to our course pedagogy [9], students were concerned about consistent quality and authority without commensurate engagement from faculty. Graduate students described seeking opportunities to supplement this variable training by finding opportunities for transferable skill development outside of their research group, but explained that these types of opportunities required considerable time investment and often reduced their ability to focus on their thesis work. In some cases, supervisors were not fully supportive of such distractions from experimental work.

In response we developed a course that would help students develop these transferable skills while simultaneously improving their time to completion through activities that aligned with research milestones, including conducting a literature review, articulating a motivation and rationale, developing a hypothesis, designing and troubleshooting experiments, and presenting preliminary data. Through this approach we could help students improve skills for professional readiness, including project management, teamwork, and communication, while alleviating supervisor concerns about course work that might distract students from research productivity. The course combines activity-based instruction and consistent peer-to-peer discussion and feedback, emphasizing the value of communicating about one's research as central to refining and improving one's research goals and approach.

While our course development was informed by significant stakeholder engagement, including graduate student focus groups, review of data from alumni surveys and discussion with graduate supervisors from across the department, continued community involvement has helped to further its development, as we have launched a faculty-wide offering and an online repository of course activities and resources and continued to refine our course topics and methods. An alumni interview assignment, which challenges students to learn more about graduate-level experiences, resources and skills that inform engineering work in industry, provides an important tool to maintain the currency of this course.

Alumni Interview Assignment

The alumni interview assignment was developed as a method to ensure that we were meeting a central aim of this course: providing students with an understanding of the industry applications and opportunities for their work. By asking students to connect with an alumnus from industry we give them an opportunity to practice their networking skills and connect them to the industry applications of their work, while gaining valuable insight about the currency of our course content.

In the assignment, students identify an alumnus (from our institute or a comparable program) whose career path they find interesting, and conduct an interview that focuses on the resources and opportunities that helped them succeed in their post-graduate career, as well as the types of activities or strategies that they feel would have been helpful in retrospect. Students are given three constraints for their interview subjects: 1) they should be from industry rather than academia; 2) they should have at least five years of post-graduate experience; 3) they must have

at least the same terminal degree as the graduate degree that the student is pursuing. Beyond these constraints students are free to seek out and connect with an alumnus of their choice, with some instruction supporting this decision-making: students engage in a brief in-class activity to get them thinking about the type of professional they are interested in connecting with, receive instruction on how to effectively and professionally contact their desired interviewee, and are given a list of possible interview questions. Following the interview, students share their findings in a short presentation. From 2020 to 2023 these presentations were partnered, meaning that students each interviewed one alumnus, but presented these in a single presentation and corresponding slide deck. This format acknowledged the value of finding common insights between alumni while also adjusting to scheduling constraints: in larger sections it was difficult to get through all of the presentations in a single ninety-minute class. As of fall 2023 we modified this reporting structure, requiring students produce an individual slide deck to present in a structured sharing activity to a group of their peers; following the presentation they submit the slide deck and a written summary for assessment.

Data from the alumni interview presentations provides insight into: 1) the skills and mindsets that alumni feel enabled their graduate school success; 2) the skills that they have transferred from their graduate school experience to their careers; and 3) the skills they feel were missing from their graduate experience or that they developed on the job.

Analytical Methodology

This study analyzes 178 slide decks from presentations across fourteen cohorts of the course, from winter 2020 to fall 2024. Six of these cohorts were made up of Chemical Engineering students only, and seven were faculty-wide sections of the course, consisting of students from Civil, Mechanical and Industrial, Material Science, and Electrical and Computer Engineering. Each class was made up of both PhD and Masters research stream students.

These 178 slide decks cover insights from 300 alumni. This discrepancy in numbers arises from the partnered presentation format described above, as well as students who elected to interview and report on more than one alumni.

To examine which skills the alumni highlighted as being the most important for graduate success and beyond, this study took a two-pronged analytical approach. The first phase constituted an initial analysis of student presentation slides. This analysis included reviewing slides from each class and highlighting the general themes that existed, including alumni information, to see if there was a relationship between advice given by alumni and their degrees and professions. This phase also allowed for the initial noting down of skills highlighted in student presentations, providing a skeleton for what to focus on in the next phase of analysis. Words like “communication,” “graduate success,” “networking” and “problem solving” and their overall frequency was documented.

The second phase of analysis involved manually coding presentations to examine the frequency of essential skills needed to succeed in graduate school and in future careers, which allowed for a thorough analysis of this unique medium: presentation slide decks. Taking the frame of words from the initial analysis, seven primary codes were created, detailing transferable skills

highlighted in student presentations. These codes had a list of secondary codes that were created from frequent words used in the initial phase to describe the primary codes. The presentations were coded to examine the frequency of skills considered most important by alumni for graduate success. The table below describes the primary and secondary codes.

Figure 1. Coding Categories

Primary Codes	Secondary codes
1) Communication skills Describe skills used to exchange information effectively, including speaking, writing, and listening.	Listening/ active listening
	Clarity
	Concision
	Adapting communication style
	Feedback
	Presentations
	Confidence in communicating
	Responsiveness
	Respectful communication/ interaction
	Friendliness
	Writing papers
	Written communication
	Visual communication
	Non-verbal communication
	Preparing ahead of time
2) Networking skills Describe ways of building relationships with industry specialists, mentors and peers for graduate school professional opportunities and future industry jobs. These skills are often essential for attending networking events such as conferences, workshops, and internships.	Conferences
	Events
	Internships
	Building meaningful relationships
	Interacting with diverse networks
	Elevator pitch
	Professional development
	Email etiquette
	Consistency in networking
	Interviewing skills
	Mentorship
	Collaboration on assignments/ Working with peers/colleagues
3) Teamwork and collaboration skills Describe interpersonal skills needed to effectively collaborate and work with peers and teams.	Reliability
	Responsibility of work
	Flexibility
	Interpersonal skills
	Independent thinking
4) Problem-solving skills	Research efficacy
	Critical thinking
	Investigating problems
	Product design

Describe skills used to critically analyze and identify problems and implement creative, real-life solutions.	Creativity
	Information processing
	Overcoming obstacles
	Real-world problems and solutions
	Leadership
	Organizational skills
	Budget organization
	Task organization
	Risk management
5) Project management skills Describe skills to manage, execute, delegate and complete tasks and projects.	Quality management
	Project initiation
	Managing teams
	Conflict resolution/ negotiation
	Delegation of tasks
	Scheduling
	Goal Setting
	Deadline setting
	Prioritization
6) Time management skills Describe skills aimed at efficiently and productively utilizing time to finish tasks and projects.	Planning
	Stress management
	Time-blocking
	Multitasking
	Software proficiency
7) Technical skills Describe skills to effectively perform technological and specific jobs that require current software, tools for analysis, programs and knowledge.	Data analysis
	Programming/ Computer operations
	Online courses
	AI
	Certifications

The results of coding were further divided into three categories:

- 1) Graduate skills that alumni feel contributed to their graduate school success;
- 2) Graduate skills alumni considered important to transition from academia to industry jobs;
- 3) Graduate skills alumni wished they had developed while they were in graduate school.

Coded data was moved into the relevant category, and the frequency of skills was documented.

Interrater Reliability

While the primary method of analysis for this study was manually coding information, a round of coding using NVivo was conducted by a secondary researcher in order to check the validity and consistency of the created code book, and measure the differences and similarities between independent coders for the same slide deck.

Results

Figures 1-3 summarize the cumulative data from 178 slide decks, covering 300 interviews.

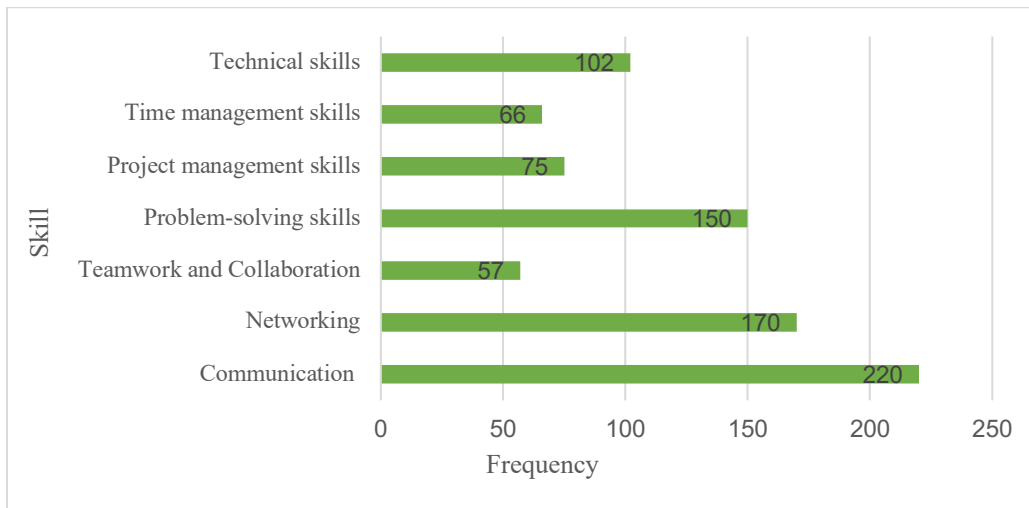


Figure 1. Skills that contributed to graduate school success

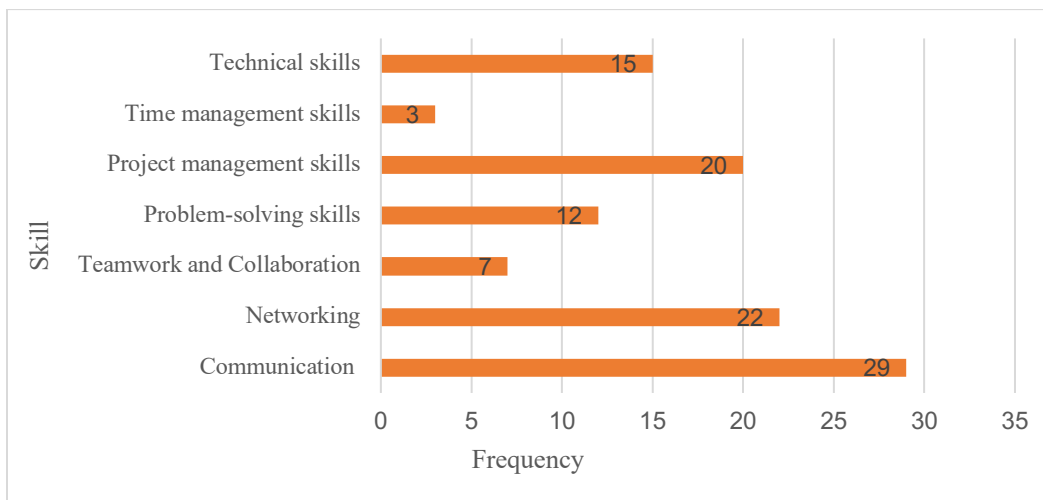


Figure 2. Skills alumni wish they had further developed during graduate school

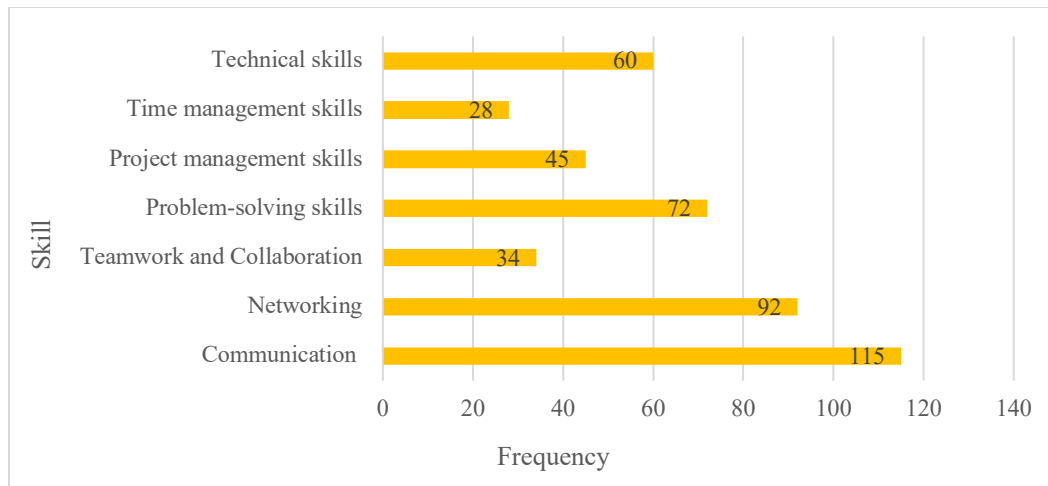


Figure 3. Skills alumni identified as valuable for the transition to industry

Cumulative data confirms the value of transferable skills for both graduate school success and the transition to industry. Communication was most commonly identified as the skill that contributed to graduate school success as well as the most valuable skill (of those discussed) for industry success. Despite or perhaps because of the importance of this skill, it was also identified as the skill that alumni wish they had further developed. This correlation between the perceived value of a skill and a desire to have further improved this skill during graduate school is also evident in alumni observations on networking. Problem-solving skills are also valued for both graduate school success and industry. Technical skills were seen as supporting graduate school success by the majority of alumni and are utilized by many in industry. Time management skills were identified as relatively more critical to graduate school success than industry, which is perhaps not surprising given the degree of independent learning required for many graduate students as well as the lack of hard deadlines for many research projects.

It is challenging, given the nature of this data, to determine whether a relatively low level of responses in the “wish for development” category indicates training success (students learnt what they needed) or a lack of utility (we don’t need it now). Such is the case with time management, where over a third of the data indicates that time management supported graduate success, but relatively few alumni indicated they wish they had further developed this skill.

Limitations

This study makes use of an existing course assignment to identify trends related to skills developed during and required for graduate school and professional success. Although we benefit from this data as an informal feedback source, the dataset lacks the consistency, accuracy and granularity that could be provided by formal mechanisms, like an alumni survey, or more complete data, like an interview transcript. The slide decks are multiple steps removed from the original interview. The student has shaped and worded the questions they wish to ask to understand the graduate school experience of their alumni, and they have been encouraged to let the conversation evolve naturally, rather than sticking to a script, which means that not all interviews have the same level of focus on skills developed or applied. The students have reviewed their interview transcripts and made decisions about what information they wish to

highlight; this decision-making reflects their own interests as well as the story they wish to share with their colleagues. The students have also selected the amount of information to include on their slides, meaning that sometimes only part of the information that was shared verbally has been captured for this analysis. For example, sometimes, students choose not to share information on their slides regarding the specific professional position of their alumni.

For this first analysis we focused on identifying trends in the data, which aligned with or confirmed our takeaways from in-course observation of these presentations. Future analysis will parse out responses to identify the number of presentations (from the whole) that identify a particular skill, rather than coding for multiple instances in a single presentation. It will also look for trends between professional sector and skills applied (acknowledging that not all professional sectors have been recorded in the slide decks).

Aligning Course Content with the Data

The alumni industry data supports many of our initial choices in the course while continuing to inform its evolution. A current snapshot of our course topics (see Table 2) reflects the transferable skills that were emphasized in many of the alumni interviews.

Table 2. Course Content

Class	Topic
1	Introduction – Making the most out of your graduate training
2	Project and network mapping
3	Reading a paper – How to read an article effectively and efficiently
4	Argument design and structure for papers and proposals
5	Outlining your thesis rationale
6	Planning your project objectives
7	Pitching your thesis persuasively
8	Research project execution – what are your barriers?
9	Effective communication in research teams
10	How to achieve your project goals – writing a hypothesis
11	Feedback on your motivation document
12	How to achieve your project goals – troubleshooting experiments
13	Alumni interview presentation day
14	Outlining your research approach
15	Identifying logic gaps in your research approach
16	Visual design and caption writing
17	Creating a graphical abstract 1
18	Creating a graphical abstract 2
19	Communicating beyond your community – analogies
20	Effective slide design
21	Understanding your presentation style
22	Storyboarding your final presentation
23	Research approach presentation + final reflection

While Table 2 summarizes current course content the discussion below explains how we have adapted our approach to each of these transferable skills over the evolution of the course. These skills have been organized by relative importance (as articulated in the alumni interviews) to graduate school success, which is of course the central aim of our course.

- 1) Communication: The importance of communication to research effectiveness is central to the course's design. We begin and end the course by emphasizing to students that communicating about one's research is not an outcome or a practice that comes at the end of one's research journey. Instead, it's central to forwarding and improving a research project, as the act of communication not only helps you to find collaborators and supporters, but also helps you to clarify your own thinking. As is evident in the table above, students consistently communicate about their research to their peers and the instructional team.
- 2) Networking: The course is bookended by discussions about networking. The alumni interview assignment described here is introduced in lesson one and students are asked to analyze their success as networkers during a final reflective assignment. In recent years we have also introduced new strategies to understand their professional network. In the first class we ask students to develop a networking map that complements a mind-map of their research motivation and objectives. By comparing these two maps students can identify gaps in their network—the human connections that will help them towards their project success.
- 3) Problem-solving: Given the research orientation of this course students are given many opportunities to investigate and consider their research problem from different angles. After the first couple of years of the course we introduced a new class on experimental troubleshooting, which helps students to generate a more systematic approach to problem solving within the research space. This activity has had to be adapted for students with a more qualitative project (particularly students in engineering education and some civil or industrial labs), to troubleshoot methodological challenges in qualitative or mixed methods research.
- 4) Project management skills: Our approach to project management—guiding students through multiple goal-setting activities, including a breakdown of key milestones in their research project—has not changed during the run of this course.
- 5) Technical skills: Teaching technical skills was never the central mandate of this course and as a result we have not made changes to our instruction in this area.
- 6) Time management: We have taken various approaches to instructing time management in this course. In our first iteration we delivered a short (two class) time management module, in which students first practiced working in fragmented time through a number of low-stakes timed games, and next generated strategies for effective time management. Ironically, we received student feedback that the time spent on time management seemed like a waste of time. Since then, we have continued to provide a forum to share strategies for effective time management, but within a class on barriers to completion, in which we

invite students to share the challenges that are slowing their progress and to generate solutions. Time management is a frequent topic of discussion in this class, but is covered alongside related factors, including competing project timelines, supervisory requests, and research group dynamics.

- 7) Teamwork and collaboration: We began instructing teamwork in our second iteration of the course through roleplays around research group dynamics (including but not only supervisory relationships). Given the significance of a student's research group and supervisory relationship to their graduate success, we have continued to hone this session. Now we begin by having our students complete a Bolton and Bolton inventory to identify their leadership style, and we ask them to map their own style and that of their research team to consider how the distribution of styles impacts the team's work. We then introduce a roleplaying exercise in which students troubleshoot common research group challenges (keeping in mind the different leadership styles). At the end of this session we have groups analyze and respond to issues that could potentially arise with a supervisor and share these with the whole class. We also encourage students to make a plan to share their individual development plan (created at the beginning of the course) with their supervisor in an upcoming meeting.

Conclusion

Despite the limits of the alumni interview as a data gathering tool, the trends that are observed in the alumni presentations (and formally through this data analysis) continue to inform our course content and delivery. In fact, the alumni interview assignment is one feedback mechanism employed among others to continually improve course design and delivery in Research Methods and Project Execution. Other tools—course evaluation surveys, student feedback forms and session debriefs also contribute to our continued course development and improvement. Given the orientation of this course towards transferable, practical skills, alongside its status (at least for the faculty-wide cohort) as an elective course, finding evidence for the utility and effectiveness of the skills we teach is crucial to student and faculty buy-in. It is also important information for achieving our own course mandate: providing consistent meaningful graduate training to improve graduate school and professional success.

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