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Evolving Engineering Technology Capstone Projects to Bring Students Closer to Industry

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Abstract

ABET has long required a capstone or integrating experience for accredited Engineering Technology programs. This requirement comes from the need to make graduating students as job-ready as possible. For Bachelor of Science programs in Engineering Technology, this experience is generally an open-ended project demonstrating knowledge in a student's relevant field of study along with project management skills. This paper looks back at the evolution and impact of more than 30 years of history of senior capstone projects for Engineering Technology programs at Purdue University Northwest (PNW), with focus on how industry partnerships have contributed to capstone project success. Other types of projects completed as capstone experiences, including individual, academic, and regional, national and international competitions are also examined. Finally, this paper explores the role of industry collaboration in shaping course and program curriculum, graduate readiness, faculty skills, and industrial funding to support academic experiences.

Introduction

Teaching through experiential learning practice is a given for an Engineering Technology (ET) baccalaureate program, but experiential learning comes in many forms. It is also expected that an accredited Engineering Technology (ET) baccalaureate program require capstone coursework as one of the ways to execute experiential learning. Since TC2K was implemented as the "new" wave of accreditation for ET programs at the turn of the century, ABET has required that ET program content be integrated within a capstone course that develops student competencies in applying both technical and non-technical skills in solving problems [1]. This experiential learning encounter typically uses a Project Based Learning (PBL) approach to accomplish this objective.

It has been the experience of the authors, that PBL for senior design capstone courses in ET can be segregated into two major buckets; 1) projects conducted with/for industrial partners, and 2) projects conducted without industrial partner. These two categories observed in capstone experience courses are consistent with the types of Experiential Learning categories described by Lewis and Williams (1994) as Field-based learning (including internships, practicums, cooperative education, and service learning) and Classroom-based experiential learning (including role-playing, games, case studies, simulations, presentation, and various types of group work) [2].

Some examples of experiential learning capstone projects that have been executed without industry partners include

- Student competitions [3]
- Individual student initiated projects [4]
- Faculty initiated projects through a given design problem [5]

There are also many examples of capstone courses that are structured to be integrally tied with industry partners. Some examples of these experiential learning structures include

- Students who are employees conducting projects for their employer
- Senior Design Clinic [6]
- Industrial Sponsored paid projects [7]
- Grants for consulting [8]

It does not appear that one category is more effective than another in achieving their objectives. Rather, it is the experience of the authors that how faculty members effectively organize and accomplish capstone curriculum is an extension of the needs of students and stakeholders. At PNW, the ET faculty have found that over the past several decades, as student profiles and stakeholder needs have changed, the approaches required to facilitate the experiential learning of a capstone course based on the categories described here have also had to evolve.

Many faculty in the Engineering Technology programs at PNW have been involved with or directly taught senior capstone courses for 20 to 30 years or more and have collected data showing evolution, assessment and impact of this experience over time. Specifically, the authors of this paper have been directly involved over the years teaching Mechanical, Industrial, Manufacturing, and Mechatronics Engineering Technology capstone courses at PNW.

In the 1980's and 1990's, capstone projects were typically associated with a student's workplace at this university which was, at that time, focused on part-time adult learners. In the past two decades the student body has shifted to younger, full-time students and senior capstone project topics, execution and outcomes have changed with the changing student body. With the shift away from part-time students, there are fewer adult learners in the classroom who are currently working in the field. This results in a larger population of students who do not have existing access to industrial project experiences.

Prior to this recent trend at PNW, a majority of projects the authors' have facilitated through capstone coursework were designed and executed for employers of adult learners. In these past situations, faculty developed industry partnerships through their students. It was part-time students that were a main connection to supporting industry collaborations. Engineering Technology faculty at PNW now find that they must focus on being the initiator to develop and maintain industry collaboration in order to keep an effective senior capstone course that has helped foster the student experiences necessary to develop job-ready skills, maintain currency and encourage academic-industry partnerships at PNW.

History of Purdue University Northwest

At PNW there has been a varied mix of industry sponsored and non-industry sponsored projects.

A major factor in this has been the evolving profile of students. When the BS Mechanical Engineering Technology (MET) program at PNW was first accredited in 1972, the campus had a different focus from its present day. PNW was established after WWII as two separate regional campuses in a large, state funded university system [9]. For nearly 50 years, the campuses existed as commuter campuses largely serving working adults. Most campus activity occurred after 3PM. In 2005, residence halls were built on one campus and PNW began a slow process of changing from a commuter to a residential campus. This began in earnest in 2013 when the state's Commission for Higher Education mandated that most programs be truncated to 120 credit hours. This was almost fully in place at PNW's Hammond campus location by 2015 and a majority of campus activity now ends by 5PM. This leaves adult learners disenfranchised, but PNW has now fully converted to be full-time student focused at both its Hammond and Westville campus locations.

The fact that there are two campus locations in differing degrees of transition from commuter to residential student-focus has also created further discriminating factors. These factors have lead to other hurdles in keeping pace with changes to the curriculum and methods of executing capstone design projects [10], but these factors are not discussed in this paper. It is enough to say, the Engineering Technology senior capstone project requirements have changed as the campuses and student focus have changed. The following paragraphs describe this change and PNW's plans to keep senior capstone projects relevant through 2030 [11].

Organization of Senior Design course

Engineering Technology programs have been in place at Purdue University Northwest since the 1960s. As soon as Bachelor of Science Degrees in Engineering Technology became available, senior capstone courses were part of the curriculum. Initially at PNW, these courses were informal, often did not meet on a regular class schedule and consisted of a project at the student's place of work loosely supervised by a faculty member. While this was an informal process, it was typically successful because of the industrial basis for the projects. Over the years, many projects had significant impact on local industry, and many students have progressed to high-level positions in their careers since graduating.

In the mid-1990s, this changed as enrollment increased and more full-time students began to enter the student body. Formal class meetings with defined objectives emerged coinciding with ABET's TC2K criterion. Fewer industrial projects were available to students, and the faculty struggled to work with students to find appropriate projects. Funding of projects without industry backing also became a new hurdle to overcome. Many of these changes occurred as ABET was changing to outcomes based assessment as part of the TC2K paradigm shift in accreditation.

After the change to TC2K, PNW's senior capstone courses for Mechanical, Industrial and Manufacturing (today, Mechatronics) Engineering Technology programs evolved to include a two-semester course sequence, each course being 3 credit hours.

- The first semester course is a capstone project survey course. In this course the students brush up on the design process and choose an open-ended project based on their interest and research done as part of the class. The class outcome is a written proposal with the project goals, specifications, and deliverables delineated. A final presentation to the faculty and students is required.

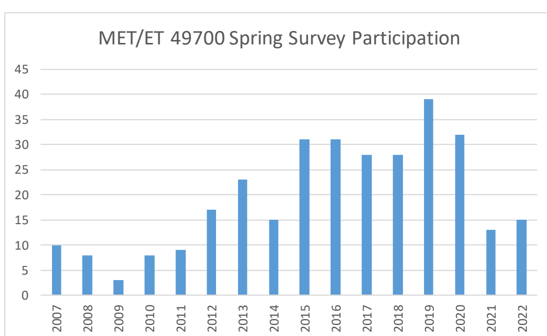
- The second semester course involves the actual execution of the capstone project. The student completes the project under faculty supervision insuring the goals, specifications, and deliverables are met. A significant report and a final presentation are the course outcomes.

The evolution of this formalized two-course sequence capstone project for all Engineering Technology students continued from 2001 through 2018. Clear approvals of goals, specifications, and deliverables were required. Based on advisory board input, risk assessment, safety, and project management topics were added as pre or co-requisites. Student team sizes were limited to a maximum of two students per team in an effort to insure everyone was doing a reasonable amount of work. However, by 2018, the faculty noted distinct changes in enrollment from earlier years and allowed team sizes to grow to three or four students per team to allow for feasible facilitation. See the enrollment survey data below in Figure 1.

Since the worldwide pandemic, enrollment has again shifted, but it is assumed that the reduction in enrollment in the senior project course may have direct correlation to a slow down in the academic progression of some students. If this does prove correct, the return to larger senior project class sizes could once again prove to be a challenge for faculty trying to keep student team size at a minimum.

Figure 1 – Capstone Project Student Enrollment Data

MET/ET 49700 Spring Survey Participation																
Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Enrollmen	10	8	3	8	9	17	23	15	31	31	28	28	39	32	13	15



The enrollment increase in 2015 coincided with a distinct final student population shift from a mostly part-time to a mostly full-time student body that began in 2005. Part-time, adult student learners brought a wide range of experience and generally came up with excellent, real-world projects from their workplace. Losing this link to industry created frustration for faculty as they noted a distinct drop in the quality of projects being worked on by students and the lack of ability to consistently achieve course outcomes. Currently, the capstone course outcomes indicate that students will be able to:

1. Successfully complete a complex, open-ended project using multiple areas of knowledge.

2. Demonstrate written communication skills at a professional level by preparing a report detailing the chosen project.

3. Demonstrate oral communication skills at a professional level by giving a presentation to the faculty, other students, and guests detailing the chosen project.

These outcomes correspond to ETAC of ABET Program Educational Outcomes and criterion with direct connection for assessment purposes.

Assessment of the capstone courses is also evolving. Grading for the capstone project is currently as follows:

Scope of the project	10%
Oral Presentation	25%
Progress reports	5%
Ethics project	10%
Written Report	50%

The scope and oral presentation components have been graded during student presentation by the faculty using a simple rubric that was based on TC2K criterion. ABET required that an ethics related outcome be added to the curriculum in TC2K and assessment of this outcome was incorporated as a separate assignment in the capstone course, but it should really be integrated into the curriculum earlier on.   This is noted as a future evolution consideration.

In the 2019-2020 accreditation cycle, ABET changed to a more robust assessment system that assesses the primary student outcomes with specific measures defined by the institution. The final report in the 2020 capstone project course was a test case for other course assessment changes at PNW based on this new method using a rubric (see Figure 2) founded on AACU principles [12].

Students also prepare a poster and present their project at a showcase sponsored by the PNW College of Technology each spring. Members of the ET advisory committees and the general public are invited for this all-day event. While not a direct consideration when first initiating the showcase in 2008 as part of the senior capstone course, the university has noted that several students each year since find jobs as a result of a contact made during the showcase.

Changing Industry Partnerships

In the more than 20 years since TC2K, the drastic reduction in industrial projects completed

Figure 2 – Capstone Project Grading Rubric

MET/ET 49700 Written Project Evaluation Rubric adapted from AACU

Names:		Date:	Project:	

	Capstone	Milestones		Benchmark	
Professionalism *Includes considerations of audience, purpose, and the circumstances surrounding the writing task(s).*	Demonstrates a thorough understanding of context, audience, and purpose and provides excellent, professional level writing and organization.	Demonstrates adequate consideration of context, audience, and purpose and provides good, near professional level writing and organization.	Demonstrates awareness of context, audience, purpose, but writing and organization needs improvement.	Demonstrates awareness of context, audience, purpose, but writing and organization has errors and needs significant improvement.	Unacceptable
Score	10	7	5	2	0
Depth of Coverage	Professionally describes the project including how the goals, specifications, budget, and schedule were met with the final design. Professional use of appropriate technology including CAD and analysis tools with proper drawings, data, and conclusions.	Adequately describes the project including how the goals, specifications, budget, and schedule were met with the final design. Good use of appropriate technology including CAD and analysis tools with proper drawings, data, and conclusions.	Describes the project including how the goals, specifications, budget, and schedule were met with the final design, but possibly some small errors. Uses appropriate technology including CAD and analysis tools with adequate drawings, data, and conclusions.	Describes the project including how the goals, specifications, budget, and schedule were met with the final design, but with possible errors and ommisions, but still a plausible design. Reasonable use of technology including CAD and analysis tools with adequate drawings, data, and conclusions.	Unacceptable
Score	15	10	7	5	0
Solution	Well thought out, carefully considered solutions with proper data showing project success.	Good solutions with proper data showing project success.	Plausible solutions with reasonable data showing project success.	Plausible solutions with possible errors or omissions. Data may not fully support project success.	Unacceptable
Score	15	10	7	5	0
Sources and Evidence	Demonstrates skillful use of high-quality, credible, relevant sources to develop ideas that are appropriate for the discipline and genre of the writing in correct APA format.	Demonstrates consistent use of credible, relevant sources to support ideas that are situated within the discipline and genre of the writing in correct APA format..	Demonstrates an attempt to use credible and/or relevant sources to support ideas that are appropriate for the discipline and genre of the writing in correct APA format.	Demonstrates an attempt to use sources to support ideas in the writing.	Unacceptable
Score	5	4	3	2	0
Application of Risk Assessment	Professional level risk assessment showing before, design changes, after.	Uses straightforward risk assessment that generally conveys risk and appropriate mitigation with few errors.	Uses risk assessment that generally analyzes risk with mitigation, although writing may include some errors.	Attempted, but errors in analyzing and reducing risk, unclear conclusions.	Unacceptable
Score	5	4	3	2	0
				Aggregate Score:	Out of 50 points

during the capstone course has been significant at PNW. For instance, in the Spring 2019 semester, only 5 out of 28 projects were industry sponsored. Other projects came from various places; 2 were from collegiate competitions (Society of Automotive Engineers (SAE) Mini-Baja and National Fluid Power Association (NFPA) Hydraulic Bike), 11 were personal projects, and 10 were academically sponsored. So, fewer than 20% of the Spring 2019 projects were industry sponsored. Prior to 2000, a majority of the capstone projects were industry sponsored. In 2003, PNW began consistently participating in SAE Mini-Baja competitions and more recently SAE Formula and NFPA Hydraulic Bike competitions. Each year, several projects from these competitions are used for capstone projects, but they are usually less than 15% of the active projects. Anecdotally, the faculty have noticed that students who complete an industrial project or a student competition project typically get more responsible and higher paying jobs than those students who complete a personal or academic project. This plays a significant role in upcoming course changes and challenges.

As previously noted, there are many models that can be followed in terms of how to design a successful experiential learning capstone course, some with industry partners and some without. The question is, which successful model of a capstone course, or variation of a model, is the best fit for PNW's student population? Should all students be required to complete an industry sponsored project or a student competition project? Or can personal and academically sponsored projects be designed so that they offer students the same experiential learning opportunities to make these projects worthwhile as well?

Examples of Successful Experiential Learning Capstone Models

By 2018, it became clear that the old method of requiring individual students to find and initiate their own capstone project topics was no longer viable. The increase in course enrollment alone created a requirement for larger student teams in order for faculty to effectively facilitate the projects. Several successful experiential learning capstone courses noted in the literature offer some options for redesign that could be considered at PNW.

Student competitions are an excellent way to involve students in structured team experiences that often include close ties to industry while not necessarily having a direct industry partnership. One example of an extremely successful student competition experience is illustrated by IUPUI's Motorsports Engineering program. This program did not just partner with a particular company within the motorsports industry, but rather utilized an industrial advisory board and essentially partnered with the motorsports industry as a whole to support all employers in the motorsports industry. They used assessment for their capstone project that mirrored industry assessment and their project outcomes were actual racecars. "The approach yields courses and student projects and experiences more closely aligned with industry needs. Feedback from both students and industry has indicated that program graduates have a much better perspective on the solutions to the challenges they will face when working in the rapidly evolving and demanding motorsports industry [3]." PNW has similarly found that students working on student competitions that hold the students to high industry standards, do result in students who hold themselves to higher standards. This is a good option for student capstone design.

At Purdue Polytechnic New Albany campus, a multidisciplinary entrepreneurial senior capstone was initiated that resulted in small scale startup companies [4]. This approach is a testament to the student's job-readiness and knowhow shining through in a capstone project that was initiated by an individual student or group of students.

Yet another model for successful capstone projects is to have faculty initiate and drive a project. Xiao et. al describe using project-based learning to allow students to gain knowledge and skills through developing real products. The students were given a design problem to design and build a competitive desktop 3 axis CNC router for less than $500 capable of cutting hard wood for hobbyists and DIYers. These are all very specific customer requirements provided by the faculty for the student to follow. The students then followed a systematic design process to develop a product concept, design and prototype, test and evaluate, refine and produce the product [5]. This process mimics industry experience well and keeps students focused on the task.

These three examples are not integrally intertwined with a specific industry partner but appear to have been just as effective in providing students with job-ready skills as an outcome. Looking at models that are intertwined with industry does highlight that when working with an industry partner, there is typically a higher level of complexity involved as well as more complexity in funding and administrative operations. One example of a senior design clinic at the University of Toledo describes a 17 year history of 90+ projects as of 2010 with over 1200+ students. Their projects were interdisciplinary and industry based [6]. With this type of structure, there was one faculty member that serves as Course Director and was in charge of all administrative aspects of the course, including identifying the projects. Each group was supervised by a technical faculty advisor and a client advisor who meet on a weekly basis. There was also dedicated office space for the students to use when meeting with the client.

A similar structure was found at Seattle University that boasted a 20+ year history with over 100+ projects and 37 sponsors. With this model, the industrial sponsors paid $5,000-$20,000 for each capstone project which was administered through the Seattle University Project Center [7]. This center handled all of the administrative duties related to the senior capstone such as recruiting the projects, signing contract agreements and managing all aspects of the projects. They had a staff consisting of a director, a corporate relations manager, and an administrative assistant. In addition there was an advisory board to evaluate the projects. This type of model once well established, provides the infrastructure needed to maintain ongoing industry partnerships, however it can be difficult to initially establish.

A slightly different approach to creating industry partnerships was conducted by Robert Durkin who argued that the approach to acquiring knowledge is by doing and it should be the same approach used by industry; use a team based design experience that includes both leadership and teamwork components. To accomplish this, faculty applied for a grant to offer free consulting to local industry. This resulted in 32 students conducting 17 industrial capstone projects over three summers [8]. This approach was a bit less complicated than the first two industry based capstone centers described above. It was also shorter lived, but still effective.

Paradigm Shift for Choosing Capstone Projects

To initiate a new paradigm shift for capstone projects at PNW, faculty have implemented two major changes to the course. First, faculty have adopted a new method for choosing projects that was tested during the Fall 2019 semester. This new method was a first step toward allowing faculty to maintain a higher probability of successfully achieving the student outcomes for the course while laying the foundations for implementation of other capstone models as resources and infrastructures for these new models are being developed. Below is the new method faculty have adopted for students to be assigned to a project.

> <u>Determining Student Capstone Projects</u>
> All students will submit project requests as part of the first course in the two-course capstone sequence. Based on the requests, students will be assigned projects and groups

as follows:

Industry Based Capstone Projects

1. Work Project: If a student is working in an Engineering Technology field, they are encouraged to submit project requests from their job. If the student's project is approved, the student will be the group leader. Additional group members will be assigned only after discussions with the student's employer.

Capstone Projects without Industry Partners

2. Student Competition Projects: A student may participate as a team member of an established competition project team with instructor approval.

3. Individual Student Initiated Project: If the student project is approved, that student will be the project leader and will be assigned additional group members by the faculty.

4. Faculty Initiated or University Project: Students will be assigned a project and a group by the faculty.

The faculty found that by categorizing each project that students proposed for their capstone work into one of four categories (Work Project, Student Competition Project, Individual Student Initiated Project, Faculty Initiated or University Project) that more flexibility is provided to accommodate students who are working or involved in an entrepreneurial endeavor as well as providing enriching project experiences for less experienced students. The faculty creates teams of two to four students with cross evaluation of team members included in the grading. The team evaluation effects 1/3 of the final report and presentation grade, so is a significant incentive for group members to maintain a high level of participation.

A second major change to the capstone course that the faculty made was the result of PNW's College of Technology determining that a more proactive approach should be taken to initiate industry sponsored projects for Engineering Technology students. There is ongoing effort to increase industry sponsored projects within the ET programs and the role they play in the capstone project experience. To that end, PNW's College of Technology hired an industrial relations specialist with the roles of connecting students with industry as well as teaming up with industry on appropriate projects that provide a breadth of knowledge to senior students. Whereas an industrial relations specialist is helpful with many aspects of developing industry partnerships (ie: bringing awareness of job opportunities to students, providing a single point of contact for local industry to connect to the college), it was found that the best method to increase industry sponsored projects was to have faculty connect directly with industry partners. This creates an avenue for sharing of specialty expertise areas for problem solving. To this end, specific College of Technology faculty have been tasked with the responsibility to connect directly with industry and identify viable projects that students will work on under the tutelage of a faculty expert.

In addition, a new facility called the Center for Innovation and Design in Engineering Technology (CIDET) has been developed under the College of Technology. This Center consists of a space that has been designed specifically for industry collaboration with students. The facility was recently completed in 2021. With CIDET in place, the faculty in charge of the senior capstone courses will now be able to integrate multidisciplinary projects more fully across multiple Engineering Technology disciplines (ie: integrate Electrical Engineering Technology projects with Mechanical Engineering Technology projects) thus creating a more real-life project experience akin to that which students will encounter in the workplace. This new CIDET facility has been structured to allow for the basic foundational facility, administrative resources and logistical support needed to expand the integration of industry support into capstone projects. This structure provides similar foundational aspects that have proven successful in other capstone models such as a senior design clinic, proposing grants for consulting work and/or setting up a self-supportive industrial sponsored paid project center.

Capstone Project Funding

The issue of funding capstone projects will always be of paramount importance. Over the decades, as PNW's Engineering Technology student profiles have shifted, so have the methods of identifying funding for capstone projects. As was stated previously, in the 1980's and 1990's, capstone projects were typically associated with a student's workplace which was, at that time, focused on part-time adult learners. These projects were typically funded by the "industry partner" that was the student's employer and de facto project sponsor. These types of projects could be completed for as little as a few hundred dollars to extensive projects costing in the hundreds of thousands of dollars depending on the student's experience and current position within the company. For example, a recent capstone project was completed by a student who designed, built, and installed a robotic deburring cell for a local company that manufactures automotive transmission components.

As the types of capstone projects shifted to projects for student competitions, individual student-initiated projects and faculty-initiated projects, finding sources of funding for the projects required the students and faculty to get creative. Several sources of funding were identified for competition type projects. For ongoing yearly competitions such as the SAE Baja competitions, a student club that existed for SAE Baja shifted its activity to include a philanthropic aspect. The students set up a website that provided a location for sponsors to donate and the students began to engage with potential sponsors to get their support. The students also actively participated in local trade shows to support the PNW College of Technology which provided opportunities to display their past vehicles that proudly display past sponsor logos thus encouraging future sponsorships. At the end of the competitions, the students provide the sponsors with pictures and plaques to further cultivate their continued support. In addition to the industry sponsor donations, another method of fundraising for the competition groups is an annual student clubs sponsored car show. This is a funding model that is student initiated and university backed which brings in club funds that can then be used to support capstone projects that happen to be intertwined with the clubs' competitions.

Another major funding source for competition type capstone projects completed by the Baja team and the National Fluid Power Association (NFPA) hydraulic bike competition is requests for undergraduate student research funding from the PNW Vice Chancellor for Academic Affairs office. This option for funding provides for $300 for any individual student research project and $600 funding support for teams of two or more students. This funding option is also available for any individually initiated student capstone project. Some examples of successful individual student projects that were funded from these sources include developing, designing and building a plastic shredding machine and a platic molding machine. Student initiated projects that require funding beyond what the Vice Chancellor for Academic Affairs allots are usually supplemented by the students themselves.

Funding for faculty-initiated projects requires yet another funding approach as these projects are usually developed for use by the ET department for future research or laboratory work. Some examples of these types of projects include designing and building several types of pneumatic trainers, HVAC Systems, Heat Transfer Laboratory Equipment, and a Portable Tensile Testing Machine. These projects allowed students to put their coursework to direct use and to show industry partners just how well they could apply the concepts they learned to create working units. For these types of projects, the Engineering Technology department was the direct stakeholder. These projects were therefore funded from department or college funds.

As project work shifts and PNW's Engineering Technology department takes a more proactive approach to initiate industry sponsored projects for Engineering Technology students, it is anticipated that the funding source model will again change. With the implementation of CIDET, as previously stated, opportunities for a paid industry projects model is taking form where industry can fund projects through donations or contracts. PNW is also looking into using these funds to pay senior project class tuition for the students working on the projects.

Conclusion

Although PNW's College of Technology administration understands that industry partnerships in capstone design are key to developing work-force ready Engineering Technology graduates, the capstone design courses still face numerous challenges in the future. The faculty need to maintain the paradigm shift in order to identify quality projects and continue to collect data on their student population in order to understand this and other driving forces beyond the course itself. Faculty will need to determine how best to develop and maintain industry partnerships on an on-going basis with the resources that are being put in place, a method to finance the administration of projects that is up to industry standard must be identified, and a fair grading systems for both individual and team accomplishments must be developed for the course.

Gone are the days of individualized capstone projects initiated by students in the Engineering Technology programs at PNW. In the days of the part-time working student at PWN, it was possible for students to seamlessly integrate their classroom knowledge with what they experienced at work. As the university continues to transition away from part-time working students, other means of integrating industry experiences must be found to properly prepare full-time students, who do not have industrial experience, with professional skills and technical knowhow. Ultimately, these skills should be integrated throughout the curriculum not just added in a final capstone course and then the final capstone course should allow students to be immersed in a professional environment. An industrial basis for as many projects as possible will provide students the richest learning experience and help prepare them for their future careers.

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