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Case Report

Shared Learning from the Implementation of a Technical Leadership Program

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Abstract: Capstone projects have been an established vehicle of student–industry engagement in a university setting. In engineering, capstone projects are a point of transition from student to professional, as student engineers gain practical work experience and apply their technical skills and knowledge for an industry-proposed design, research, and/or development challenge. In this paper, we report on a supplementary program—the Technical Leadership Program (TLP)—which was designed and delivered for students to hone their technical leadership skills within a capstone project. To report on the outcomes of this case study, we use a student-as-partners philosophy to share the case study as a series of vignettes from co-authors who participated in the TLP. These have been collated into four key thematic areas including building awareness through technical leadership; building a personal repertoire of leadership; creating a common platform for collaboration; and transitioning into a professional workplace environment. The reflections are then shown to map to relevant competencies in technical leadership. Alongside these themes, the paper shares the design of the TLP delivery and reflects on the challenges and benefits of this mechanism to enhance student experience.

Keywords: technical leadership; students-as-partners; systems engineering; capstone project

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1. Introduction

The Technical Leadership Program (TLP) was created in response to the observation that students were spending much of their project *doing* the technical work of engineering projects, rather than using the project as a place to do the cognitive process of *learning about doing* engineering [1]. This distinction is critical in the establishment of life-long learners and future-skilled workers [2–5] who will be continuously required to learn and revise their mental models of leadership in engineering as they navigate new scenarios throughout their career.

This paper shares the experiences of two staff who implemented a program to help students broadly develop the above skills alongside a one-semester capstone project. The goal of the program was to give space for student leaders to experiment and reflect on their learning throughout the project. To report on this case study, 14 students across four cohorts of the capstone project were invited to participate in the authorship, modelling the approach used within the program of co-creation with students.

Technical leadership—that is, the leadership required to manage and deliver a technical output in a collaborative team—was identified as a focus point for this leadership

program [6]. The program was designed to share experiences between project teams by creating a common language for team members to discuss issues and devise leadership experiments within their own team [7]. Technical Leadership is an established International Council on Systems Engineering (INCOSE) competency [8,9] and recognised activity for developing talent, as seen in the INCOSE Institute for Technical Leadership [6,10] from 'awareness' level to 'expert'.

2. Background

There has been an increasing demand from the industry and government organizations that hire graduate engineering students to develop professional competencies among the students along with technical skills [11,12]. Capstone projects in engineering are a major attractor for students looking to get valuable work and professional experience to increase the chances of employability after graduation [13,14]. Yet, there remains a challenge in bridging the gap between the professional and technical skillset [15–18]. Engineering bodies that align with the Washington Accord have emphasized the importance of these professional competencies for graduate engineers through various guidelines and competency benchmarks [19,20].

The INCOSE Systems Engineering Competency Framework [8] highlights the importance of technical leadership, which is the encompassing proficiency in skills such as "understanding of customer need, problem-solving, creativity and innovation skills, communications, team building, relationship management, operational oversight and accountability skills, coupled with core Systems Engineering competency and engineering instinct." [8]. This situates the need for leadership skills not in opposition to the traditional technical skills of an engineer but as a necessary extension required for successful collaboration and delivery of a technical project.

This capstone project course—known locally as 'Capstone'—is typically taken in the final year of a four-year engineering degree. It was re-designed in 2017 by one of the co-authors to achieve the goal of delivering real value to the community, including the client, the project team and other teams in the Capstone Project [21–23]. Capstone incorporates a student partnership model called the Many Eyes feedback process [22], where students, peers, academics, and clients participate in open review cycles of work. Teams benchmark their individual and team performance throughout and, at the conclusion of the projects, against a set of known project indicators. This process has been shown to be successful in delivering real learning value to students and enabling students to deliver real value to clients by balancing project outcomes and good governance [23].

"Real-world" student group projects within an academic learning environment can be challenging to deliver. Students are attempting to satisfice a range of known and unknown criteria as they balance their lived experience within the educational culture, such as a predominantly grade-focussed academic culture and a visible outcomes-focussed engineering culture [11]. This can often lead to a two-project syndrome: the project that is done for assessment, and the project that is done for the client. Although these factors can be aligned through course design, the important learning here for students is that a technical leader can balance the value for the project between stakeholders. This is a valuable lesson in professional practice, as outlined in accreditation frameworks such as the Washington Accord [11,12].

Design of the Technical Leadership Program

In Capstone, the primary activity is delivering a project for an external client. The main academic interaction is a weekly team meeting with a tutor working towards the client outcomes. The TLP was designed as a supplementary program within Capstone and TLP participants engaged in a 2-h workshop which ran for 8 weeks of a 12-week semester. No additional grades or rewards were given to participants of the TLP other than any benefits derived due to participation in the program.

Capstone is undertaken by between approximately 70–100 engineering students per semester in project groups of 4–6 students, involving approximately 10 h of participation per person per week. Each group nominates 1–2 students to be a part of the TLP program, with 14–22 students taking part each semester during the case study period. These data are shown by cohort in Table 1.

Table 1. Cohort data over the case study period.

Year (Semester)	Students Enrolled in Capstone	Students Participating in the TLP Program	Authors Participating in This Study
2019 (S1)	110	22	4
2019 (S2)	77	14	3
2020 (S1)	106	21	3
2020 (S2)	71	16	4
Total	364	73	14

Each week, a TLP workshop covered an emergent topic that was loosely aligned with the project progress aimed at facilitating opportunities for participants to develop their awareness of concepts in technical leadership. Topics included: meaningful project initiation; harnessing teamwork capabilities; understanding different leadership models; navigating and dealing with conflict; managing cognitive bias; empowering team effectiveness; benchmarking performance; communicating project outcomes; and developing a professional portfolio. Aspects of relevant theory were included to stimulate discussion when appropriate, such as the Cynefin Framework [24], the six thinking hats [25], the Johari window [26] and adaptive leadership [27,28].

Participants were typically asked to devise an experiment during each workshop as an informal action-learning experiment [29]. This typically involved implementing topics from the workshop in relation to their own team's project, and a report back to the group on insights gained from the experiment the following week. Hence, TLP participants would focus on the project work for most of their time allocated on the course and would augment this time with leadership experiments within the constraints of their team and the project requirements.

3. Case Study Methodology

A key philosophy of the TLP is the idea of 'learning together'. This indeed has been an underlying principle in the methodology of creating this paper. A former and current convenor of the program invited 3–4 representative TLP participants from the four cohorts shown in Table 1 to contribute to this case study. Participants were selected in anticipation of receiving a range of views, rather than on academic or any other performance measure, and were not paid, graded, or otherwise incentivised to participate in the case study. No invited participants declined to contribute to the paper.

Initially, participants were invited to contribute a 200-word reflection against a range of seven broad prompts: "How did the TLP help or hinder your . . . ":

- Understanding of your own team's performance;
- Collaboration with and learning from other teams;
- The process of benchmarking team activities;
- Effective leadership within the team;
- Consolidation of systems engineering knowledge;
- Transitioning to the engineering profession;
- Developing engineering skills and capacity.

Upon completion of the reflection, participants joined the authorship team and attended at least one of two workshops for the sharing of challenges and ideas brought up in the reflections. During these workshops, reflections were clustered by the authorship group, broad themes arising from the reflections were agreed and feedback notes were

formalised to develop ideas further. Individual authors revised and updated their contributions in relation to the workshop and subsequent feedback. Hence, this work shares the collective learning as staff and student partners [30,31] who explored this space as an area of inquiry over the two years of the case study period.

It was agreed by the authorship group that these contributions from participants should be presented as individual vignettes separated by a contextual statement. This format allowed the TLP participant's individual voice to come through in an area of consideration. It was also agreed that the vignettes would not be attributed individually, as the experience from the contributing author was often representative of others' experiences. Hence, this paper represents an authentic shared practitioner's report on the insights from the program.

4. Results

Four thematic themes emerged from the clustering of contributions, representing the areas in which the TLP had an impact on the participants. These were:

- Building awareness through technical leadership (7 vignettes);
- Identifying a personal repertoire of technical leadership (8 vignettes);
- Creating a common platform for collaboration (5 vignettes);
- Transitioning into a professional workplace environment (4 vignettes).

The following section discusses the key themes arising from the workshops, interspersed by reflective vignettes in each of the four thematic areas.

4.1. Theme 1: Building Awareness of Technical Leadership

The TLP was perceived as an additional forum to build awareness about emerging leadership styles, discuss ideas and share leadership experiences across groups. One benefit of the TLP is the opportunity to discuss issues within the team with an audience of peers outside of the team, allowing the participant to reconsider approaches and develop their own repertoire of leadership skills:

> *"I think one of the most valuable parts of the TLP was the opportunity to share our experience with other people and hear about their experiences in other groups. I tend to repeat leadership techniques that had been 'good enough' in the past without thinking about whether it was even the right kind of leadership, or how doing things differently might have improved outcomes for the team. In the TLP, I saw many concrete examples of the different ways of being a technical leader, which made me reconsider my approach. The TLP encouraged active reflection and I found that my awareness of what was happening in my group, and why, improved."*

This forum also served as an opportunity to share and then implement these leadership skills and applicable engineering approaches back to project teams, providing an important peer learning mechanism within the course:

> *"In my project, we were required to build a physical prototype for our client which required fostering collaboration and idea generation to produce a workable solution. The TLP really improved my awareness of processes and meeting client needs as there was constant sharing of ideas which helped everyone bounce off each other. This led to a more efficient final solution within my project team. Currently working as a project manager, it made me realise to always confirm with the clients what the needs are and always take feedback seriously as the smallest changes made can lead to big differences."*

The TLP has become an important space to exchange approaches for feedback. This in turn can help participants build awareness and develop strategies for managing aspects of their teamwork. However, implementing these ideas back into the team can be challenging, highlighting the difference of structured thinking around technical leadership between participants and non-participants:

> *"The TLP assisted me in having a platform to discuss solutions to internal team problems, such as teamwork, motivation, and internal friction. It provided me with insights and opportunities to benchmark the other team's progress, dynamics, and ideas for improvement. There were candid discussions and follow-up on how to motivate unmotivated team members: whether having a stern talking-to would help or even if they had that authority within the team. However, the nature of the TLP sessions meant it attracted the more motivated, diligent students. This increases the chances of inflating certain issues that 'non-TLP' students might not see as a problem."*

Part of this accountability of reporting back gave TLP participants an opportunity to experiment with and practise different leadership philosophies. Evolving an understanding of leadership and shifting mindsets is an indicator that a process such as the TLP has value to its members:

> *"I have always believed that a collaborative leader produces superior results than a controlling leader. Before I had the opportunity to be a part of the TLP, the traditional leadership style of "command and control" has been a proven and effective approach to complete quality university projects on time. There have been numerous projects in the past where I had adopted this approach due to a personal fear of allowing group members to work autonomously and because I knew this approach would work. Through the TLP, I became more aware of the type of leader I wanted to become, which was a leader that fostered collaboration and maximised the team's ability whilst positively encouraging everyone to challenge their limits."*

The TLP prompted participants to preventively tackle issues around team management and project outputs within the team for the participants. The development of a cohort of technical leaders positioned members to help each other with specific team-based problems and practice technical leadership skills and techniques:

> *"Hearing updates from other teams during TLP sessions made it possible to understand what issues groups can go through and develop some tactics to resolve these problems. This allowed me to make small adjustments to my own team's work to prevent similar problems. For example, some groups mentioned their struggles with the allocation of produced work. To prevent the same problem within my team, I included a Work Allocation section in the meeting minutes and a To-Do list with a checking system. From this, team members were able to easily track work and identify responsibility."*

The TLP supported building awareness around using a structured approach to manage team decision-making and performance, rather than employing intuitive techniques. Having a structure to follow also allowed for more efficient decision-making within the team:

> *"Through TLP I was able to gather key insights that would be applicable in assessing my team's performance from an objective standpoint. Previously, I approached teamwork and decision making with an ad-hoc approach, unsure of any structured frameworks. This unstructured method of decision making and teamwork made it difficult to assess the team's performance against a standard benchmark. We were able to use a structured benchmarking process when analysing the feedback received post-audits and subsequently improve our project work significantly."*

The TLP helped build a transferable skill set and an understanding that technical leadership needs to respond to the current context of the project. Different teams, and moving through stages of the lifecycle, provided opportunities to practise different leadership styles:

> *"I continued the same project from the last semester, but with a different team. This allowed me to witness the successes and mistakes of other groups in the first team, which I was able to use to help guide the second team. I had to adapt my leadership style with the new team, such as focussing on communication and avoiding micromanagement. During TLP, I was able to offer some guidance to the other team and impart the knowledge I had*

developed to help any team that was struggling in one aspect or another. To me, there was value in helping all teams to achieve high results from their respective projects."

Building awareness across teams and of different technical leadership concepts became a critical outcome of the TLP. This leads into the next theme, where we present views on identifying and developing a personal repertoire of practised leadership tools and techniques participants could use beyond the scope of the course.

4.2. Theme 2: Identifying a Personal Repertoire of Leadership

To develop a personal repertoire of leadership, the TLP encouraged participants to tailor generic tools to their individual situation. Hence, an important emphasis was placed on exposing participants to tools that would allow them to build their own strategies on how to approach internal team issues, such as improving performance through understanding team dynamics:

"The TLP helped improve my own leadership by introducing a balanced framework in which to think about performance. Prior to the program, I thought about performance in quite a traditional sense, in relation to project outputs. Completing these dashboards gave me (a) a more complete way to assess the team's performance and (b) a deeper understanding of the kinds of factors that influence performance. This allowed me to develop my leadership capability by focusing on improving team dynamics."

The timing of discussion of appropriate tools to intervene was also critical. By providing the right tools at the right time, participants could rapidly try out their ideas in situ to the project, which was crucial to further the outcomes of the project:

"The most important part of the TLP was the fact that we were given the tools and models and the opportunity to apply them in a real-world setting. This application enabled me to learn at an accelerated rate as I could synthesize, apply, reflect then reapply the learning in a setting with tangible outcomes. The teamwork and decision-making tools in the TLP allowed me to effectively communicate my thought process and ideas to my team members in the context of the project. By empowering me with knowledge of the problem we faced and ideas as to how to scope the problem, I found that I could apply the tools and be effective as a technical leader in the project."

The use of performance dashboards was one of the key tools covered in the TLP. These provided a useful way to help balance the perceptions of performance between team members. This was something that the participants could take back to their teammates and engage in a difficult conversation around issues within the team:

"Using the team dashboard from the TLP allowed us to understand and reflect on our progress using a common tool. We then use this to discuss each individual team member's perspective on the team's current position. This helped us in identifying specific weaknesses against performance criteria, to which we redirected our efforts. I was surprised to find that there was an actual dissonance between individual and team perception. It is important for all team members to aware of the team and individual perceptions of progress to bring all team members on the same page. I can envision myself modifying and implementing this approach of benchmarking when I am in the industry."

Though benchmarking was valued as a key takeaway for many in the TLP, the tools needed to be used carefully to be of value to the team. One important leadership attribute is having an objective view rather than an optimistic view, which could lead the team towards problems in the future:

"Progress indicators can be subject to interpretation and different team members might interpret their meaning in different ways. Not being objective with progress and accepting "looks fine" and "going well" as valid progress markers can be disastrous, as small issues compound into larger issues. My project was always benchmarked as "doing well", while I knew that aspects of the project had fallen behind schedule, as was the case for the software production and optimization. On reflection, I should have communicated with

the team more objectively about the output benchmarking, allowing for a more accurate reflection of the state of the project."

The approach of the TLP helped participants to consistently build awareness by "taking a balcony view" and to provide a safe space to experiment with different leadership and team management styles. This resulted in the sense of a safe space for participants to practice and implement their technical leadership skills:

"It is often difficult to take a view from the outside of a project you are involved in but sometimes getting this view is crucial in leading well. Putting my experience into an open forum, receiving feedback, and sharing ideas made reaching that viewpoint easier. I would often think "what would I do if I were in that situation?", or "what would I do if I encountered that problem?". Being in the TLP gave me a certain freedom to experiment with different approaches in a real project, free from the judgement of team members. This was valuable because there haven't been (and I doubt that there will be) other opportunities through my engineering studies to do something like this."

As the TLP was run in conjunction with an industry project, it provided a clear opportunity to build awareness around applying relevant industry approaches to project management and the importance of the self-benchmarking process:

"As engineering students, we are inclined to jump into problems and barrel our way through until we find a solution. Systems engineering makes us take a step back from this inclination and gives us the processes to regulate this, but we sometimes just go through the motions of these processes without seeing their direct benefit. The TLP sessions helped bring the importance of the known processes, and other processes, to the fore of the project. Most student projects are assessed by academics and tutors against the requirements of the course. The workshops in the TLP provided perspectives and advice on how to tailor our own objectives, conduct our own benchmarking, and demonstrate our performance against our project's requirements."

However, in some cases, participants found that the time and effort required to undertake the TLP was not of clear benefit to the project; time spent 'thinking' about the project is not spent 'doing' the project, and the overhead of time and effort required is not always clear:

"The TLP encouraged us to experiment with concepts and apply them to our team. I found it challenging to conduct experiments, such as learning a new skill, within my team. Each team member was brought onto the project with a purpose, to fill a role, and each member did so outstandingly. To disrupt their workflows in such a way would not have been of any benefit to my team. By allowing the team to continue their work as they saw fit meant that we were able to achieve predetermined milestones quickly, leaving room for us to achieve "stretch goals", optimisations, and successive iterations."

Further, in designing the TLP, care needed to be taken to help participants balance the short-term direct project outcomes versus long-term and indirect skill development:

"While I signed up for the TLP I did not participate until the end of the semester. This was because I felt my time could be better used in other ways to maximise my grades. While I can certainly see the value of the TLP, it was also quite time-consuming, which comes with an opportunity cost. My team decided this time could be better spent on the project and based on the success of our project. While it is possible that the long-term benefits of participating in the TLP could have been greater, at the time I was more concerned about my grades."

These reflections show that TLP was a platform for participants to develop their own understanding and repertoire of leadership within their project team, but also balance the priorities of a broader educational context. The following section discusses the value of forming collaborations across teams for generating ideas and understanding deliverables within teams.

4.3. Theme 3: Creating a Common Platform for Collaboration

The TLP helped build a sense of collegiality among the participants, and explored the importance of peer learning. Proactive reflection and the use of formative feedback to change the direction of the project or balance team dynamics was perceived as a key outcome from the TLP:

> *"Our team did not have a consistent leader throughout the project. The techniques learned in the TLP were dispersed amongst team members which benefited overall team cohesion in addition to decision-making practices. Critically reflecting on the way we distributed and completed tasks had the profound impact of allowing a dynamic leadership structure to quickly address conflicting decisions and create a far more efficient distribution of work based on technical expertise. This played a key role in delivering exceptional value in a highly technical project."*

The TLP allowed teams to develop autonomy and strategies on delivering the project, such as how to structure their team, leading to better project outcomes and better ownership of the outcomes and project progress:

> *"The TLP session that resonated with me the most was when we looked at team calibration and enablers. Specifically, linking the relationship between 'development maturity' and 'governance maturity' allowed the team to balance the various roles needed to effectively create the technical outcomes we desired, without the need for a hierarchical leadership structure or the need for extensive supervision. We decided to organise using a distributed leadership model into functional teams (i.e., electrical, mechanical, and biomedical), and to be flexible to change our roles if needed. Some members within each functional team would also take on governance roles."*

Further, opportunities for reflection helped build an understanding of managing technical processes requiring integration of the functional subsystems in the project:

> *"Involving the team within the benchmarking practice heightened our awareness of accountability towards the final project output. The team originally organised into separate technical subsystems but, through the TLP sessions, I was able to identify inefficiencies with the approach. While this structure allowed for a perceived faster completion of work, I could see that a "big-bang integration" approach did not allow for optimal subsystem combination. We were able to quickly restructure our team and adapt our specific systems engineering practice to what was needed at the time."*

Embedding the TLP alongside Capstone allowed participants to formalise intuitive methods for collaboration, allowing for process tailoring as changes and adaptions were made to suit the project:

> *"The TLP provided a great platform offering insight for people who are interested in leadership but did not have a lot of previous experience. The program was a great place for me to become aware of technical theories to some of the ideas that I intuitively used to foster collaboration, such as establishing a shared goal and vision for the project within the team. To achieve the best quality of the project my team made it a goal to be on the same page and proceed in the same direction for the rest of the project as early as possible."*

The TLP was also instrumental in providing detailed ideas to iterate and collaborate with all relevant stakeholders. Broadening the discussions and making the most of interactions with the experts was perceived as one of the key outcomes from the TLP sessions:

> *"Having the TLP sessions aided in navigating client interactions. The team lacked direction during the scoping stage and the client did not provide much initial information. The TLP sessions helped me to identify my interaction with the client. I learnt about probing and sensing to understand the problem space, and the technique to actively engage with the client had a big influence on improving the quality of these interactions. Client meetings went from 15-min updates to open discussions about the project. Learning*

> *how to probe and sense with the client, and identify their mental models of the problem, gave me valuable insight on how to change my thinking from 'I'm a student' to 'I'm an engineer'."*

Understanding the processes and deliverables associated with the project helped the participants to gather a set of transferrable skills, allowing them to make sense of the transition from student engineer to engineering practitioner. This transition is discussed in the final theme.

4.4. Theme 4: Transitioning into a Professional Workplace Environment

Many participants in the TLP were already active in the workplace as they moved towards graduation. The TLP became a mechanism to transition into a professional workplace environment. Skills that were abstract in the student project space became instrumental for success, reusable and transferable to the professional workspace:

> *"The TLP helped me get a grasp of the real engineering world and comprehend the opportunities for using a systems engineering approach. I learnt how to deal with clients and how to better integrate different design subsystems. I was able to learn from team members and share my experiences. This is a skill which has really helped me in the workforce in present day. I have been able to develop interpersonal skills which really helped build strong rapport with the colleagues in my current workplace. I think the TLP really helped transition from the student life to the professional work field as I was able to build on my engineering knowledge and incorporate it into the real world."*

Positioning the program as a transitional activity allowed for low-risk experimentation compared to the perceived higher-stakes activities in the workforce, providing a valuable opportunity for participants to develop skills they see as relevant in the workplace:

> *"I was able to draw connections between the low-risk Capstone project with my higher-stakes employment in my role as a defects engineer. Concurrently with the TLP, I managed a small team to rectify any construction defects with the responsibility of managing client expectations. The combination of theory and practice in both my employment and within Capstone reinforced these critical skills that I am applying as I start my professional engineering career."*

The skills developed through the TLP alongside Capstone helped with bridging the gap between student and professional activities, such as building team capacity and communicating within a team:

> *"The TLP additionally provided many new insights into the key strategies that engineers often use in improving their skills as a technical leader; skills around matching team roles and communications strategies to individuals' personality and teamwork traits and technical skills were particularly useful in structuring our Capstone team. These skills have continued to benefit me in industry work as it has allowed me to identify key technical vacancies within a team despite working in an entry-level role. The skills brought forward from the TLP sessions will undoubtedly play a major role in my work in any future leadership role, particularly in technically challenging projects where matching key technical skills with work packages becomes essential."*

Further, the TLP has been used to build identity and confidence around fields of knowledge. Valuing the skills that are developed as a student unlocks opportunities for collaboration, even in junior roles:

> *"The TLP helped me transition to the engineering profession as it showed me how systems engineering is critical in the technical fields in engineering. As a structure engineer in an aerospace company, I have noticed that the tools from the TLP commonly occur in everyday work. At work, most of my time is balanced between design, stakeholder requirements, output delivery and project management. I have incorporated these tools into my work practice as a junior engineer as it allows me to prioritise, adapt and collaborate with other people in a much larger company.*

> *"For example, when I am working on a task, I need to ensure that I gather all necessary requirements and conduct research before I produce an engineering report. The team that I work with is also very autonomous but there is fair and equal distribution of work, which is something that I believe that TLP highlighted to groups involved in Capstone."*

These reflections on the application of real-world skills covered in the TLP demonstrates that the TLP is a useful mechanism to help transition from the academic environment into a professional workplace environment.

5. Analysis

The reflections collated into the four themes, provide a rich tapestry of experiences from the participants in the TLP. To anchor this discussion, we consider the competency area of Technical Leadership in the INCOSE Systems Engineering Competency Framework [8]. In this competency area, indicators of knowledge and experience are described at five career levels, from 'awareness' to 'expert'. In its current form at the competency level, the indicators provided by INCOSE are not coherently categorized into attributes or characteristics for ready comparison.

To investigate how these competencies could be categorized for the purpose of comparison against the TLP, the indicators for Technical Leadership from the INCOSE Competency Framework across all levels were used as source material for a natural language processing experiment using Latent Dirichlet Allocation (LDA). This process is a form of unsupervised machine learning that seeks to find patterns in text and classify the text into topic areas [32]. Upon undertaking the analysis, six distinct topics describing activity were readily discernible from the text. The human-readable clustering of these topics is shown in Table 2.

Table 2. Topic clusters derived from LDA model.

Topic	Frequent Keywords for This Cluster in LDA Model
Engineering Leadership	engine *, system *, technic *, enterpri *, lead, active *, within, leadership, beyond *, trust
Self-Awareness	critic *, construct, self, accept *, challeng *, offer *, remain *, whilst, improv *, use *
Empowering Others	enable *, empow *, success *, enterpri *, boundary *, beyond *, within *, engine *, system *, lead *
Collaboration	system *, leadership *, central *, explain *, engine *, collabor *, goal *, project *, strategi *, foster *
Creative Solutions	project *, innov *, problem *, appli *, creative *, solv *, technique *, enterpri *, issu *, strategi *
Team Building	success *, explain *, vision *, mutual *, technolog *, trust *, integr *, engine *, creative *, appli *

Note: Asterisks (*) indicate word stems generated to assist with topic clustering. For example, "engine *" could refer to topics building from that stem, such as 'engineer', 'engineering' or 'engineered', but also 'engines'.

If we accept these topics as a reasonable approximation of the activities of a Technical Leader, then it is possible to consider these in relation to observations in the themes in the TLP outlined in the previous section. To illustrate this, Table 3 shows the Topics derived from the INCOSE Competencies for Technical Leadership, mapped to the four themes from our reflections. Within each cell is a demonstrated activity from the reflection that has been mapped to describe a relevant intersection.

In the context of this case study, this mapping activity is, of course, not a definitive, objective mapping. As the INCOSE Competency Framework is an indicator-based tool, the topic mapping is prototypical. Further, the subsequent mapping to our themes is in no way definitive and merely illustrative of one way that participants in the TLP have demonstrated activities in the relevant topic. However, caveats aside, this does suggest the relevant nature of the relationship between the activities undertaken in the TLP and its relevance to the Technical Competency in the INCOSE Competency Framework. From this perspective, it is reasonable to claim that the TLP activity has helped to build awareness of the nature of Technical Leadership across the participant cohorts.

Table 3. Mapping of Topics to Themes using Reported Experiences.

Topic/Theme	Building Awareness	Personal Repertoire	Platform for Collaboration	Transition to Profession
Engineering Leadership	evolving leadership practice	having challenging conversations	formalizing intuitive methods	low-risk opportunity to experiment
Self-Awareness	benchmarking processes	benchmarking performance	team-based reflection	recognizing real-world parallels
Empowering Others	motivating others	scaffolding internal reviews	methods for distributing work	matching roles to personalities
Collaboration	sharing leadership techniques	finding new perspectives	navigating client relationships	managing stakeholders
Creative Solutions	avoiding problems	applying tools and framework	managing technical integration	meeting expectations
Team Building	developing team efficiencies	identifying strengths and weaknesses	balancing multiple strengths	building rapport in the workplace

6. Discussion and Further Work

This paper establishes technical leadership as an applied skill that engineering students learn through a series of self-determined inform experiments. The broad design of a supplementary program such as the TLP is a transferable outcome to others teaching at the interface of academia and industry. The four themes identified in the writing process represent four waypoints for the ongoing design of the journey in Capstone. It is worth recognizing that the program itself is a demonstration of technical leadership, where the journey for cross-sectional groupings across career stages was collaborative, tailored and empowering.

Further work needs to consider deeply the point of concern raised by participants around the overheads for participating in the TLP. Indeed, the staff involved have had similar discussions about the overheads for the program themselves and the resources that are required to run it effectively. This is especially relevant when convenorship changes, or if a program such as this were to be provisioned in other project courses. Our experience has been that benefits outweigh the overheads, but careful design needs to ensure that supplementary programs support student learning and not burden students and facilitators with extra time or project demands. Further, the value of learning technical leadership skills earlier in the degree of a university program is unknown but has the potential to significantly change the quality of student leadership that arrives at Capstone level.

The collegiate nature of the TLP can also be seen as antithetical to some aspects of academic practice. For example, the very idea of collaborating across groups could be seen as unimaginable for traditional examination models, where examining individual knowledge is prioritized over developing collective learning. Further work should examine the effect of a supplementary leadership program in different models of capstone projects, other significant projects such as individual research projects, or indeed different program models, such as mentoring programs.

7. Conclusions

This paper described a case study involving a supplementary technical leadership program as a mechanism to support the development of technical leadership skills in parallel to capstone engineering projects. Participants from four cohorts of the program were invited to reflect on their experiences. These experiences were categorized into four interdependent themes: building awareness of technical leadership, identifying a personal repertoire of technical leadership; creating a common platform for collaboration; and transitioning into a professional workplace environment. These reflections can be mapped

to technical leadership competencies, demonstrating applicability of skills development in this area. Further work is required to explore its applicability to different contexts.

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