Translational Engineering Education: A New Paradigm for Preparing Next-Generation Engineers for the 21st Century Workforce

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Truong Q. Nguyen received the B.S., M.S., and Ph.D. degrees in electrical engineering from the California Institute of Technology, Pasadena, in 1985, 1986 and 1989, respectively. He was with MIT Lincoln Laboratory from June 1989 to July 1994, as a member of technical staff. During the academic year 1993-94, he was a visiting lecturer at MIT and an adjunct professor at Northeastern University. From August 1994 to July 1998, he was with the ECE Dept., University of Wisconsin, Madison. He was with Boston University from August 1996 to June 2001. He is currently a Distinguished Professor with the Electrical and Computer Engineering (ECE) Department, UC San Diego.

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He received the Institute of Electrical and Electronics Engineers (IEEE) Transaction in Signal Processing Paper Award (Image and Multidimensional Processing area) for the paper he co-wrote with Prof. P. P. Vaidyanathan on linear-phase perfect-reconstruction filter banks (1992). He received the National Science Foundation Career Award in 1995 and is an IEEE Fellow (2005). He received the Distinguished Teaching Award at UC San Diego in 2019. He served as Associate Editor for IEEE Transaction on Signal Processing, Signal Processing Letters, IEEE Transaction on Circuits & Systems, and IEEE Transaction on Image Processing. See his research publication at Google Scholar.

Prof. Nguyen is passionate about teaching and mentorship, creating initiatives that prepare students for career success. During his term as ECE department chair, with the help of faculty and students, he spearheaded the Hands-on curriculum, Summer Research Internship Program (SRIP), and the Summer Internship Prep Program (SIPP). He also co-created the Project-in-a-Box (PIB) student organization that brings hands-on curriculum to K-12 students. He is the Co-PI of an NSF grant to develop an engineering program consisting of hands-on technical curriculum at Imperial Valley College. He also collaborated with the Inclusive Engineering Consortium (IEC) on developing a graduate pathways program.

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Defining Translational Engineering Education: A New Paradigm for Preparing Next Generation Engineers for the 21st Century Workforce

Phuong Truong, Truong Nguyen, James Friend, Alex Phan

Abstract

This **theory paper** introduces *translational engineering education* (TEE), the concept of supporting students as they translate the education they receive into valuable real-world skills and practices as engineers. Traditionally, scientific discoveries—especially in medicine and biology—were *translated* to practice, providing societal benefit. Recently, the idea has expanded to encompass computer science, business, and even education, serving to define the process of applying theory and abstract concepts to producing imminently useful skills in solving practical problems. This ability is intrinsically implied in engineering, as the discipline is, by definition, a translational one. However, there are benefits in clearly defining a formal framework of TEE in the context of higher education. Without such a framework, engineering curricula are often defined *ad hoc* and on the basis of tradition, forming pedagogical gaps in translational training that students end up having to overcome later while on the job, putting them at a disadvantage in a globally competitive workforce. We define a framework for the process of translating engineering education to practice with TEE five stages: (T0) foundational knowledge; (T1) translation to theory; (T2) translation to projects; (T3) translation to practice; (T4) translation to community. These stages are anchored in established educational theories, such as the experiential learning framework and Bloom's taxonomy, providing a grounded approach to understanding and implementing TEE. We illustrate the utility of this definition with examples from our engineering program, showing how it can guide the assessment and enhancement of course offerings to better equip students with the practical skills and knowledge they need. Furthermore, we discuss how engineering programs and their leaders can use our TEE framework to align their curricula with the demands of emerging technologies and market trends, ensuring that graduates are prepared for the future of the industry. This paper aims to redefine engineering education, offering a new lens through which universities, department chairs, and faculty can prepare, evaluate, and train engineers for the challenges of the 21st century.

Introduction

The rising cost of college education and the accompanying increase in student debt over the past decade have become major public concerns [1-5]. While a college degree can lead to many benefits [6], the rise of online course providers such as Coursera, edX, MIT OpenCourseWare [7] call into question whether the same knowledge and skills can be acquired more economically and effectively elsewhere [7-10]. As Rose [10] put it:

> "If college does not lead to skill gains, it is difficult to argue that attending college will lead to positive economic effects after graduation [10]."

Universities have been seeking to increase the value of their degrees through many measures, including accreditation [11-13], improving rankings [14-16], supporting research [17-18], upgrading infrastructure and facilities [19-20], expanding industry networks [21-22], and implementing student success programs [23-24]. Engineering programs, in particular, grapple with added issues like high dropout rates due to inadequate academic performance, insufficient preparation, and a lack of belonging among students. These issues underscore the critical need for educational programs to ensure their offerings align with their stated objectives and the real-world experiences of their students. Specifically, for engineering programs aiming to drive innovation in the workforce, it is vital to establish a framework that guides course selection, initiatives, faculty involvement, and resource allocation toward achieving this mission. Despite engineering's significant role in transforming ideas into practical innovations, there is a notable absence of such a framework to direct engineering education programs to fulfill industry and societal demands. Consequently, the gap between the competencies required by industry and the skills students acquire in the classroom is widening.

Originally, the term *translational* was used in medicine to describe the process of moving scientific ("benchtop") discoveries to ("bedside") patient care [30-31]. Recently, this term's use has moved beyond medical innovation. For instance, in 2019, Abramson and Parashar introduced the term *translational computer science* to describe the transition of applied computer science research into wider adoption [32]. Similarly, in 2020, Corbo *et al.* [33] proposed a framework for integrating "knowledge translation" into business development for entrepreneurial teams.

In engineering education, Veety *et al.* [34] launched the *Translational Engineering Skills Program* (TESP) in 2014, aiming to equip graduate students with translational skills such as systems thinking and entrepreneurship. Stephan *et al.* [24] labeled their efforts in improving retention within engineering programs as *translational*. Turns *et al.* [35] focused on enhancing instructional practices for better learning-practice alignment as a translational pedagogy in engineering. Drawing inspiration from the traditional translational model in medicine, Ogle et al. discussed translational, project-based learning to bridge theory with practice via global challenges [36]. The literature in engineering education shows a natural parallel between *benchtop to bedside* in medicine and *theory to practice* in engineering. However, despite these analogies, the literature lacks a formal definition of *translational* within the educational context, relying instead on a conceptual similarity that has yet to be fully articulated.

We present a comprehensive definition of *translational engineering education* (TEE), drawing from existing literature and our insights into the transfer of skills from engineering education to the real world via students. Our goal is to establish a clear and formalized understanding of this concept together with a framework in which one may evaluate a given program's effectiveness in translating what students learn to skills and practices useful in their roles as engineers.

Translational Engineering Education Definition and Framework

In this work, we define the term *translation* within engineering education as

> **The process of transferring or applying skills, knowledge, and experiences of students towards social benefits.**

This definition is synthesized from the informal use cases emerging in the literature [30-36] and our own collective teaching experiences within an engineering program. We next demonstrate how the formal definition and an associated framework can collectively help to determine how to increase the useful and incremental translation of skills learned by a student within an engineering program to eventually benefit society.

Theoretical Foundation: Bloom's Taxonomy and Experiential Learning

To create a translational framework from the definition of TEE, we first ground our work upon Bloom's Taxonomy and experiential learning theory. Bloom's Taxonomy, introduced in 1956, organizes cognitive skills into a hierarchy from basic to advanced levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. This framework helps educators design learning objectives that target specific cognitive skills [37-38]. The taxonomy was updated by Krathwohl [39] to include revised categories: remember, understand, apply, analyze, evaluate, and create, in ascending order of cognitive complexity. Since its inception, Bloom's taxonomy has been instrumental in ensuring that educational assessments are aligned to learning objectives [40-41].

Course objectives articulate the intended engagement of students with the material, guiding how they interact and learn. For instance, a statics course might aim for students to "understand the principle of transmissibility and the line of action," leading to assessments focused on understanding these concepts. Conversely, if the objective is to "analyze and solve problems using the principle," assessments will challenge students to *analyze* and *apply*, demanding a deeper level of cognitive engagement with the material and enhanced problem-solving abilities from the students. The crafting of course objectives, reflective of broader program aims, is crucial for the success of a translational model that aligns educational outcomes with overarching program goals.

Experiential learning is essential to the education of aspiring engineers. Engineering combines theory with practical application, requiring a learning approach that encompasses both for the sake of societal safety and integrity of the solutions engineers provide. Experiential learning offers a diverse array of learning opportunities grounded in real-world experiences; in engineering education programs it is usually manifested as hands-on projects, laboratory courses, capstone design projects, internships, participation in student organizations, and student-led competitions. Such experiences enable students to actively engage in problem-solving and critical thinking in an environment approximating their likely role in society after completing their degree, enriching their understanding of the field and the value of the esoteric theory they learn in the program. The recent proliferation of *Makerspaces* and rapid prototyping facilities at educational institutions [43-44] underscores the growing value placed on experiential learning within engineering education [46-47], indicating a significant shift towards more immersive and practical learning methodologies. Consequently, the authors consider experiential learning important in building a translational engineering education model.

Translational Engineering Education at the *Jacobs School of Engineering*

Drawing from the composition of our own engineering program at UC San Diego's *Jacobs School of Engineering* combined with Bloom's taxonomy and the value of experiential learning, we define the framework for TEE as shown in Fig. 1. The framework naturally divides into five stages, with the cognitive skills *commonly* used in each stage of the process. In this framework, our goal is to enhance the transfer of skills and experiences of engineering students in our program toward societal benefit, prioritizing student learning as an aligned series of experiences from foundational knowledge to theory, application, practice, and onward to the real world. The stages are as follows:

- **Foundational Knowledge (T0)**: The requisite universal skills needed for engineering such as critical thinking, comprehension, mathematics, and basic sciences. These skills are developed prior to entering college and in early fundamental math and basic science courses.
- **Transition** (⇆): Learning experiences that support transition between T0 and T1
- **Theory (T1)**: A translation of foundational knowledge to theory, with a list of the cognitive skills relevant to training students on theory.
- **Transition** (⇆): Learning experiences that support transition between T1 and T2
- **Projects (T2)**: A translation of theory to projects, with a list of the cognitive skills relevant to training students on experiential learning.
- **Transition** (⇆): Learning experiences that support transition between T2 and T3
- **Practice (T3)**: We describe how project experiences move to practice through internships and applications and list the relevant cognitive skills associated with T3.
- **Community (T4)**: Students apply their skills from internship experiences to their careers and real world practices with the goal of serving society.

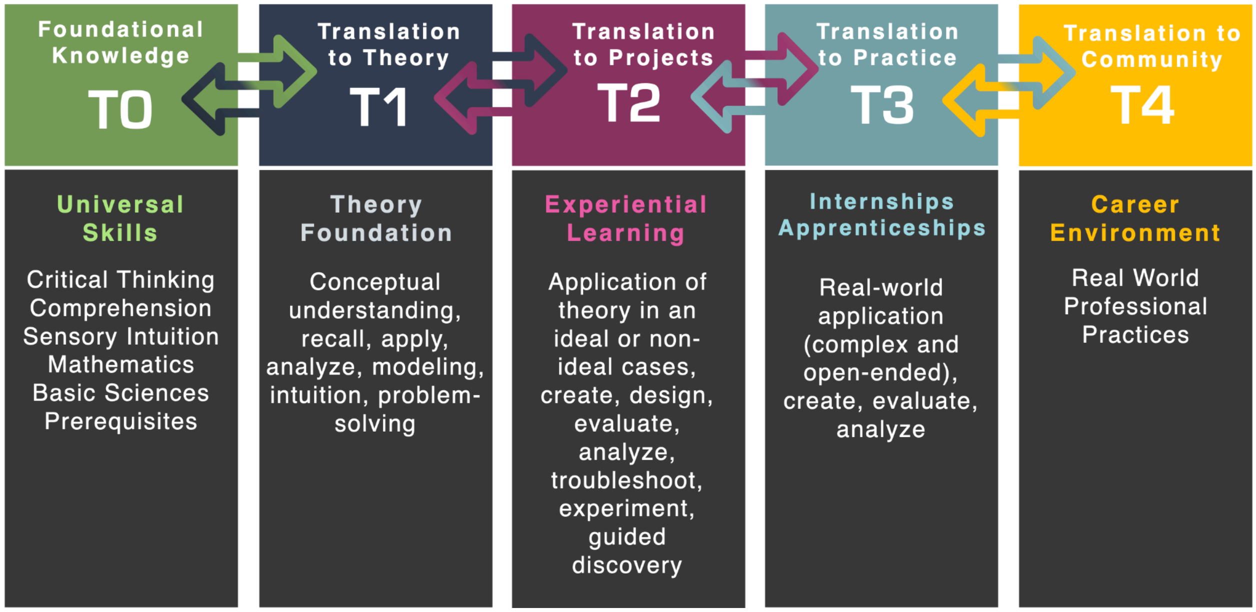

Fig. 1. The *translational engineering education* (TEE) model describes the five stages of translating student skills to societal benefits.

Our framework extends beyond its five defined stages by emphasizing the critical role of *interconnectedness*, as illustrated in Figure 1 by the symbol ⇆, which signifies seamless transitions between stages. For instance, an experiential learning course should build upon the theoretical knowledge from previous courses to enhance and further develop analytical skills, rather than existing as an isolated experience.

We advise that experiential learning courses designed as introductory or overview sessions, which do not incorporate theoretical foundations, should be viewed as transitional phases (⇆) rather than as part of the second stage (T2). In the T2 stage, experiential learning should involve students either individually or in groups completing projects that engage advanced cognitive skills like analysis, evaluation, and creation. These projects should compel students to apply theories in practical contexts, such as using principles from statics to calculate the maximum load a bridge made of wooden sticks can bear. If students do not apply theoretical knowledge to these practical challenges, the activity serves more as a primer for theoretical application, marking a transition towards T2 rather than embodying T2 itself.

Furthermore, a notable gap often exists between the theory-focused T1 and the application-oriented T2, as well as between T2 and the industry-aligned T3 stages in engineering education. Courses in the theoretical domain are typically designed by faculty with a deep interest in theory, while hands-on, experiential courses are developed by those with a preference for practical teaching approaches. This division can create a disjointed learning experience, where students struggle to bridge theoretical knowledge with practical application. This misalignment becomes particularly apparent in industry-supported programs and internships, which require a skill set not fully covered in the earlier T1 and T2 stages.

We also introduce the concept of *loss* via the framework, referring to the diminished effectiveness of the educational program when courses fail to build upon previous skills and knowledge. If too much time has passed, previous knowledge is never provided, or there is a lack of continuity, students will struggle to compensate for the cognitive gap in the program. Instructors are forced to review prerequisite material or students are forced to independently learn or relearn the material [48]. It is important for courses to be coordinated in constructing a body of student knowledge and experience upon past material to translate the skills onward towards eventual use, preventing loss.

Program-Level Analysis

We next utilize the TEE model as a framework to analyze skills transferred within our engineering program. An important and significant point to note is that there will not be enough time and resources for any engineering program to comprehensively produce good results in all five stages for all skills. A broad range of skills and knowledge are important and not all require translation. Thus, in program-level analysis, faculty and program leaders can look at their course offerings holistically to observe the movement of a ***targeted*** skill down the translational pipeline. We recommend targeted skills be the ones in line with the program's mission and goals for its students. We provide below a hypothetical example (Fig. 2) of classes from a mechanical engineering program with the goal to produce students possessing design skills.

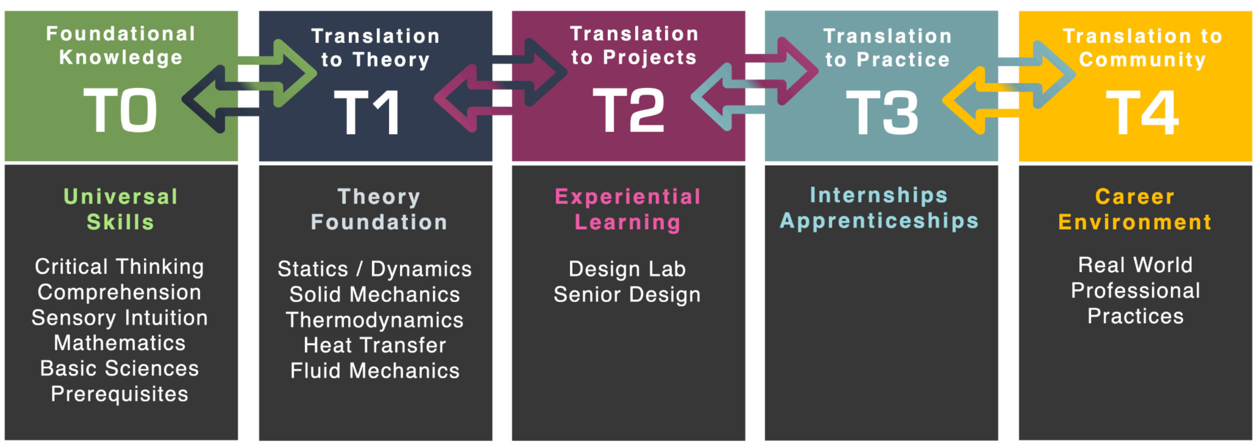

Fig. 2. An example of a program-level view of a hypothetical mechanical engineering program with the goal of producing students with design skills.

In this hypothetical scenario, we work backwards from T3, with a senior design course with a project that requires students to design a combustion engine in collaboration with an industry partner. The project may draw from a student's experiences from their mechanical design lab, senior design, and theory classes such as thermodynamics, heat transfer, and fluid mechanics. From a holistic view, one can observe that students have very limited experience synthesizing these subjects and limited experience in experiential learning to move the skills out of T1. Thus, students may feel underprepared, lost, and require a significant amount of support to create a meaningful experience out of the project. If the program identifies that job growth in the automotive engines industry is in demand over the next decade, it may respond by increasing T2 courses and T3 opportunities in this area of study. The response may include a more holistic and multi-prong strategy, employing student success units, courses, and student organizations to increase the translational pathway. It is important to note that while nearly all accredited engineering programs possess these efforts, misalignment may occur without a framework to align initiatives towards student learning goals.

Course-Level Analysis

The authors use two courses to demonstrate an example of how the translational model could be used by faculty and instructors to evaluate the translational characteristics of their course. The two courses presented are: ECE 144: *Labview Programming Design and Applications* (an experiential learning course) and MAE 150: *Computational Methods for Design* (a theory-based course). This analysis investigates the degree of translation built into the courses to enable students to translate (practice) skills covered in them.

ECE 144: Labview Programming Course-Level Analysis

ECE 144 is a quarter-long (10 weeks) upper-division experiential learning course within the Electrical and Computer Engineering Department designed to teach students LabVIEW programming with applications into system integration and hardware. The course's pedagogical composition employs a blend of evidence-based practices such as hands-on labs and projects (experiential learning), peer-to-peer learning, and polling (student response quiz questions with class discussion on answers). At the end of the course, students build a completed physical LabVIEW-based system and present their work at an industry showcase organized by the instructor. Outstanding projects and student teams are selected by industry to interview for internships after the showcase. Students complete the course by taking the Certified LabVIEW Associate Developer (CLAD) exam to certify their skills and receive a certificate from National Instruments. The passing rate of the CLAD in the course averages 80% among 15 cohorts of students (approximately 30-35 students per cohort). It is important to note that the instructor organized the course, showcase, certification exam, and interviews all within the context of the pedagogical strategies used to increase translation in the classroom.

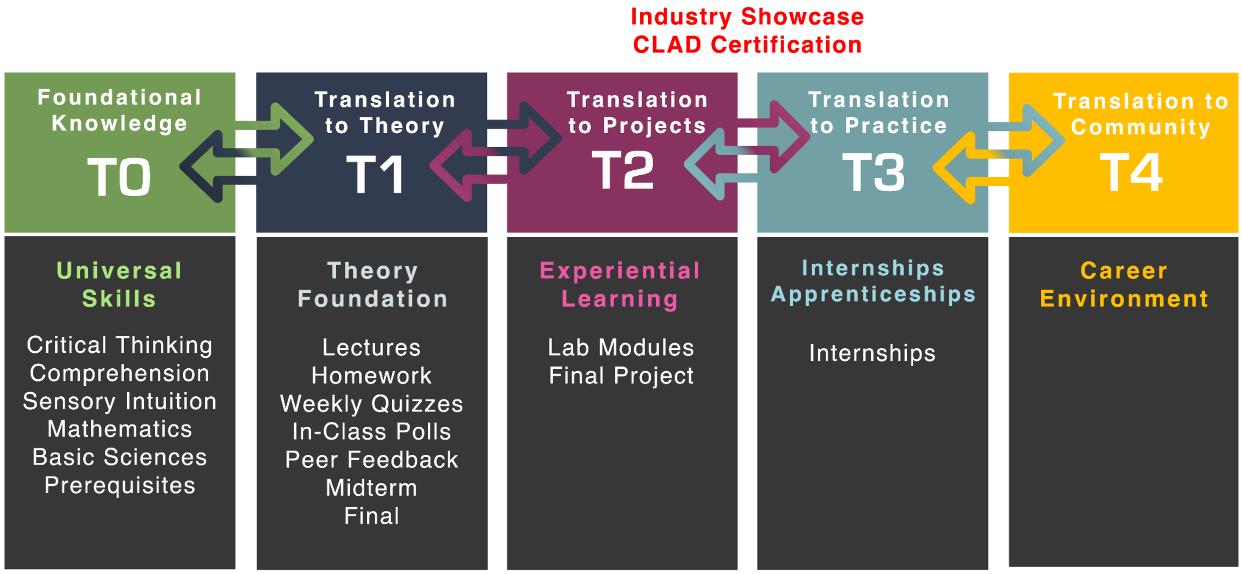

Fig. 3. Translational analysis of ECE 144 and its pedagogical composition to translate skills between TEE stages.

In Fig. 3, we look at the translation of T0 to T1 stages, where foundational skills (prerequisites), such as programming and math are used to help them understand the LabVIEW language. The course employs lectures, homework, weekly quizzes, polling, and exams to reinforce T1 stage so that students learn and apply LabVIEW programming. In the next stage, we look at the translation from T1 to T2, where students must successfully deliver a completed LabVIEW system and their accompanying lab modules. Students apply themselves in this stage and overcome intermediate drawbacks to submit a final completed and working system. Next, we evaluate at how the course enables students the opportunity to translate to practice via internships. Note that transitions (⥃) are distinguished from the stage itself. Transition arrows indicate opportunities such as the industry showcase, CLAD Certification. In order to increase translation to T3, students must acquire an internship and perform LabVIEW in practice. The authors note that while not all students will take the opportunities beyond T2, that the course instructor organizes all components from T1 to T3 as apart of the pedagogical strategies contained in the class. Thus, ECE 144 provides an excellent example of a course composition that provides key opportunities and translational pathways for students to take their basic skills to real world practices and career environments. The final translational degree results in T0 ⥃ T1 ⥃ T2 ⥃ T3 for ECE 144. The authors note that while internships may exist outside of the class for students to pursue, in order to achieve a particular stage in class evaluation, the class itself must provide the opportunity. In this case, the showcase, interviews for internships, and certification exam was all organized by the instructor and a part of the pedagogical strategies contained in the class.

MAE 150: Computational Methods for Design Course-Level Analysis

MAE 150 is a senior-level upper division course in the Mechanical and Aerospace Engineering Department that teaches students various computer aided design (Solidworks), design methodologies, linkage analysis, cam dynamics and analysis, finite element analysis, and more. The course consists of lectures, homework, midterms, and a final. Students are provided the opportunity to listen to industry and academic guest speakers on design, observe in-class demonstrations, and review case studies and examples of real-world engineering.

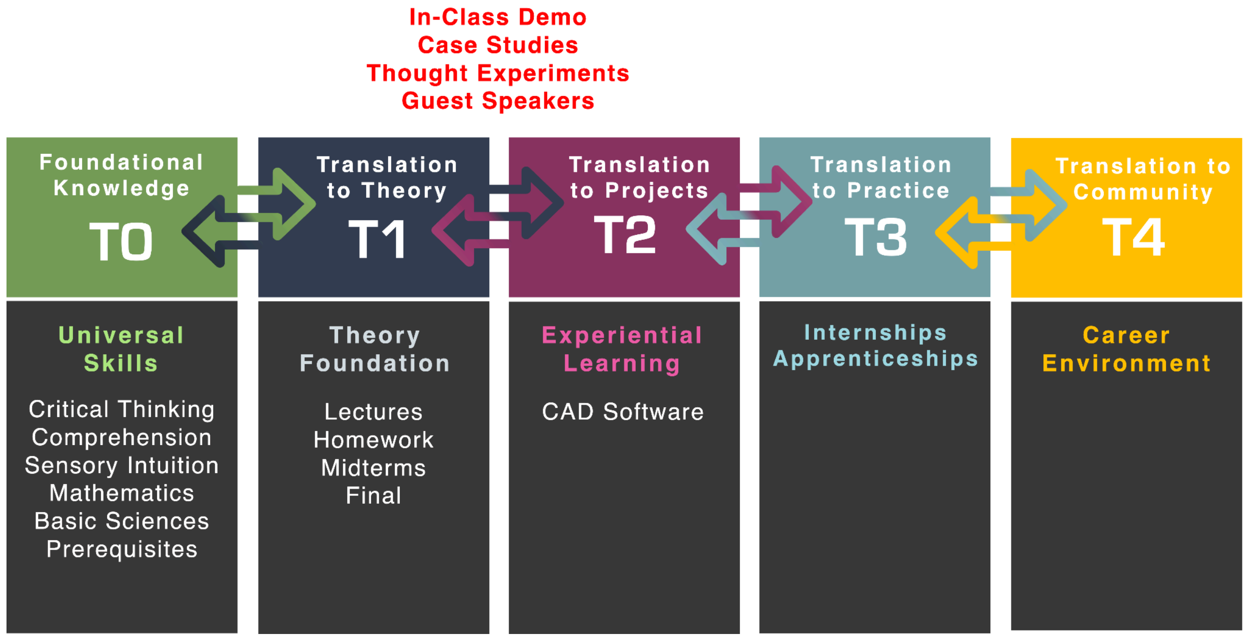

Fig. 4. Translational analysis of MAE 150 and its pedagogical composition to translate skills between TEE stages.

In Fig. 4, the lectures, homework, midterms, and final draws from students prerequisite knowledge from math, physics, and prior engineering courses to transition from T0 to T1. Students are taught theory using traditional lecturing methods and provided a course reader. To improve students' transition (⇋) to the next stage, in-class demos, case studies, applications, and observation are provided. While these aspects are added to enrich students experiences, students do not completely attain on T2, but rather arrive at a transition (⇋) due to the lack of experiential opportunities for most topics. Outside of the computer aided design (CAD) software used in homework assignments, students do not employ theoretical knowledge to deliver projects. Thus, the highest level of translational degree is **T0** ⇋ **T1** ⇋ T2 for MAE 150. Based on these results, the instructor can directly focus in areas or change instructional practices to include more translational stages or transitions. These results will differ from instructor to instructor depending on pedagogical practices. Faculty and instructors are encouraged to utilize this model to emphasize specific skills and knowledge by increasing translational opportunities for each stage and transition.

The authors note that pure experiential learning simply means that the course possesses T2 while removing the T1 stage altogether. For courses with only experiential learning, the analysis may begin with **T0** ⇋ **T2** or **T0, T2** or simply **T2** which denotes either the experiential learning leverages fundamental knowledge to achieve experiential learning, or keeps fundamental knowledge and the experiential experience unrelated, or only provides experiential learning, respectively. Transitions and interconnectivity is crucial to the purpose and use of the model as students' ability to connect concepts and knowledge between courses can improve efficiency in the translational process and reduce knowledge gaps and disparities between learning experiences.

Student Success Perspective using the TEE Model

As shown in Fig. 5, unique to the translational model are not the stages themselves but the transitions (⇆) between the stages. Areas of interest and gaps within an engineering program can be identified by looking at the transitions of the translational model. For example, how does preparation gap affect how students students transition (⇆) from T0 to T1? Do difficulties translating T0 to T1 lead to program attrition? Does the preparedness of students in their last year determine if they will take another year to complete their program (perhaps waiting for an internship)? Using the model can help guide student success units to respond to gaps and needs within the program while aligning with program goals and keeping student learning at a focal point.

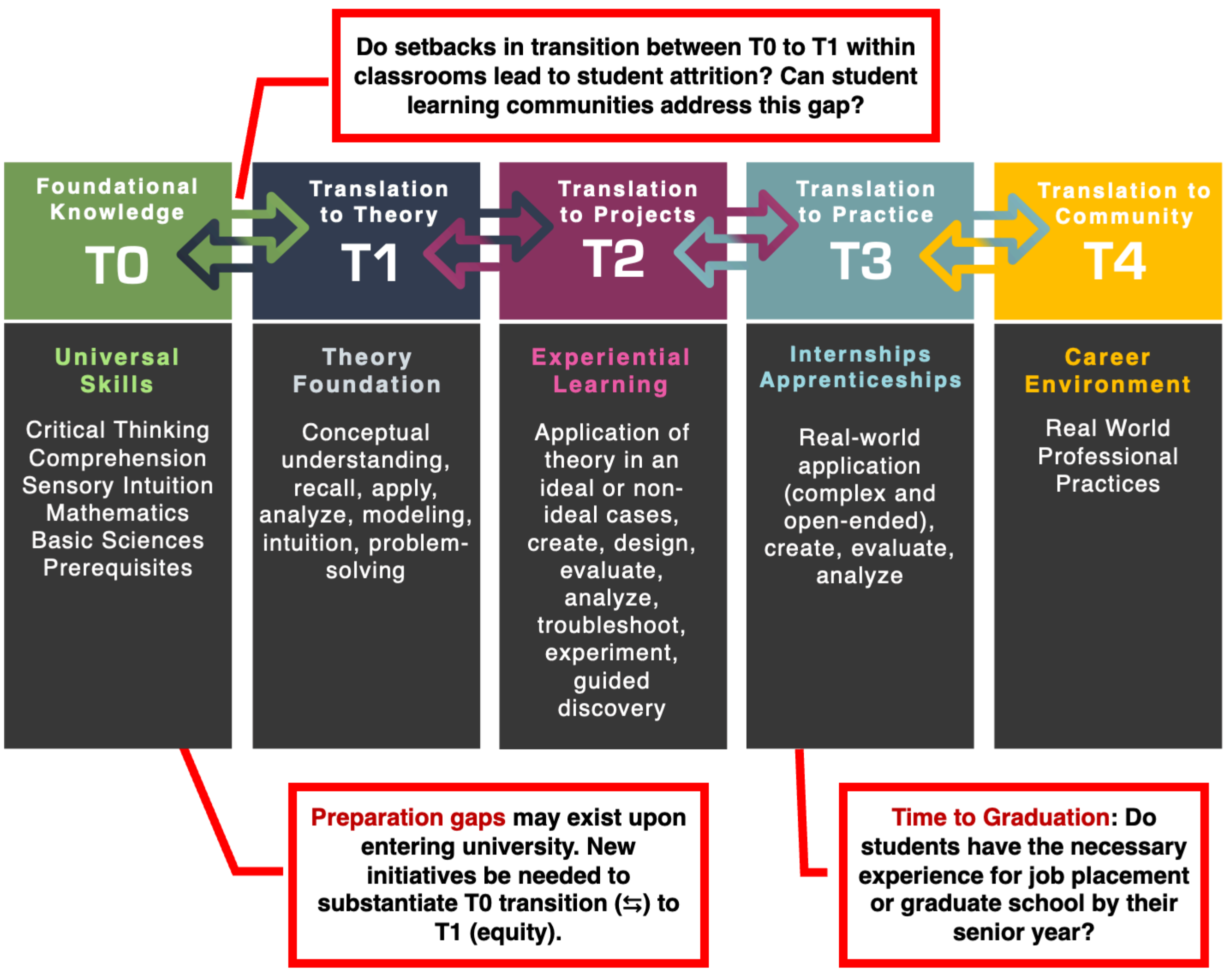

Fig. 5. Translational Engineering Education model can be one way to look at student success areas to divert or direct program resources and focus areas during strategic planning.

Discussion and Conclusion

We provide a definition and framework for analyzing engineering programs at the course level and program level. It serves as a framework that will continue to evolve as new pedagogy and cognitive frameworks help us better understand how students learn and how programs can help create environments and classrooms to cultivate student success. As a tool, the framework can be used by faculty leaders, department chairs, and university leadership to optimize and align their initiatives towards program goals.

We encourage departmental chairs, deans, student success units, and university leadership to utilize the framework to determine and uniquely predict workforce demands and competitive skills required of graduates and focus their energy and efforts on those targeted competencies within their program. We recognize the need for broad experiences and topics within an engineering program, and recommend increasing translational experiences in engineering degrees to provide the important skills required in the workforce to increase job placement and program goal achievement.

Minimizing loss, increasing goal alignment, and improving student translational skills are all goals of the translational engineering education model. We recognize that programs and courses are constrained by time, resources, and the ever increasing student to teaching team ratio. Thus, to prepare our engineers for the 21st century workforce will be no easy task. Campus and program leadership will need to view learning and goal alignment as a cumulative effort among courses, student organizations, student success programs, career centers, and more. Using the TEE framework provides a powerful instrument for alignment with outcomes focused on student learning that will fuel the strength of university degrees and the value of higher education to society.

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