Creativity, Innovation and Entrepreneurship, Vol. 125, 2024, 112–122
https://doi.org/10.54941/ahfe1004727

Engineering Project Management Skill Development in Research vs. Corporate Realms

Donovan Esqueda-Merino[1], Hector R. Morano-Okuno[1], Daishi A. Murano-Labastida[1], J. Enrique Chong-Quero[1], Gloria A. González-Sarmiento[1], Arturo Vargas-Olivares[1], Arturo D. López-Rojas[2], Carlos A. Cruz-Villar[2], Joaquin Loaiza-Martínez[1], Armando R. San Vicente-Cisneros[1], and Daniel Rodríguez-Flores[2]

[1]Tecnologico de Monterrey, School of Engineering and Sciences, Monterrey, N.L. Mexico
[2]CINVESTAV-IPN, Electrical Engineering Department, Mexico City, Mexico

ABSTRACT

Through this work, we present two different educative approaches taken in a capstone course for Senior Mechatronic Engineers. Having a common syllabus and learning outcomes, this course was lectured by different groups of professors: one group would teach with a research orientation in partnership with a research laboratory, while the other group would teach with an enterprise orientation in collaboration with diverse internal and external stakeholders. For this course, students had to elaborate on a team project that would end up in a physical prototype and a poster demonstration at an Engineering fair. Students would then participate in a mock interview assessment evaluated by their professors, where they would also assess their self-efficacy related to different skills. Results show that while the difference between the professor's expectations and the student's self-assessment is not that big, the course's emphasis might affect which skills were further developed.

Keywords: Project management, New product development, Research and development, Educative innovation, Higher education

INTRODUCTION

Mechatronics Engineering requires an understanding of diverse topics across different engineering specialties (i.e. mechanics, electronics, control systems, computer engineering). This is of utmost importance to design, integrate, validate, or evaluate proposals involving multiple engineering domains. Thus, students of this major must have a very comprehensive skillset to be successful.

Capstone courses provide an excellent opportunity to evaluate the performance of students regarding both hard and soft skills. However, empowering newly formed Mechatronic Engineers for their capstone projects necessitates exposure to applied core concepts, tools, we well as strategic thinking skills

(García-Moran et al., 2021). This can be fostered with adequate challenges that become relevant and motivational for the students.

Since 2019, Tecnológico de Monterrey has included Training Partners (i.e. institutions providing real-life business cases to students) as part of their educative model. As presented by Esqueda et al. (2023a, 2023b), they actively participate in different ways in the best interests of the student's education, at the time that they explore new ideas to help their companies become more competitive.

The industry-university collaboration programs benefit students by immersing them in a work-related context, facilitating learning of industry procedures, teamwork, independent learning, communication, and collaboration (Morano-Okuno et al., 2019). Moreover, higher education aims at students' development of essential competencies in students, encouraging technical, technological, analytical, and critical thinking growth (Miranda et al., 2021) that will be useful in their future work lives. Likewise, employers place importance on soft skills possessed by future graduates as much as on technical skills (Low et al., 2021).

In industry, Mechatronic Engineers leading innovative projects involving new product development must have a clear understanding of design, manufacturing, and business alike (Esqueda et al., 2019). Educational methodologies such as the one presented in Esqueda et al. (2023c) explore teaching by linking a course's learning outcomes and Key Performance Indicators (KPIs) in engineering courses, specifically aimed at product development.

However, the requirements of research projects might be slightly different from those of industry, as their KPIs and timelines are different. Yet, common ground can be identified in Research & Development (R&D) projects, where there exists a higher incertitude of the project's commercial success. Often, alliances are made between the academy and industry even when there is no expected tangible outcome, but rather a learning experience over the whole innovation cycle (Perkmann & Walsh, 2007).

To facilitate project execution in collaborative R&D projects, Barnes et al. (2006) propose having clear objectives, defined roles, and responsibilities. Additionally, DeCampos et al. (2022) state the need for adequate frameworks and methodologies, especially when dealing with the latest technological developments posed by Industry 4.0 (Cotrino et al., 2020, Ribeiro et al., 2021), to whom Mechatronic Engineers are akin.

However, quantifying the competence of project management is challenging (Crawford, 2000, El-Sabaa, 2021). In fact, the developments 4th Industrial Revolution necessitates new ways of managing projects, emphasizing the need for insights into the leadership style of project managers (Marnewick & Marnewick, 2019), which is crucial since having an adequate motivation for the team strongly supports the project's success (Anantatmula, 2010).

Measures of self-efficacy beliefs are considered the best predictors of individual performance, highlighting a clear gap in project management literature (Blomquist et al., 2016). Self-efficacy, defined as an individual's belief in their ability to succeed (Bandura, 1977), emerges as a valuable metric for students managing complex Mechatronic projects (Blomquist et al., 2016, García-Moran et al., 2021, Borg et al., 2023).

Assessing self-efficacy helps educational institutions develop students' confidence and skills necessary for navigating the complexities of Mechatronic projects effectively. However, to reduce the bias in the students' perception, it is equally important to have an external assessment of the student's performance.

Through this paper, we present a comparative look at two groups of Mechatronic Engineering undergraduate students developing an R&D project for a Training Partner in the context of a capstone course. Both courses, taught by different professors, have different teaching emphases but still focus on the project's completion. Assessments are provided by both the students and their professors to contrast the results.

COURSE CONTENT AND LEARNING OBJECTIVES

The present work falls within the closing capstone course for the Mechatronics Engineering Major at the University, named Design and Implementation of Mechatronic Systems. This course lasts 11 weeks, for a total of 260 hours of work.

This course has the following learning objectives (Tecnológico de Monterrey, 2023):

- O1. Propose feasible and cutting-edge technological solutions to solve industrial, social, and environmental problems.
- O2. Apply methodologies and technological tools for the design of mechatronic systems.
- O3. Validate automation proposals guaranteeing quality, safety, and productivity.
- O4. Implement automation proposals using cutting-edge technologies.
- O5. Prepare state-of-the-art research based on reliable sources to generate a proposal for a mechatronic system.
- O6. Generate innovative proposals for a mechatronic system according to standards.
- O7. Evaluate the technical and economic feasibility of technological development based on restrictions.

This involves a series of lectures and project-oriented activities in relation to the following modules: research methodologies, definition of the project and development of the proposal, conceptual design, detailed engineering, and implementation and evaluation. The direction of the projects is set out with the help of the Training Partners, which can be chosen as internal or external entities to the University as long as they pose a real-life industrial problem to the students.

METHODOLOGY AND SKILLS DEVELOPMENT

In the first half of 2023, a total of 37 students at our campus at Greater Mexico City enrolled in said course, distributed into two different groups having different professors, projects, and emphases – one geared towards academic research and the other tailored to meet industrial needs (see Table 1).

Table 1. Student projects as part of the capstone course.

Group 1 projects	No. of students	Partnership
Drones with visual recognition	3	American multinational information technology company
Train recognition system using artificial vision	3	Small-sized industrial weighing company
Signal filtering for industrial button panel	3	Small-sized distributor of industrial components
Automatic screw-counter for screw-making machine	3	Small-sized screw-maker company
Bioreactor instrumentation	4	Internal
Solar panel with sun tracking	3	
IoT greenhouse	3	
Group 2 projects	**No. of students**	**Partnership**
Force feedback system between 2 robots	4	Mexican Governmental Scientific Research Institution (CINVESTAV)
Physical human-robot interaction with a cobot	4	
Mobile robot with top-view camera for navigation tasks	4	
Mobile robot following people through artificial vision	4	

Students could choose in which group to enroll based on the titles of the potential projects they could be working on, as well as the name of the professors, without any further information. Then, on the first week of class, professors would provide further information about the projects, their Training Partners and their expectations of the projects, size of the teams, among other important information for the grading of the course. Students would then be able to contact partners as needed, but some progress updates would be established with the assistance of the professors. If specific elements from the Training Partner were required (e.g. drone, industrial panel button, Cobot), professors would make sure they were accessible to the students (see Figure 1).

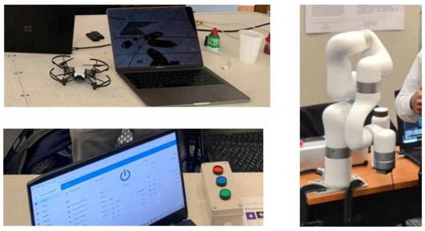

Figure 1: Top-left: Drones (for visual recognition project), bottom-left: Industrial button panel (for signal filtering project), right: Cobot (for physical human-robot interaction project).

While both groups of professors would cover all the syllabus topics of the course, they would teach them in a way in which they could satisfy the requirements of their partnerships. For example, Group 1 (i.e. Enterprise-focused projects) would use SCRUM (Sutherland & Schwaber, 1995) as a project management methodology, whereas Group 2 (Research-oriented projects) would focus more on a progressive execution of the project with slightly more flexible deadlines. Another example is related to the research of the state-of-the-art, which was more thorough in Group 2. Nevertheless, both groups of professors would make sure that students had all the right tools to successfully accomplish their projects before the end of the course.

IMPACT ASSESSMENT

The objective of this study is to identify if there are any differences in the development of skills and sub-competences (i.e. a mix of skills, knowledge, behaviours, and abilities) among the students in relation to the way in which this course was taken. To measure this, students participated in different activities with distinct means of evaluation:

Poster Exhibition and Mock Interview

After students presented their projects to their Training Partners and their final grade for the course was computed, they had to take one last one-week course to fulfil their semester. This pass/fail course, oriented towards feedback the students, had two main activities (see Figure 2):

Figure 2: Left: Poster presentation at engineering fair. Right: Mock interview assessment.

The first one implied an oral presentation with a poster at the Engineering fair of the campus. When possible, a space for their prototypes would be assigned so that they could show their functionality. It was requested that all students participate in it and that through the 4 hours that it lasted, their poster was never left alone. During this time, students would present their projects to faculty, peers, and special guests from the industrial and entrepreneurial world.

The second one was a Mock Interview Assessment. This activity is one that has been carried out at the campus for several years for diverse engineering majors, and that has no relation to their past projects whatsoever. Instead, it follows up on some of the abilities that partner companies have reported as relevant when hiring young graduates. For this matter, a leading professor provides students with an engineering business case, strategically distributing the information over time to the students. In parallel, guests evaluated the performance of the students in the teamwork sessions and two-people presentations of their findings regarding the following sub-competences:

- SC1. Effective communication
- SC2. Teamwork
- SC3. Engineering problems formulation and resolution
- SC4. Methodological approach to design
- SC5. Impact on business, society, and environment
- SC6. Ethical commitment
- SC7. Innovation capability
- SC8. Leadership

Self-Efficacy Evaluations

At the end of the one-week course, students would fill out a 5-point scale Likert questionnaire (Nemoto & Beglar, 2014) regarding their self-efficacy associated with the learning outcomes of the course and the short-version project management self-efficacy questionnaire proposed by (Blomquist et al., 2016):

- PM1: Effective communication with stakeholders regardless of their technical or operational understanding.
- PM2: Work breakdown considering tangibility, measurability, commitment, and reachability.
- PM3: Execution of effective meetings introspection analysis and plan of action.
- PM4: Convincing key stakeholders by clearly introducing business benefits and product features.
- PM5: Elaboration of a project charter or similar document to get sign-off from key stakeholders.
- PM6: Evaluation of progress and acting on feedback based on stakeholder's approval.

Figure 3 presents the results of these self-efficacy questions, in which we can observe that the enterprise-oriented group felt that their projects allowed them to further reach the learning objectives of the course (except the part of the technological proposal). However, on the side of the project management skills, we can see that while this same group felt that they became better at planning and communicating, their skills for execution, evaluation, and convincing of the Training Partners were less developed than such of the Research-oriented group.

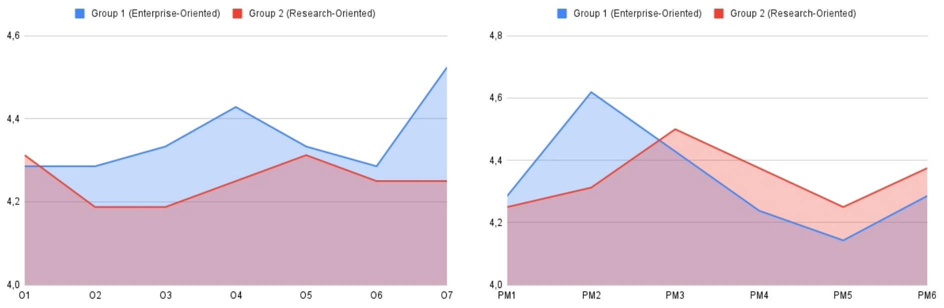

Figure 3: Self-assessment evaluations. Left: learning outcomes of the course, right: project management skills. Both were evaluated using a 5-point likert scale.

Cross-Evaluation

As a final element, we were interested to see if the self-efficacy of students was similar to the evaluation given by the guests to the assessment. However, guests focused on the previously presented sub-competences instead of skills, so a relationship had to be established. Table II relates the 8 sub-competences (i.e. SC1-SC8) with both the Project Management Skills (PM1-PM6) and the Learning Objectives (O1-O7) of the course.

Table 2. Externally evaluated sub-competences versus self-efficacy skills assessed.

	Project Management Skills						Learning Objectives						
	PM1	PM2	PM3	PM4	PM5	PM6	O1	O2	O3	O4	O5	O6	O7
SC1	X		X	X	X	X					X		
SC2	X	X	X		X	X							
SC3		X	X		X	X	X	X	X	X	X	X	X
SC4		X	X	X	X	X	X	X	X		X	X	X
SC5	X			X	X	X	X		X				X
SC6							X		X				
SC7							X			X	X	X	
SC8			X			X	X						

The grading of the sub-competences was done on a scale of 1 (incipient) to 4 (outstanding). However, as the self-efficacy evaluations were carried out on a Likert scale of 1 to 5, for both cases the data was normalized to values going from 0 to 1.

As a second step, the equivalent sub-competence (*ESC*) is calculated. This was obtained as the average value of the related sub-competences and related learning objectives. For example, and considering Table II, the first and last element's equivalent sub-competences were calculated as presented in (1) and (2):

$$ESC_1 = \frac{PM_1 + PM_3 + PM_4 + PM_5 + PM_6 + O_5}{6} \quad (1)$$

$$ESC_8 = \frac{PM_3 + PM_5 + PM_6}{3} \quad (2)$$

Then, an equivalent student's index $\Delta SC_n(m)$ was calculated for each student (m) related to each sub-competence (n) as presented in (3).

$$\Delta SC_n(m) = ESC_n(m) - SC_n(m) \tag{3}$$

The mean value and standard deviation of the responses of the different students can be observed in Figure 4. As we can observe, the standard deviation is similar in all rubrics (close to 0.15), meaning that in general the opinions of both the students and the guests didn't vary too much.

From Figure 4 we can observe that both guests and students had a similar feeling in relation to sub-competences 1, 5, and 6. For sub-competencies 2, 3, 4, and 7, the difference becomes more important. Lastly, it is important to see that students have a much higher self-appreciation of their leadership than what the external guests could identify in the exercises.

This last element becomes interesting as not everyone can be a leader in the team at the same time, but since it wasn't requested neither in the project nor at the mock interview to state the role of a leader, most of the students felt that they were implicitly taking the role. Moreover, as stated by (Low et al., 2021; Marnewick et al., 2019), leadership is of paramount importance in project management roles, even if it is not usually implicit hierarchically.

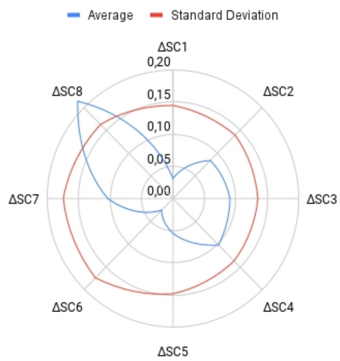

Figure 4: Difference (ΔSC_n) between sub-competence evaluation (SC_n) provided by external evaluators and equivalent student's index (ESC_n) calculated from their learning outcomes and project management skills self-assessment.

CONCLUSION

Mechatronic Engineers dealing with innovative technology-based projects require a merger of technical expertise, soft skills, strategic thinking, and effective collaboration. As vicarious experiences are not enough for students of this major to be able to develop such projects, challenges with Training Partners were provided as part of their capstone course to bridge this gap and mirror real-world demands.

This study examined two educational paradigms: one research-oriented, the other enterprise-driven. Outcomes show that enterprise-oriented students felt more proficient about the learning objectives of the course and their planning skills, in contrast to research-oriented students who felt more confident in the project execution and dealing with the Training Partners. Lastly, Self-assessments indicated higher leadership proficiency among students compared to the professors' observations, underscoring the pivotal role of leadership in managing technological projects.

Future work could include the use of the product development framework presented in Esqueda et al. (2024) with startup companies to compare against new groups both orientation towards research and enterprise realms.

ACKNOWLEDGMENT

The authors would like to acknowledge the financial support of Writing Lab, Institute for the Future of Education, Tecnologico de Monterrey, Mexico, in the production of this work. We would also like to thank Emilio Caudillo, Rodolfo Figueroa, Fernando Méndez, Ivan Trujillo, Iker Villagomez, Manlio Quintana, Carlos Castro, Israel Abarca, Diego Balderas, Hector Munro, and Ulises Romero for sharing their work to illustrate this research.

REFERENCES

Anantatmula, V. S. (2010). Project manager leadership role in improving project performance. Engineering management journal, 22(1), 13–22.

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. Psychological review, 84(2), 191.

Barnes, T. A., Pashby, I. R., & Gibbons, A. M. (2006). Managing collaborative R&D projects development of a practical management tool. International Journal of Project Management, 24(5), 395–404.

Blomquist, T., Farashah, A. D., & Thomas, J. (2016). Project management self-efficacy as a predictor of project performance: Constructing and validating a domain-specific scale. International Journal of Project Management, 34(8), 1417–1432.

Borg, J., Scott-Young, C. M., & Borg, N. (2023). Early career project managers' work readiness: Adopting a self-efficacy lens. International Journal of Project Management, 41(2), 102454.

Cotrino, A., Sebastián, M. A., & González-Gaya, C. (2020). Industry 4.0 roadmap: Implementation for small and medium-sized enterprises. Applied sciences, 10(23), 8566.

Crawford, L. (2000, June). Profiling the competent project manager. In Proceedings of PMI Research Conference (pp. 3–15). Newton Square, PA, USA: Project Management Institute.

DeCampos, H. A., Fawcett, S. E., & Melnyk, S. A. (2022). Collaboration expectation gaps, transparency and integrated NPD performance: A multi-case study. Journal of Purchasing and Supply Management, 28(4), 100789.

El-Sabaa, S. (2001). The skills and career path of an effective project manager. International journal of project management, 19(1), 1–7.

Esqueda-Merino, D. M., Bargalló-Rocha, A., García-García, A., Maldonado-Carrillo R., Chong-Quero, J. E. (2023). Enhancing student learning through multi-case collaboration industry partnerships for Product Design Education. Technological Advancements & Innovations of Future of Education: Select Proceedings of FOE 2023, in press.

Esqueda-Merino, D. M., Delgado-Cepeda, F. J., Morano-Okuno, H., & García, A. (2019). Engineering product design education with a mixed design-thinking & lean start-up approach. In DS 95: Proceedings of the 21st International Conference on Engineering and Product Design Education (E&PDE 2019), University of Strathclyde, Glasgow. 12th-13th September 2019.

Esqueda-Merino, D. M., González-Sarmiento, G. A., Morano-Okuno, H. R., San Vicente-Cisneros, A. R., López-Rojas A. D. & Quintero-Fernández D. A. (2023). Developing Industry 4.0 Skills: A case study for Engineering students. Technological Advancements & Innovations of Future of Education: Select Proceedings of FOE 2023, in press.

Esqueda-Merino, D., Jaramillo-Godínez, R., Miranda-Mendoza, J., Contreras-Domínguez, D., FRACTAL methodology for Industry 4.0 & Society 5.0-Driven New Product Development: empowering engineering students for startup innovation (2024). 12th International Conference on Information and Education Technology. in press.

Esqueda-Merino, D. M., Mondragon-Ugarte, D., Vargas-Olivares, A., Chong-Quero, J. E., & Herrera-Corral, J. A. (2023). Role: Role-Oriented Learning Environment: Innovative Educational Approach for Engineering Education. In Proceedings of the 2023 8th International Conference on Information and Education Innovations (pp. 55–61).

Garcia-Moran, E., Esqueda, D., Solis-Cordova, J. D. J., Villagomez, L., Morano, H., & Ramírez, R. (2021). Industry 4.0 Competencies as the Core of Online Engineering Laboratories. Design and Technology Education, 26(3), 30–51.

Low, S. P., Gao, S., & Ng, E. W. L. (2021). Future-ready project and facility management graduates in Singapore for industry 4.0: Transforming mindsets and competencies. Engineering, Construction and Architectural Management, 28(1), 270–290.

Marnewick, A. L., & Marnewick, C. (2019). The ability of project managers to implement industry 4.0-related projects. IEEE Access, 8, 314–324.

Miranda, J., Navarrete, C., Noguez, J., Molina-Espinosa, J. M., Ramírez-Montoya, M. S., Navarro-Tuch, S. A., Bustamante-Bello, M. R., Rosas-Fernández, J. B. & Molina, A. (2021). The core components of education 4.0 in higher education: Three case studies in engineering education. Computers & Electrical Engineering, 93, 107278.

Morano-Okuno, H., Sandoval-Benitez, G., Caltenco-Castillo, R., Esqueda-Merino, D., Garcia-Moran, E., & Garcia-Garcia, A. (2019, December). Industry-University Collaboration: An Educational Program with Automotive Industry. In 2019 IEEE International Conference on Engineering, Technology and Education (TALE) (pp. 1–7). IEEE.

Nemoto, T., & Beglar, D. (2014). Likert-scale questionnaires. In JALT 2013 conference proceedings (pp. 1–8).

Perkmann, M., & Walsh, K. (2007). University–industry relationships and open innovation: Towards a research agenda. International journal of management reviews, 9(4), 259–280.

Ribeiro, A., Amaral, A., & Barros, T. (2021). Project Manager Competencies in the context of the Industry 4.0. Procedia computer science, 181, 803–810.

Sutherland, J., & Schwaber, K. (1995). SCRUM Development Process; Business Object Design and Implementation. In 10th Annual Conference on Object-Oriented Programming Systems, Languages, and Applications Addendum to the Proceedings. ACM/SIGPLAN October.

Tecnológico de Monterrey. Planes de Estudio. (2023) Website: https://samp.itesm.mx/Materias/VistaPreliminarMateria?clave=MR3002B&lang=EN#.