The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #43538

A New Personalized Learning Approach Towards Graduate STEM Education: A Pilot in Chemical Engineering

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Abstract

Over the past two decades, there have been calls to develop and deploy graduate STEM education models that prepare students for careers outside academia. Few innovations have emerged to meet students at their current skill and preparation levels when entering their graduate studies while also considering students' individual desired career paths. The U.S.'s current approach to graduate STEM education does not emphasize preparing students with professional skills and experience outside the lab. Further, students from differing socioeconomic and underserved backgrounds are often not adequately supported. Through a National Science Foundation Innovations in Graduate Education (IGE) award, the University of Pittsburgh Swanson School of Engineering is creating and validating a personalized learning model (PLM) for graduate education within the Department of Chemical and Petroleum Engineering. This model aims to transform and modernize graduate STEM education through a personalized, inclusive, and student-centered approach, which will, in turn, advance existing knowledge on the relationship between personalized learning and student outcomes.

The principles of personalized learning guide the PLM. It is comprised of five components. The first three components provide an intentional approach to learning: *Instructional Goals* developed for each student based on a learner profile and individual development plans (IDP), a purposeful *Task Environment* that breaks the traditional three-credit coursework into modules and co-curricular professional development streams, and a resolute approach to *Scaffolding Instruction* that leads to mastery in the student's area of focus. The last two components provide feedback and reflection: *Assessment of Performance Learning* quantifies students' progress, and *Reflection and Evaluation,* where improvement opportunities help the student to develop further. Incorporating personalization at every touchpoint of a graduate student's academic journey creates an authentic, customized, student-centered approach to graduate education. This paper describes the model, the literature behind its development, and the assessments used to guide students.

Introduction

Graduate STEM training and career preparation has historically followed a "one size fits all" approach that is narrowly focused on research skills, adapts slowly to emerging trends, and provides professional development primarily for academic careers. This approach limits an institution's ability to prepare students for the requirements of the 21st-century workplace, which increasingly requires students to translate their knowledge beyond traditional disciplinary boundaries and pursue novel opportunities by switching jobs. [1] Further, it largely disregards that students have different starting points upon entering the graduate program, which reflects not only the student's academic preparation but other aspects of their background (e.g., socioeconomic, sociocultural, prior work experience, professional development), resulting in a lack of inclusivity.

In contrast to undergraduate engineering education, the pedagogy of graduate education needs more attention. Progress is reported in increasing diversity and inclusion, enrollments, graduate bridging programs, [2] preparing graduate students for teaching, [3] interdisciplinary graduate programs, certificates, new courses, working with industry, [4] preparing for non-content-oriented materials (e.g., communication skills), [5] and life beyond graduate school. [6] However, little research has been reported on advancing pedagogy in the graduate space. [7,8] Reports have outlined the need for innovation in STEM education at the undergraduate and graduate levels over the past two decades. [1,9] Although STEM education research has flourished, there has yet to be equal activity in the propagation of these innovations, as the National Research Council (NRC) highlighted. [10] The NRC called for the propagation of engineering education research into practice, including adopting evidence-based practices. Further, the need for more successful propagation has also been highlighted by an ASEE report [11] that included an appeal to funding agencies to use resources to propagate better efforts that have proven successful. Although educational innovations have been produced over the past few decades, Rogers highlights a need for knowledge of how to implement the innovation correctly and a lack of underlying fundamental principles that lead to the discontinuance of innovations. [12]

The University of Pittsburgh's Swanson School of Engineering (SSOE) recognizes the need for personalized learning and a modernized curriculum, as do leading experts around the country. Both the Council of Graduate Schools (CGS) [13] and the National Academies [1] highlight the need for a significant upgrade to the U.S. graduate STEM enterprise, specifically, for a shift from the research enterprise to one focused on graduate students. [1] Through a National Science Foundation Innovations in Graduate Education (IGE) award, SSOE is creating a personalized learning model (PLM) for graduate education and piloting the model in the Department of Chemical Engineering. The goals of this innovation in graduate education are to (1) break the traditional "one-size-fits-all" approach to graduate STEM education by creating and validating a PLM that is inclusive to all students and (2) propagate our engineering education research into practice by generating the knowledge to extend this innovation to other STEM graduate programs.

The Personalized Learning Model (PLM)

Seeded by a shared vision across SSOE and guided by experts in engineering education, we are piloting, measuring, refining, and institutionalizing the PLM for STEM Graduate Education (Figure 1). Recognizing that a program with "pointwise" personalization (i.e., a single course or professional development focus) will have a modest impact, we propose a personalized learning model that permeates throughout the entirety of the graduate student experience. Based on the assessment outcomes, the model is revised. Thus, the innovation lies in integrating the components into a department-wide model that (1) mutually supports an individualized, student-centered educational strategy and (2) deploys rigorous assessment to quantify the impact of our approach on students and faculty. We are undertaking a sweeping overhaul of STEM graduate education while documenting the process and outcomes, establishing the potential for adoption across our school and nationwide.

The model is derived from the five principles of personalized learning by Watson and Watson[14] and comprises the following key components: (1) establishing *Instructional Goals* for each student through learner profiles, strength finders, and individual development plans, (2) defining the *Task Environment* through one credit, modular classes that provide topic flexibility and content customization, and "Professional Development Streams" - a set of co-curricular activities organized around industry, academia and entrepreneurship, and (3) *Scaffolding the Instruction* to provide pedagogy that leads to independence and mastery in the student's area of focus. (4) *Assessment of Performance and Learning* tracks progression toward the student's instructional goals, followed by guided (5) *Reflection and Evaluation.* Components (4) and (5) provide improvement opportunities for students toward their instructional goals and feedback from students and faculty on improving the PLM. This student-centered approach to graduate education will create an inclusive environment by meeting students at their current skill levels, allowing them to customize their educational experience to their career goals. In the following sections, we will introduce each component of the PLM and discuss early implementation and assessment observations.

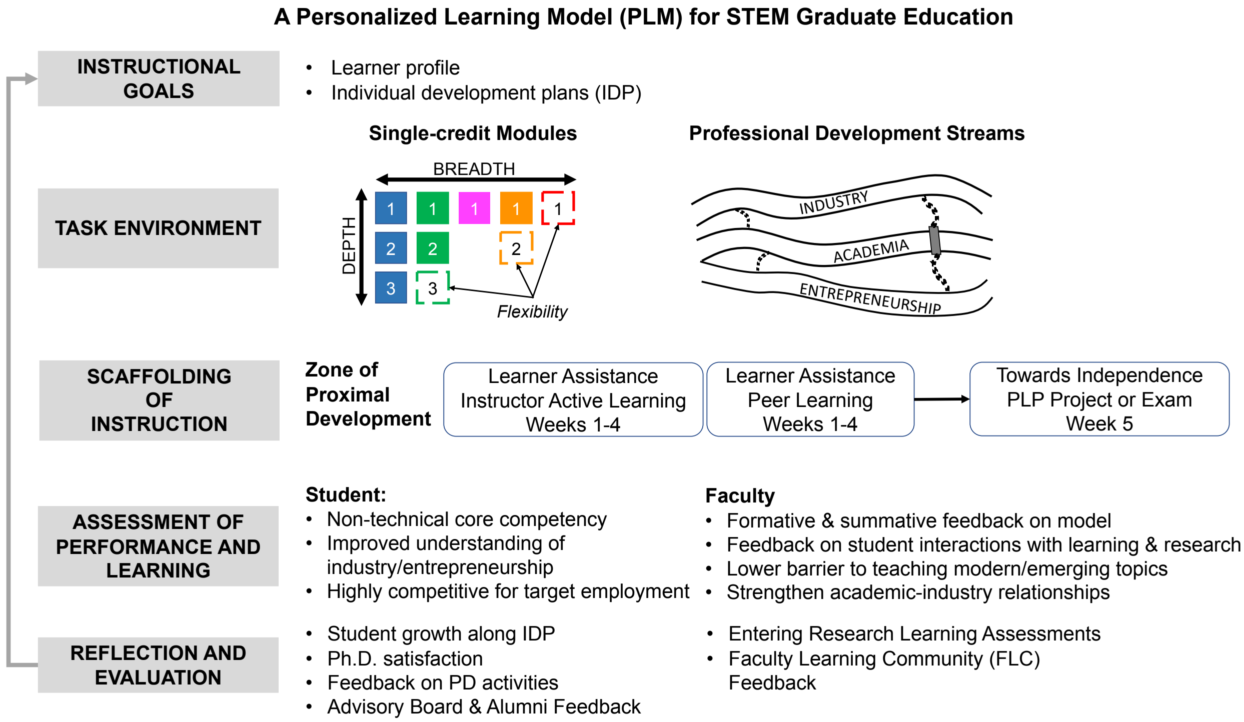

Figure 1: Overview of the Personalized Learning Model for STEM Graduate Education being developed and deployed to innovate graduate education.

Instructional Goals

Extrapolating from Deci's Self Determination Theory, [15] we are working with graduate students to create their long- and short-term career goals. This includes developing an Individualized Development Plan (IDP) incorporating the Strength Finder assessment, AAAS' myIDP platform, and assessment of students' background in STEM content (in this case, Chemical Engineering). Goal setting, while a valuable personal and professional skill, will also help students assess their learning throughout their graduate degree alongside faculty and help chart their path within the proposed modular curriculum, as described in the task environment.

Task Environment

To create a personalized Task Environment, we will provide a *Modular Curriculum* that replaces the standard 3-credit classes with single-credit classes. This change will enable students to customize their education to fit program requirements and student interests, thus controlling the breadth and depth of their intellectual development. One-credit modules also create flexibility that will enable faculty to quickly deploy new content in response to emerging trends, further increasing students' ability to tackle relevant challenges immediately after graduating. Existing literature points to positive student outcomes when personalizing graduate engineering coursework, as evidenced by Mistree et al., who incorporated pillars of personalized learning (e.g., student learning goals, course flexibility, and scaffolding of instruction) in a graduate-level mechanical engineering design course at the Georgia Institute of Technology, [16] and later this approach extended to a mechanical engineering course offered jointly between the University of

Oklahoma at Norman and Washington State University. [17] They note that personalizing a course to a student's needs, interests, and skills leads to more motivated students and deeper learning. Students reported that they became more aware of the learning process and recognized the importance of setting learning objectives.

The Task Environment is enhanced with *Professional Development Streams* organized as suites of co-curricular activities with three broad professional targets: industry, academia, and entrepreneurship. Streams will provide educational breadth beyond technical skills, enabling students to develop a solid professional identity and prepare for their target careers *before* graduation. Professional development streams are also expected to significantly impact URM students, who are more likely to lack access to mentors who have successfully navigated their targeted career path.

Examples from literature that incorporate formal career and professional development into STEM graduate programs include Love Stowell et al., who developed a model to prepare better students for *academic careers*. The Department of Ecology and Evolutionary Biology at the University of Colorado at Boulder has implemented this approach. [18] It begins with pedagogical training, mentorship, and support from the start of the student's graduate career. It includes (1) learning pedagogical techniques, (2) assisting in learning/classroom management, (3) collaborating on curriculum development, and (4) serving as lead instructor. No follow-up report on outcomes was identified.

Another example targeted to academic careers is described by a 3-year longitudinal study of aspiring college/university educators in STEM at the University of Wisconsin-Madison by Bouwma-Gearhart et al. [19] All participants engaged in the "Delta Program in Research, Teaching, and Learning," part of the Center for the Integration of Research, Teaching, and Learning (CIRTL). Many participants received additional teaching-related professional development, which has a positive impact by broadening their views of academic careers and helping them become more confident and effective educators. By and large, graduate STEM programs are now beginning to prepare students for the professoriate; few programs are dedicated to preparing students for industry or entrepreneurship.

One example of *industry-focused* professional development comes from North Carolina State's "Accelerate to Industry (A2i)," funded by NSF IGE grant #1855978. Data from the first session in 2020 provides strong evidence that the job search module increased some participants' perceptions of their professional networking skills. [20] Additional competencies where participants saw improvement include exploring career possibilities, creating a resume and professional portfolio, interviewing for a job, professional communication, and leadership. [20]

Entrepreneurship as a career path receives the least attention; however, a recent example from the University of North Carolina, Charlotte, is their "PAtENT program," also funded by an NSF IGE grant (#1954978). This program offers an alternative STEM doctoral pathway in entrepreneurship, implemented in the Mechanical Engineering and Engineering Science Department. [21] The program includes research partnerships with faculty, two six-week training modules, and cross-curricular courses with the Business School. This program may lead to a "Doctor of Innovation degree" (as opposed to the traditional Doctor of Philosophy) for which patents, instead of journal publications, would be the targeted deliverable. Most professional development pathways described in the literature have led to measurable enhancements in graduate education; however, none integrate all components into a single program.

Professional Development activities coupled with mentorship are mutually supportive and include strategic engagement with partners outside the university, including (1) industry partners; (2) AIChE, the national professional organization of chemical engineering; and (3) alums at major companies in sectors relevant to our students. These external partners will serve on our advisory board, facilitate internship opportunities, and participate in our course modules.

Scaffolding of Instruction

Simply creating a new task environment does not mean that students will learn. For this model to be successful, instructors will adopt a pedagogy that helps students move toward independence and content mastery. [22] Students gain competency in the material first through learner-assisted activities, which include instructor- and peer-based active learning activities, and then move towards demonstrating competency via an independent project based on their professional stream or through exams. Siddique et al. discuss that scaffolded assignments in a graduate mechanical engineering course allowed individualization.[23]

Our faculty are equipped with active learning approaches through SSOE's Engineering Education Research Center (EERC). This consistency is crucial given the unconventional task environment and the fact that students enter the course at different levels (e.g., background knowledge, long-term goals, etc.). This aspect of the model is particularly relevant for minoritized students who are often viewed through a deficit-based framework where achievement and knowledge gaps are assumed to lie within issues of these students rather than the systemic barriers they face. [24] The approach proposed through the PLM will move towards an asset-based framework, where the individual strengths of all students are identified, and knowledge gaps are filled.

Assessment of Performance and Learning

In graduate education, faculty members are typically central in assessing students' performance. Student artifacts are created from the 1-credit modules (e.g., competency exams, projects, etc.). Similarly, students create artifacts from their research with faculty mentors. Students compile a portfolio demonstrating their growing competencies according to their long-term goals and professional stream. Students can assess their satisfaction with the Ph.D. program, relationships with their instructors and advisors, etc. Simultaneously, model content and deployment are assessed from student learning and faculty perspectives.

Reflection and Evaluation

Students, faculty, and administrators will take a meta-cognitive review of the learning process and outcomes. Formative feedback regarding student progress will help students reflect and, where needed, revise their short-term goals to meet their long-term goals better. In the following section, we discuss the assessments we have begun and will implement in the future to evaluate the PLM holistically.

Assessment of the Model and Implementation

For the model, we are following a mixed-methods approach requiring data from our students and faculty across several instruments to measure change over time for the PLM and its impact on graduate students. Both qualitative and quantitative methods in both formative and summative manners are employed. As part of the first component, *Instructional Goals*, students create an Individualized Development Plan using the AAAS' myIDP platform. [25] In doing so, students take assessments on the platform that help them determine their professional skills, interests, and values. In addition, students take the CliftonStrengths assessment. [26] To compare each mentee's skill development from their perspective and their mentor's, we will collect the Entering Research Learning Assessment (ERLA) from students and their research mentors. [27] This information is coupled with annual student reflections, a Ph.D. satisfaction survey [28], and interviews regarding their matriculation through the Ph.D. program. Further, we track the various professional development activities that students engage in and their curricular assessments. It is essential to provide an annual evaluation of students' progress along their learning plan and refine it as needed or desired (*Reflection and Evaluation*). It demonstrates that students are confident about their career path and are satisfied with their Ph.D. preparation. Students under the new educational model are compared to students under the traditional graduate education model, who have completed their IDP and taken the same instruments.

Students provide one aspect of model assessment. Assessment of the *Task Environment* and *Scaffolding of Instruction* components is necessary. Here, we restructure 3-credit classes into 1-credit courses focusing on undergraduate fundamentals, graduate level, and specialized learning. Because content restructuring is involved, our technical advisory board assesses the appropriateness of content in each module. Further, given the course restructuring, instructors are adopting a pedagogy that helps students achieve independence and content mastery. [22] To demonstrate that the Task Environment and Scaffolding of Instruction components have improved the student experience, we are measuring the classroom environment pre- and post-restructure using the College and University Classroom Environment (CUCEI) [29] instrument to garner students' perspective of the learning environment as well as Wieman's Classroom Observation Protocol for Undergraduate STEM (COPUS). [30]

In addition to the stated assessment, the overarching PLM curricular approach will be evaluated to determine if adopting the model provides a new approach to how graduate education is delivered and learning is acquired. In addition to the data collected, feedback will be acquired from students via focus groups and from faculty and administrators through interviews.

Initial Insights – Establishing Instructional Goals

To take advantage of an individualized curriculum, students must reflect on their short—and long-term goals to decide which pathways will best prepare them for post-graduation. To support students in their selection, we guide them through creating an Individualized Development Plan (IDP) on the AAAS' myIDP platform.

In the fall term of data collection (the first term of the grant), we recruited from the non-PLM cohort of current doctoral students, including students in their first semester of the program through students completing their dissertations in the Fall 2023 semester. We utilized the self-assessment and IDPs to assess how well students could articulate their career, skill, and project goals and identify their mentor(s) to support them in achieving their goals.

Our first event was an informational session in the Chemical Engineering graduate seminar class. We shared information about upcoming professional development opportunities, and students were introduced to the CliftonStrengths assessment and the myIDP platform. Three weeks later, students were asked to complete the assessments on both platforms before a mandatory workshop.

The second event was a 2-hour mandatory workshop attended by master's and doctoral students. This workshop had two main goals: guiding students through (1) interpreting their CliftonStrengths results and (2) writing their own goals using the SMART goal parameters (with SMART being an acronym for Specific, Measurable, Achievable, Realistic, and Time-Bound) for the myIDP platform. Incorporating more SMART elements into a goal increases its quality, improving one's ability to meet stated goals and supporting students in articulating and meeting their own goals. A total of 95.6% of all 68 M.S./Ph.D. Chemical Engineering students either attended the in-person workshop (n=54) or a subsequent makeup online workshop (n=11).

Following the workshop, students were asked to submit their completed IDP document from the myIDP platform via a Qualtrics survey and to discuss their IDPs with their research mentor. First-year students who have not formally selected their research mentor met with the Vice Chair for Graduate Education. The research team created an inductive coding scheme with descriptive codes based on the elements of the myIDP report form (see Appendix) to assess the IDPs. Each section in the IDP report was coded for the presence/absence of various elements. For example, students can select or write up to two career plans and write short-term goals for these plans. A "Career Plans" code includes the codes NONE, SINGLE, and MULTIPLE to describe reports where the career plan is empty, contains one career plan, or includes more than one career plan, respectively. Additionally, we assessed the goals that students wrote in their IDPs for elements of the SMART framework. Each IDP section with goals was coded for how many SMART elements were common in the written goals: (MINIMAL) most goal(s) are missing 4 to 5 or more SMART elements; (AVERAGE) most goal(s) are missing 2 to 3 or more SMART elements; and (ADVANCED) most goal(s) include 4 to 5 SMART elements.

All submitted IDPs were coded by a single researcher, providing a snapshot of students before implementing the PLM curriculum. We received 44 IDPs during Fall 2023. The majority of the IDPs (41) were from Ph.D. students (74.5% of all Ph.D. candidates), and 3 IDPs were from M.S. students (23% of all M.S. candidates). Most of the missing Ph.D. candidates' IDPs were from more advanced students, including 20% of the 2020-21 cohort, 46.7% of the 2019-20 cohort, and 100% of students who started before Fall 2019. Additionally, nearly all the submitted IDPs included the Self-Assessment summary (97.7%), facilitating the building of IDP goals in the myIDP platform.

Our first observations of the pre-PLM Ph.D. students' ability to share career plans and write goals for themselves in their IDPs indicate that 80% of students - regardless of their number of years in the graduate program - listed at least one career plan, with 37.5% of all students articulating both long-term and short-term career plans. Interestingly, when analyzing the SMART elements of the 3 sets of goals (career, skills development, and project management), there is a notable difference between first-year and more advanced students. None of the first-year students included most career goals with 4 to 5 SMART elements in their IDP (Figure 2A). Comparatively, 33.3% of second-year students and 37.5% of third-year and more advanced (third-year++) students wrote career goals that primarily used 4-5 SMART elements (Figure 2). One student from the third-year and more advanced (third-year++) group did not include any written Career Goals (None).

Similarly, first-year students wrote goals with fewer SMART framework elements in their Skills Development Goals (Figure 2B) and their Project Management Goals (Figure 2C). Most (66.7%) of first-year students included a majority of skills development goals with minimal (0-1) SMART elements in their IDP (Figure 2B). This contrasts with only 22.2% of second-year students and 24.0% of third-year++ students whose skills development goals were coded as having minimal SMART elements (Figure 2B).

The most significant gap in SMART goals between first-year students and more advanced students was observed with project management goals (Figure 2C). Most second-year students (66.7%) and third-year++ students (76%) wrote project management goals with average (2-3) or advanced (4-5) SMART elements compared to only 16.7% of first-year students (Figure 2C).

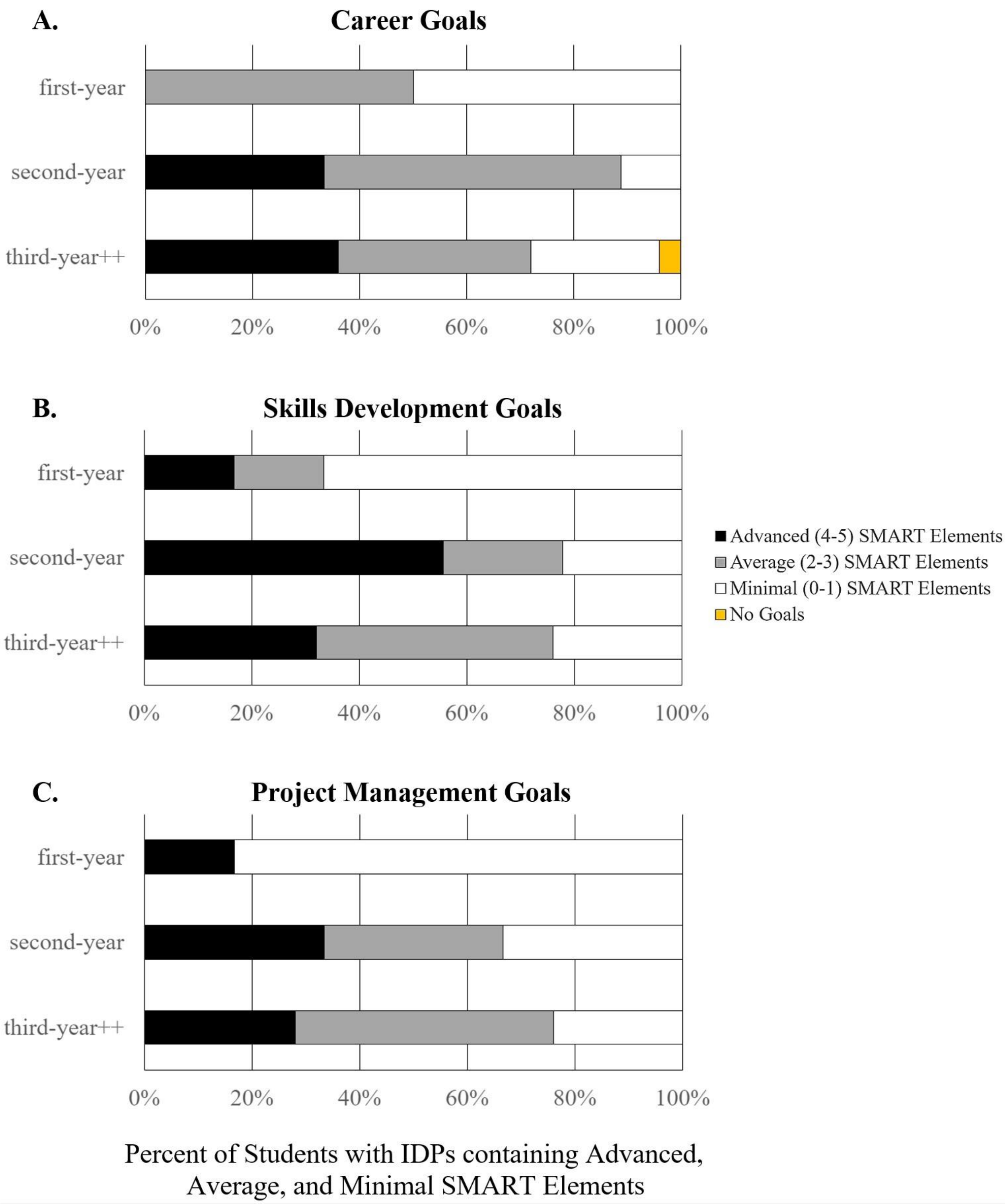

Figure 2: Distribution of SMART elements in Career, Skills Development, and Project Management Goals

These data suggest that doctoral students have progressed in communicating SMART goals in their IDPs as they advance through their graduate degrees. Regardless of the student's year in the program, a significant portion listed at least one career plan, although there were varying degrees of planning for the short and long term. However, as students progressed, there was a noticeable improvement in the quantity and depth of goal-setting. Specifically, more advanced students tended to incorporate more SMART elements into their career, skills development, and project management goals than their first-year counterparts. This may indicate that as students become more familiar with their academic and professional environments, they can better articulate their goals using the SMART framework.

We collected reflections from faculty mentors who met with their graduate mentees regarding their IDPs. We received 12 reflections from faculty (out of 17 faculty) mentoring graduate students. The most common theme raised in the reflections was that their meetings with mentees using the IDP were valuable and positive experiences (9 responses) that helped frame discussions (4 responses) about students' progress toward goals. Many faculty (5 responses) reported that their mentees struggled to write meaningful SMART goals. Although first-year students' goals were reported as having fewer SMART elements, this was not isolated to only first-year students' IDPs. A few reflections (2 responses) mentioned that this activity was less useful for their students because they already use similar goal-setting practice and feedback discussions as mentoring activities. These faculty reflections highlight that more training for writing meaningful SMART goals is needed, especially for first-year students.

Additionally, it reveals that pre-PLM training in some skills, like goal-setting, is not uniformly a mentored experience for all trainees. Using IDPs as a mentoring tool may help standardize some of the mentored experiences among all students in a program by providing similar scaffolding for regular discussions between mentors and mentees. Additionally, these findings underscore the importance of providing guidance and support to students, particularly in their early years, to facilitate the development of effective goal-setting skills essential for their academic and professional growth.

One question that arises from this data is: *Do first-year students only need more time, practice, and feedback on writing SMART goals specifically, or do they need to acquire more experiences in their doctoral program before they can write more detailed career, skills development, and project management goals?* As we collect data after the spring semester, we will gather information from the first-year students during their end-of-the-year meeting with the Chemical Engineering Vice Chair for Graduate Education to answer this question.

Initial Insights – Defining the Task Environment

As mentioned, the task environment consists of redesigning the core curriculum from three-credit courses into single-credit modules and developing three professional streams of industry, academia, and entrepreneurship.

Our first-year Chemical Engineering graduate curriculum comprises five courses: Thermodynamics, Kinetics and Reactor Design, Transport Phenomena, Mathematical Methods, and Safety and Ethics. Although this curriculum is fairly standard in Chemical Engineering graduate education, it leaves little room for customization, specialization, and flexibility on emerging topics. This structure also makes it difficult for students to test out of specific content. Our one-credit modules enable students to adapt to their prior knowledge level and customize their education while maintaining vital core training. Specifically, the modules have three levels: undergraduate fundamentals, graduate level, and specialized learning. The first course modules (undergraduate fundamentals) will be required, but students may test out by demonstrating mastery via a written exam before the start of the semester. This assures a uniform starting point for students from varying undergraduate backgrounds. The second module will be mandatory for all students, maintaining a core graduate-level ChE curriculum beyond undergraduate mastery. The third credit will be specialized content that remains within the scope of transport, kinetics, and thermodynamics. Still, the focus will be flexible and likely a topical area that is timely and well-aligned with the instructor's expertise.

To achieve this, we are developing a graduate-level body of knowledge (BOK) along these three levels for each course. Faculty have developed detailed learning objectives for their course through a workshop based on Bloom's revised taxonomy. [31] With subject matter experts from academia and industry, we are using GroupWisdom [32] software to categorize the course learning objectives into three levels. This work is currently underway. Once complete, faculty will transition their courses into modules that take advantage of Vygotsky's Zone of Proximal Development, [22] whereby students are first exposed to content in a learner-assisted mode; then, as they develop competency, they will move toward independent learning. During the last week of the module, students will demonstrate independence via an exam or a professional-stream-based project.

Propagation of the Model

Transferability of the model is the second goal of this project. As discussed, the propagation of innovations in engineering education has not caught up with the activity level of developing these innovations.[10] One highlighted example of propagating engineering education research into practice and adopting evidence-based practices is the NSF-funded CIRTL program, [33] a graduate STEM program that trains next-generation faculty members in evidence-based teaching practices.

One reason for inadequate propagation is that there are obstacles to overcome, as Rogers [12] discussed. We intend to generate the knowledge and examine the potential to extend the PLM from one STEM context to another (i.e., from Chemical Engineering to other engineering fields at our institution, other STEM fields at our institution, and other Chemical Engineering and STEM departments at other institutions). This innovation will involve several types of adopters (i.e., individual faculty, department administrators, and institutional administration), who will be at various stages of 1. *being aware* of the innovation, 2. *being persuaded* to have a favorable attitude towards innovation, 3. *deciding* to engage in activities to adopt (or not) the innovation, 4. *implementing/adopting* (or adapting) the innovation, and 5. *confirming* that the adoption of the innovation continues. Faculty learning communities (FLCs) will be employed, and specific "how to" instruction will be disseminated to engineering and STEM faculty via workshops, videos, and other avenues. In doing so, we are adopting the D-Cubed Dissemination Framework [34] and the Designing for Sustained Adoption Assessment Instrument (DSAAI) [35] to help assess our work throughout the project, providing formative feedback on uptake of aspects of our work, as well as areas that need improvements in propagation. Further, we will interview engineering and non-engineering faculty at routine intervals to determine if other STEM departments at Pitt or other institutions are adopting the intermediate and later stages of Roger's Diffusion of Innovation.

Acknowledgments

This work is supported by a grant from the National Science Foundation (DGE-IGE 2325599). Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. We wish to thank Drs. James McKone, Robert Parker, Chris Wilmer, and Sachin Velankar for their invaluable assistance in developing aspects of the PLM model.

References

[1] National Academies of Sciences Engineering and Medicine, *Graduate STEM Education for the 21st Century*. The National Academies Press: Washington, DC, 2018; p 202. DOI:doi:10.17226/25038 https://www.nap.edu/catalog/25038/graduate-stem-education-for-the-21st-century

[2] Amelink, C. T.; Lutz, B. D.; Karugarama, M. K.; Lesko, J. J. *Graduate Summer Bridge Program: Building Community and Preparedness for Success among Engineering Graduate Students*, Paper presented at ASEE Conferences, New Orleans, Louisiana, **June 2016**. DOI:10.18260/p.25419

[3] Website: Center for the Integration of Research, Teaching and Learning https://www.cirtl.net/ (accessed March 21, 2022).

[4] Viswanathan, S.; Evans, H. *Harnessing Industry Collaboration In Developing Graduate Degree Programs*, Paper presented at ASEE Conferences, Austin, Texas, **June 2009**. DOI:10.18260/1-2--5455

[5] Somerton, C. W.; Gunn, C. *Improving the Public Communication Skills of Graduate Students*, Paper presented at 2011 ASEE Annual Conference & Exposition, Vancouver, BC, **June 2011**. DOI:10.18260/1-2--18123

[6] Burrows, A., & Kukreti, A., & Borowczak, M., & Safwat, A. *Improving Future Faculty With Graduate Engineering Education*, Paper presented at 2010 Annual Conference & Exposition, Louisville, Kentucky, **June 2010**. DOI:10.18260/1-2--16917

[7] Borrego, M., & Newswander, L. *Journal Clubs As Pedagogy For Interdisciplinary Graduate Education* Paper presented at 2008 Annual Conference & Exposition, Pittsburgh, Pennsylvania, **June 2008**. DOI:10.18260/1-2--3665

[8] Kelkar, A. D., & Ryan, J. G. *Innovative Graduate Program in Nanoengineering* Paper presented at 2011 ASEE Annual Conference & Exposition, Vancouver, BC, **June 2011**. DOI:10.18260/1-2—18176

[9] Honey, M.; Alberts, B.; Bass, H.; Castillo, C.; Lee, O.; Strutchens, M. M.; Vermillion, L.; Rodriguez, F. *STEM Education for the Future - 2020 Visioning Report*; National Science Foundation, Spring 2020.

[10] Council, N. R., *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering*. The National Academies Press: Washington, DC, **2012**; p 282. DOI:doi:10.17226/13362 https://nap.nationalacademies.org/catalog/13362/discipline-based-education-research-understanding-and-improving-learning-in-undergraduate

[11] Jamieson, L.; Lohmann, J. *Innovation with Impact: Creating a Culture for Scholarly and Systematic Innovation in Engineering Education*; Washington, DC., 2012; https://aseecmsprod.azureedge.net/aseecmsprod/asee/media/content/member%20resources/pdfs/innovation-with-impact-report.pdf.

[12] Rogers, E. M., *Diffusion of innovations*. Free Press: New York, **2003**.

[13] Okahana, H., *Closing Gaps in Our Knowledge of PhD Career Pathways: Job Changes of PhD Graduates After Earning Their Degree*. Council of Graduate Students (CGS) Research **July 2019**, https://www.humanitiescareers.pitt.edu/sites/default/files/137_19~1.PDF.

[14] Watson, W.; Watson, S., Principles for personalized instruction. 2016.

[15]Deci, E. L.; Ryan, R. M., Self-determination theory. In *Handbook of theories of social psychology, Vol. 1*, Sage Publications Ltd: Thousand Oaks, CA, 2012; pp 416-436.

[16]Mistree, F.; Panchal, J. H.; Schaefer, D., Mass-Customization: From Personalized Products to Personalized Engineering Education. In *Pathways to Supply Chain Excellence*, Ales, G.; Yu, X., Eds. IntechOpen: Rijeka, 2012; p Ch. 9.

[17]Mistree, F.; Panchal, J. H.; Schaefer, D.; Allen, J. K.; Haroon, S.; Siddique, Z., Personalized Engineering Education for the Twenty-First Century. In *Curriculum Models for the 21st Century: Using Learning Technologies in Higher Education*, Gosper, M.; Ifenthaler, D., Eds. Springer, New York: New York, NY, 2014; pp 91-111.

[18]Love Stowell, S. M.; Churchill, A. C.; Hund, A. K.; Kelsey, K. C.; Redmond, M. D.; Seiter, S. A.; Barger, N. N., *Transforming Graduate Training in STEM Education*. The Bulletin of the Ecological Society of America **2015** *96* (2), 317-323 DOI:https://doi.org/10.1890/0012-9623-96.2.317 https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1890/0012-9623-96.2.317.

[19] Bouwma-Gearhart, J.; Millar, S.; Barger, S.; Connolly, M., *Doctoral and postdoctoral STEM teaching-related professional development: Effects on training and early career periods (WCER Working Paper No. 2007-8)*. Madison: University of Wisconsin–Madison, Wisconsin Center for Education Research **2007**, Retrieved January 5, 2023 http://www.wcer.wisc.edu/publications/workingPapers/papers.php.

[20] N.C. State University (n.d.), Accelerate to Industry. https://grad.ncsu.edu/professional-development/career-support/accelerate-to-industry/

[21] Rorrer, A.; Pugalee, D. K.; Ramaprabhu, P.; Uddin, M.; Cherukuri, H. P.; Xu, T.; Prajapati, D. *Pathways to Entrepreneurship (PAtENT) Program: Reimagining STEM Doctoral Programs*, Paper presented at Virtual Conference, **2021/07/26;** ASEE Conferences.

[22] Eun, B., *The zone of proximal development as an overarching concept: A framework for synthesizing Vygotsky's theories*. Educational Philosophy and Theory **2019** *51* (1), 18-30 DOI:10.1080/00131857.2017.1421941 https://doi.org/10.1080/00131857.2017.1421941.

[23] Siddique, Z.; Panchal, J.; Schaefer, D.; Haroon, S.; Allen, J. K.; Mistree, F. In *Competencies for Innovating in the 21st Century*, ASME 2012 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, 2012; pp 185-196.

[24] National Academies of Sciences, E.; Medicine, *Advancing Antiracism, Diversity, Equity, and Inclusion in STEMM Organizations: Beyond Broadening Participation*. The National Academies Press: Washington, DC, **2023**; p 450. DOI:doi:10.17226/26803 https://nap.nationalacademies.org/catalog/26803/advancing-antiracism-diversity-equity-and-inclusion-in-stemm-organizations-beyond

[25] Website: AAAS/Science MyIDP Science Careers: Individual Development Plan. https://myidp.sciencecareers.org/ (accessed March 21, 2022).

[26] Rath, T., *StrengthsFinder 2.0: Discover Your Clifton Strengths. Gallop:* **2007**. www.strengthsfinder.com

[27] https://wiscience.wisc.edu/2019/07/10/entering-research-learning-assessment-erla/

[28] van Rooij, E.; Fokkens-Bruinsma, M.; Jansen, E., *Factors that influence PhD candidates' success: the importance of PhD project characteristics*. Studies in Continuing Education **2021** *43* (1), 48-67 DOI:10.1080/0158037X.2019.1652158.

[29] Clark, R. M.; Besterfield-Sacre, M.; Parker, B.; Slaughter, W.; Clark, W.; Budny, D.; Bursic, K.; Norman, B.; Patzer, J., *Flipping Engineering Courses: A School Wide Initiative*. Advances in Engineering Education **2016** 5(3), 1-39 https://advances.asee.org/publication/flipping-engineering-courses-a-school-wide-initiative/.

[30] Smith, M. K.; Jones, F. H. M.; Gilbert, S. L.; Wieman, C. E., *The Classroom Observation Protocol for Undergraduate STEM (COPUS): A New Instrument to Characterize University STEM Classroom Practices*. CBE—Life Sciences Education **2013** *12* (4), 618-627 DOI:10.1187/cbe.13-08-0154 https://www.lifescied.org/doi/abs/10.1187/cbe.13-08-0154.

[31] https://www.celt.iastate.edu/instructional-strategies/effective-teaching-practices/revised-blooms-taxonomy/

[32]https://groupwisdom.com/groupwisdom?gclid=Cj0KCQiA2eKtBhDcARIsAEGTG437Qh_V7I-olcvIGdh6jGYlc9gc4Tnl-fx--VCaEMN6P0khl3a_TF0aAmUKEALw_wcB

[33] Center for the Integration of Research, Teaching and Learning (CIRTL). https://cirtl.net/ (accessed March 17, 2023).

[34] Hinton, T., Gannaway, D., Berry, B., and Moore, K. (2011). The D-Cubed Guide: Planning for Effective Dissemination. Sydney: Australian Teaching and Learning Council.

[35] Henderson, C., Cole, R., Froyd, J., Friedrichsen, D., Khatri, R., & Stanford, C., Designing educational innovations for sustained adoption: A how-to guide for education developers who want to increase the impact of their work. Publisher: Increase the Impact: Kalamazoo, MI, **2015**.

Appendix – IDP Coding Scheme

IDP-SECTION Name: Career Plans Summary

(NONE) Does not include a career plan.
(SINGLE) Lists one Career plan.
(MULTIPLE) Lists more than one career plan.

➔ If (SINGLE) or (MULTIPLE)

Career Plan Goals

(LT) Lists at least one long term career goal.
(ST) Lists at least one short term career goal.
(LT/ST) Lists at least one long- and short-term career goals.

IDP-SECTION Name: SMART Goal Summary

(NONE) Does not include a goal.
(SINGLE) Lists 1-2 goals.
(MULTIPLE) Lists more than 2 goals.

➔ If (SINGLE) or (MULTIPLE)

SMART GOAL Levels

(MINIMAL) Goal(s) from Career, Skills, and Project are mostly in the MINIMAL level, demonstrating 0-1 SMART elements.
(AVERAGE) Goal(s) from Career, Skills, and Project are mostly in the AVERAGE level, demonstrating 2-3 SMART elements.
(ADVANCED) Goal(s) from Career, Skills, and Project are mostly in the ADVANCED level, demonstrating 4-5 SMART elements.

➔ If (SINGLE) or (MULTIPLE)

(ADV Timeline) Includes 2 or more goals for each month for the 12 month plan.

IDP-SECTION Name: Self Assessment Summary

(NONE) Does not include any self-assessment summary.
(Skills) Includes Skill Summary.
(Interest) Includes Interests Summary.
(Values) Includes Values Summary.
(ALL) Includes Skills, Interests, and Values Summary.

IDP-SECTION Name: Career Exploration Summary

(NONE) Does not include any upcoming career opportunities or resources.
(SINGLE) Lists one upcoming career opportunity or resource.
(MULTIPLE) Lists more than one upcoming career opportunity or resource.
(PAST) Lists past opportunities only.

IDP-SECTION Name: Career Advancement Goals

Selected Career Goals

(NONE) Does not include a selected Career Advancement goal.

(SINGLE) Lists one selected Career Advancement Goal.
(MULTIPLE) Lists more than one selected Career Advancement Goal.

➔ **If (SINGLE) or (MULTIPLE) for Selected Career Goals**
Written-in Career Goals
(NONE) Does not include any written-in goals for any selected Career Advancement Goals.
(SINGLE) Lists one written-in goal for at least one selected Career Advancement Goals.
(MULTIPLE) Lists more than one written-in goal for at least one selected Career Advancement Goals.

➔ **If (SINGLE) or (MULTIPLE) for Written-in Career Goals**
Level Career Goals
(MINIMAL) Goal(s) included, and most are missing 4-5 or more SMART elements.
(AVERAGE) Goal(s) included, and most are missing 2-3 or more SMART elements.
(ADVANCED) Goal(s) included and most have 4-5 SMART elements.

IDP Section Name: Skills Development Goals

Selected Skills Development Goals
(NONE) Does not include a selected Skills Development Goal.
(SINGLE) Lists one selected Skills Development Goal.
(MULTIPLE) Lists more than one selected Skills Development Goal.

➔ **If (SINGLE) or (MULTIPLE) for Selected Skills Development Goals**
Listed Skills Development Goals
(NONE) Does not include any written-in goals for any selected Skills Development Goals.
(SINGLE) Lists one written-in goal for at least one selected Skills Development Goal.
(MULTIPLE) Lists more than one written-in goal for at least one selected Skills Development Goal.

➔ **If (SINGLE) or (MULTIPLE) for Listed Skills Development Goals**
Level of Skills Development Goals
(MINIMAL) Goal(s) included, and most are missing 4-5 or more SMART elements.
(AVERAGE) Goal(s) included, and most are missing 2-3 or more SMART elements.
(ADVANCED) Goal(s) included and most have 4-5 SMART elements.

IDP Section Name: Project Completion Goals

Selected Project Completion Goals
(NONE) Does not include a selected Project Completion Goal.
(SINGLE) Lists one selected Project Completion Goal.
(MULTIPLE) Lists more than one selected Project Completion Goal.

➔ **If (SINGLE) or (MULTIPLE) for Selected Project Completion Goals**
Listed Project Completion Goals
(NONE) Does not include any written-in goals for any selected Project Completion Goals.
(SINGLE) Lists one written-in goal for at least one selected Project Completion Goal.
(MULTIPLE) Lists more than one written-in goal for at least one selected Project Completion Goal.

➔ **If (SINGLE) or (MULTIPLE) for Listed Project Completion Goals**

<u>Project Completion Goal Level</u>
(MINIMAL) Goal(s) included, and most are missing 4-5 or more SMART elements.
(AVERAGE) Goal(s) included, and most are missing 2-3 or more SMART elements.
(ADVANCED) Goal(s) included and most have 4-5 SMART elements.

IDP-SECTION Name: Mentoring Summary

(NONE) Does not include a mentor or role.
(SINGLE) Lists one selected mentor for one or more than one role.
(MULTIPLE) Lists at least 2 mentors with 2 or more roles.
(Adv Mentor) Lists 3 or more mentors with 3 or more roles.