IMPROVING STUDENTS´ PROJECT MANAGEMENT SKILLS IN BIOMEDICAL ENGINEERING PROJECTS

Luis Ballesteros-Sánchez, Rocío Rodríguez-Rivero, Andrés Díaz Lantada, Jesús Juan Ruíz, Rafael Borge García, Enrique Chacón Tanarro, Miguel Ángel Peláez García, Ana Moreno Romero, Rafael Ramos Díaz.

Escuela Técnica Superior de Ingenieros Industriales (ETSII)
Universidad Politécnica de Madrid (UPM)

ABSTRACT

Earlier studies suggested the Project Management (PM) skills are core to the leadership attributes of engineers. Some interrelated research streams are available for an understanding of the challenges in teaching and learning both engineering and PM education. The need to teach and learn PM in engineering schools has been advanced by employers. Today, organizations expect engineers to excel in many soft skills, including teamwork and communication. They are keen to tap into these vital soft skills that they obtained during their studies and periods of work experience, rather than just degree-specific knowledge. In this study, an integrative Project-Based Learning (PBL) approach is presented. It is used in two courses devoted to the biomedical engineering field, namely “Bioengineering Design” and “MedTech”, included in the Master’s Degree in Industrial Engineering and in the Master’s Degree in Engineering Management, respectively, both at the ETSI Industriales from Universidad Politécnica de Madrid. These courses follow a framework completely aligned with the spirit of the International CDIO Initiative. Students from both courses collaborate in teams and live through the complete project life cycle of innovative medical devices. The PBL approach applied is aimed to allow students to learn basic PM skills such as technical, business, and human ones. From the beginning of the courses, students are provided with specific knowledge, tools, and exercises to improve their capabilities for building strong teams and achieving their project goals. By integrating PM deliverables (scope, time, cost, risk, quality and communication management) with team development strategies (team agreement, personality identification, competencies assessment, teambuilding, roles definition, and personal interviews) and specific soft skills workshops it has been possible to provide an effective learning experience for improving students PM skills. Main results, difficulties, benefits, and conclusions of the experience are presented in this work as well as lessons learned for the continuous improvement for the next courses.

KEYWORDS

CDIO as Context, Project Based Learning, Project Management, Skills, Biomedical Engineering, Standards: 2,3,4,7, 8.

INTRODUCTION

In this study, a PBL approach following CDIO principles is applied to allow students to learn basic Project Management (PM) skills. These students belong to two courses devoted to the biomedical engineering field, namely “Bioengineering Design” and “MedTech”, included in the Master’s Degree in Industrial Engineering and in the Master’s Degree in Engineering Management.

From the beginning of the courses, students are provided with specific knowledge, tools and exercises to improve their capabilities for building strong teams and achieving their project goals. By integrating PM deliverables (scope, time, cost, risk, quality and communication management) with team development strategies (team agreement, personality identification, competencies assessment, teambuilding, roles definition, and personal interviews) and specific soft skills workshops, it has been possible to provide an effective learning experience for improving students PM skills.

Main literature review, learning approach, results, difficulties, lessons learned and conclusions of this experience during the 2018-2019 course are presented in this paper.

IMPROVING ENGINEERS´ PROJECT MANAGEMENT COMPETENCIES

Earlier studies suggested the project management skills are core to the leadership attributes of engineers (Hamilton, 2006; Wearne, 2004). Some interrelated research streams are available for an understanding of the challenges in teaching and learning both engineering (Zhou, 2012) and project management education (Ashleich et al., 2012; Louw & Rwelamila, 2012). Students’ experiences have remained a major theme of interest to scholars, especially in the engineering and project management areas (Dietrich & Urban, 1998; Heer et al., 2003).

The notion of students’ experience in studying project management remains a core element of the wider teaching and learning discourse (Chipulu et al., 2011), especially in light of emerging ideas concerning the creation of reflective and creative practitioners (Berggren et al., 2008; Crawford et al., 2008). This need to teach and learn project management in engineering schools has been advanced by employers.

Project Management Competencies at a glance

The project management function is relevant and requires a wide vision of different areas to coordinate, along with a wide range of personal skills (Ahsan & Ho, 2013; Kerzner and Kerzner, 2017; PMI, 2017). To successfully manage projects, different skills are required, including interpersonal ability, technical competencies, and cognitive aptitude, along with the ability to understand the situation and people, and to dynamically integrate appropriate leadership behaviors (Pant and Baroudi, 2008).

Competencies for project management can be defined as a cluster of knowledge, aptitudes, attitudes, and behaviors that are needed to accomplish a piece of work (Boyatzis, 1982). Along these lines, Parry (1998) defines competences as a set of related knowledge, skills and personal characteristics that have an influence on individual and group work in an organization, are related to job-performance and can be improved by training and professional development.

The importance that is attributed to the strategic role of project management in organizations has led in recent decades to the growing development of frameworks of international competencies and professional standards. Some of the main competency frameworks are Project Manager Professional (PMP) certification by the Project Management Institute (PMI, 2017), the International Project Management Association certification (IPMA, 2015), the competency framework of the Association for Project Management (APM, 2008) and the professional standards that have been defined by the Australian Institute of Project Management (AIPM, 2008).

Based on previous frameworks of project management competencies, as well as other relevant researches, Takey and Carvalho (2015) propose a set of competencies categories in the project management field. These competences are presented in Table 1 along with correspondent CDIO Syllabus version 2.0. (Crawley et al., 2011).

Table 1. Project management competencies categories.
Source: Adapted from Takey and Carvalho (2015)

Category	**Competencies**	**CDIO Syllabus v2.0**
Project management processes	Integration management; scope management; time management; costs management; quality management; human resource management; communication management; risk management; contract management; environmental management; safety and health management.	2.4; 4.3; 4.4; 4.5; 4.6; 4.7
Personal	Leadership; communication; opening; relationships; teambuilding; teamwork; development of others; conflict resolution; holistic view; systemic view; assertiveness; problem-solving; ethics and integrity; commitment; self-control/work under pressure; relaxation; uncertainty; creativity; negotiation; emotional intelligence; commitment to the organization; reliability; attention to detail; delegation; search for information; analytical thinking; conceptual thinking; flexibility.	2.3; 2.4; 2.5; 3.1; 3.2; 3.3; 4.7
Technical	General technical overview; technical vocabulary; technical challenges; search for innovative technical solutions; technical solution assessment; technical risk assessment; technical trade-off decisions; relationship between technologies; design (project); technical drawing	1.1; 1.2; 1.3; 2.1; 2.2; 2.3; 4.3; 4.4; 4.5; 4.6
Context and business	Organization's profitability; strategic alignment; customer relationships; customer satisfaction; forces of industry (organization, customer and suppliers); legislation; finance; continuous management improvement	4.1; 4.2; 4.8

Project-Based learning approach

Project-Based learning approach is an appropriate mean of improving engineers´ project management competencies. Project-Based learning (PBL) is a model in which learning opportunities are organized around projects. Projects are complex tasks that are based on challenging questions or subjects that involve the students in design, problem-solving, decision making, or investigative activities. In regard to students and Higher Education (HE), dealing with projects gives the former an opportunity to work relatively autonomously over extended periods of time. This culminates in the creation of realistic products or presentations (Thomas et al., 1999; Turner et al., 2002; van Rooij, 2009). In PBL, the project is the central teaching strategy. Students encounter and learn the central concepts of the discipline by means of the project.

Some studies have shown that students retain minimal information in the traditional, didactic, teaching environment and frequently have trouble in transferring the acquired knowledge to new experiences (Schmidt, 1987). In contrast, PBL has proved to be an excellent method for developing new forms of competencies (Graaff & Kolmos, 2003; Kolmos & Kofoed, 2002). A PBL environment enables students to draw upon their prior knowledge and skills, brings a real-world context to the classroom, and reinforces the knowledge that they acquired by both independent and cooperative group work (Schmidt, 1993). In order to be considered an example of PBL, a project should have centrality, a driving question, constructive investigation, autonomy and realism (Thomas and Mergendoller, 2000). Projects should have characteristics that provide a feeling of authenticity to students. These characteristics can involve the topic, tasks, the roles that students play, context within which the work of the project is carried out, collaborators who work with students on the project, products that are produced, an audience for the project's products- or criteria by which the performance or products are judged.

DESIGN OF THE LEARNING EXPERIENCE

Industriales Ingenia is a compulsory subject (12 ECTS) of the Master's Degree in Industrial Engineering and in the Master's Degree in Engineering Management. There are 12 Industriales Ingenia different initiatives designed to cover most of the profiles of the Master's Degree in Industrial Engineering composed of approximately 300 students. 60 of these students selected in their first choice "Bioengineering Design," which is the most demanding option. The students of the Master's Degree in Engineering Management are 41 and they could choose between three different tracks for studying Industriales Ingenia. "MedTech" was the first option for 12 of them, who were all accepted. Therefore, a total number of 53 students are participating in these two subjects, working together in seven teams. These teams were formed with an average of 6 people from "Bioengineering Design" (technical profile) and 2 persons from "MedTech" (business and management profile). Although one project manager was required at the beginning of the course for every team, all the teams decided to work with a shared leadership for managing the project, giving an opportunity to horizontal organizations. These organizations maintain a decentralized power structure and place emphasis on teamwork and collaboration to achieve a collective goal. The group of professors agreed with this decision of working with shared leadership. Table 2 shows the characteristics of engineering students and their projects.

Table 2. Teams and projects participating in the experience.

Team members	Projects
1 MT* + 6 BD	Visual display for veins
1 MT + 7 BD	Standing frame

2 MT + 6 BD	Thumb prostheses
2 MT + 6 BD	Eyelid cleanser
2 MT + 6 BD	A smart insole for detecting blows to the diabetic foot
2 MT + 4 BD	Legs' massager for varicose veins
2 MT + 6 BD	Pump for liver transplants

*MT = MedTech; BD = Bioengineering Design

These seven multi-disciplinary teams work with the PBL approach under the supervision of the nine professors involved in these subjects, through lecture sessions and practical sessions, combined to reinforce the learning process. The PBL approach allows the members of each team to learn the four categories of PM skills.

Lecture sessions, together with some specific conferences led by professionals of the Bioengineering arena, allow the teams to improve their capabilities and achieve their project goals. Furthermore, for three sessions teams were divided to deal in depth with prototype design on the one hand, and into the marketing and entrepreneurship on the other hand. The rest of the sessions were shared and dealt with teamwork, project management and sustainability. Based on the PM style, some deliverables are required to the teams along the course. Table 3 shows the PBL methodology and techniques used for reinforcing the PM skills.

Table 3. The methodology used during the course.

Techniques	**Description**
Roles definition	Clients (professors), project managers* and team members
Teamwork and team development	Multidisciplinary teams; Team agreements; Personality assessment; Interviews; Organization charts; Competency assessment; Teambuilding activities; Conflict resolution activities.
Deliverables	A set of deliverables is scheduled with deadlines. They are linked with the four project management competencies categories. Some examples are: CAD designs; Simulations; Prototyping; Usability; Business Plan; Team performance; Project Management Plan.
Oral presentations	An interim presentation for assessing the progress and a final presentation is scheduled. They include technical, management, business, and sustainable aspects.
Meetings and interviews	With stakeholders (round tables with practitioners, hospitals, clients, doctors, regulators, etc.); and Professors (Mentoring);
Complementary workshops	Arduino-Matlab; Simulations; Sustainability; Biomechanics; Electronic design; Biomaterials; Leadership and communication skills; Entrepreneurship.

*The role of the project manager was distributed between the team members looking for a horizontal hierarchy.

LESSONS LEARNED DURING THE PROJECT PERFORMANCE

The six projects chosen by the students are shown in Figure 1. The first lesson learned is to afford the students to choose their own project. It allows students to become more involved in their designs. In addition, it allowed them to choose a project that responds to a close need, often lived by a family member or a friend. Then, the ability to obtain first-hand information also

increases and it is easier to align their entrepreneurship strategies with the client's needs. Thus, the skills related to the business are developed at the same time as the technical skills.

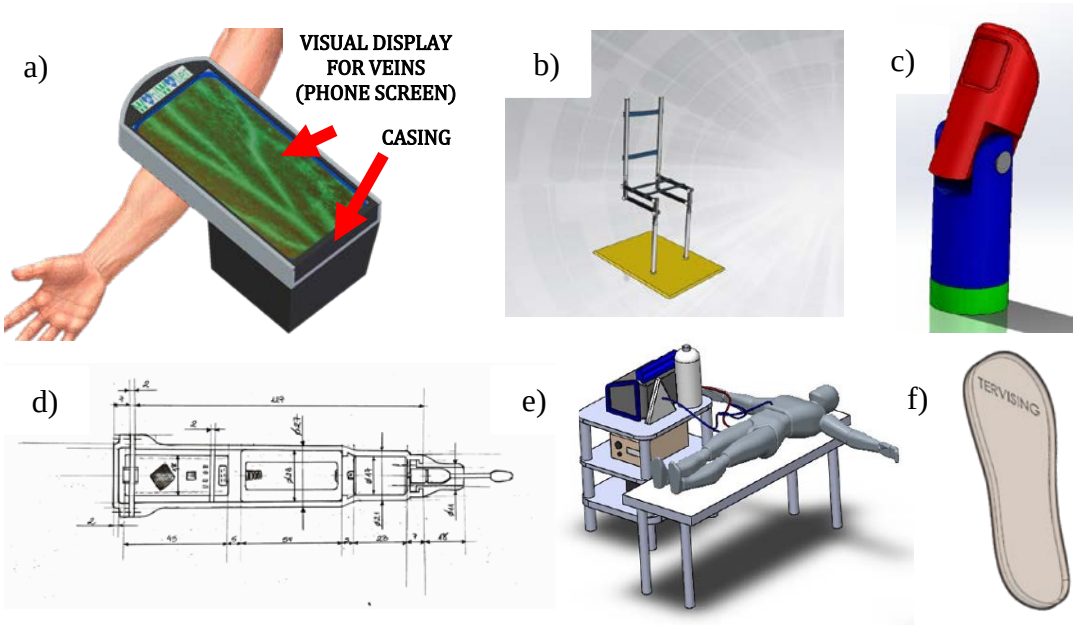

Figure 1. Selected conceptual design examples from different projects.
a) Visual display for veins. b) Standing frame. c) Thumb prostheses. d) Eyelid cleanser. e) Pump for liver transplants f) A smart insole for detecting blows to the diabetic foot.

A second interesting finding is that the millennials generation prefers to work in horizontal teams, where the hierarchies are not very marked, in the style of teal organizations (Laloux, 2014).

Third learning is that working with some project management tools (See Figure 2) allows the students to manage their time better and to share the tasks properly. With the Work Breakdown Structure and the Gantt chart, the tasks are well identified and programmed, and team members know in which tasks are delayed. Other tools used for helping the team to achieve their objectives were roles definition and personality classification. By defining a set of responsibilities and functions of each person, based on their own strengths, training and experience, it is easier for them to better carry on their work with high commitment and performance. Personality classification, based on a simple game of 4 colors (red, blue, yellow and green), depending on the combination of Introversion-Extraversion and Rational-Emotional dimensions gives students the opportunity to improve self-awareness and communication with other team members. The process competences for the project manager are implemented for the first time for most of the students. It brings them a little closer to the future work that awaits them once they finish their masters.

The fourth but not last lesson learned is that when an appropriate follow-up to the teams is done, the team-work improves significantly. The monitorization of the teamwork was reinforced through some workshops for discovering the different personalities of the team members or the requirement of presenting their team buildings activities. This increases their personal competences for being future project managers.

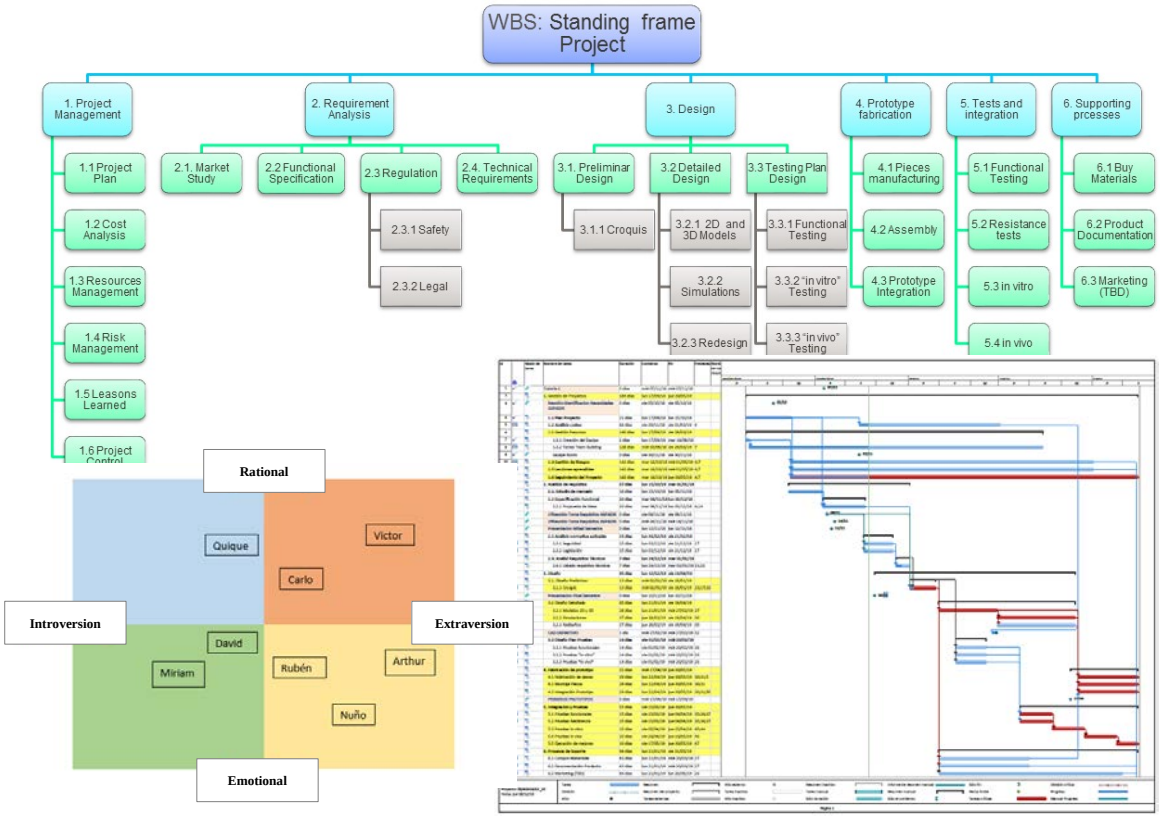

Figure 2. Several examples of project management tools used by students.

Concerning quantitative verification of the course, an interpersonal competencies survey was planned to be implemented by the students before and after the learning experience, in order to assess whether the course has an impact on their performance. The survey was built based on 37 performance indicators grouped along 8 competencies units: 1) Emotional management (5 items); 2) Self-confidence (4 items); 3) Commitment (4 items); 4) Effective communication (5 items); 5) Conflict management (4 items); 6) Effectiveness (5 items); 7) Team leadership (5 items); and 8) Professionalism (5 items). To measure the competencies, each item was defined by an extended Likert scale (from 1 to 7), which was used to assess the frequency (level) of each performance criteria.

Results for competencies measurement (n=40) at the beginning of the experience are shown in Table 4 and Figure 3. As seen, students have lower performance in *Effectiveness* (time management), *Conflict management* and *Communication*. On the other hand, they have really high means for *Professionalism* and *Commitment.* At the end of the course, the same survey is going to be implemented again by the same students so as to analyze differences and therefore the impact of this approach on students' performance, allowing to propose improvements actions for the next courses.

Table 4. Personal competencies self-assessment at the beginning of the course.

COMPETENCE UNIT	MEAN (N=40)	S.D.	MAX	MIN

1. Emotional management	5,14	1,30	7	1
2. Self-confidence	5,23	1,41	7	1
3. Commitment	5,64	1,05	7	2
4. Effective communication	4,80	1,39	7	1
5. Conflict management	4,88	1,23	7	2
6. Effectiveness	4,85	1,26	7	1
7. Team leadership	5,07	1,34	7	1
8. Professionalism	5,82	1,24	7	3

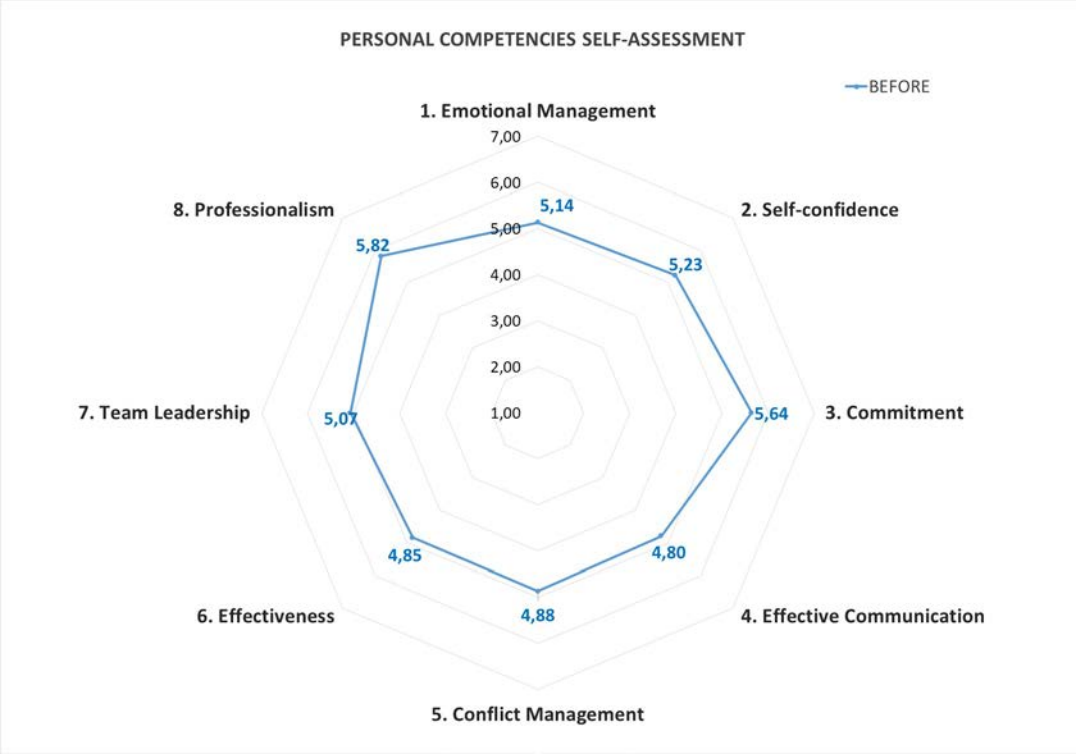

Figure 3. Personal competences self-assessment chart at the beginning of the course.

The main difficulties that raised during the experience were in the first place the effort needed by professors to be well coordinated, taking into account the ambitious objectives of the approach and the combination of two different master students in one project. As well, some difficulties have to do with the limitation in time and experience of the students, since they have several subjects with additional work and different agendas that make difficult to for them to work always together as a team.

CONCLUSIONS

The learning experience following the PBL approach and CDIO principles is showing to be really effective for future engineers and professionals. They have learned by doing, covering a wide range of competences related to project management. This experience is being

considered by both students and professors as really innovative and successful, bringing the possibility for other subjects to reproduce the methodology as an effective model.

This model gives the opportunity to students to have an experience very close to a professional one but maintaining the spirit of the university, focusing on continuous learning and using all skills necessary to be a competent engineer. Indeed, working in real projects allows them to deal with project management skills, highly required for employers nowadays.

A new way of teaching future engineers is emerging, which have some challenges both for students and professors. Students more and more have to be able to deal with a goal orientation mind combined with team building, commitment, conflict resolution, and emotional management issues. On the other hand, professors must be capable of accompanying students from a technical and human perspective, bringing them the opportunity to deploy all their potential.

ACKNOWLEDGMENT

This research was partially supported by the UBORA project, funded by the European Union's Horizon 2020 research and innovation programme under grant agreement 731053.

REFERENCES

Ahsan, K., Ho, M., & Khan, S. (2013). Recruiting project managers: A comparative analysis of competencies and recruitment signals from job advertisements. *Project Management Journal*, *44*(5), 36-54.

Ashleigh, M., Ojiako, U., Chipulu, M., & Wang, J. K. (2012). Critical learning themes in project management education: Implications for blended learning. *International Journal of Project Management*, *30*(2), 153-161.

Association for Project Management. (2008). APM competence framework. Buckinghamshire: Author.

Australian Institute for Project Management. (2008). Professional competency standards for project management. Sydney: Author.

Berggren, C., Järkvik, J., & Söderlund, J. (2008). Lagomizing, organic integration, and systems emergency wards: innovative practices in managing complex systems development projects. *Project Management Journal*, *39*(1_suppl), S111-S122.

Boyatzis, R. E. (1982). *The competent manager: A model for effective performance*. John Wiley & Sons.

Chipulu, M., Ojiako, U., Ashleigh, M., & Maguire, S. (2011). An analysis of interrelationships between project management and student-experience constructs. *Project Management Journal*, *42*(3), 91-101.

Crawford, L., Cooke-Davies, T., Hobbs, B., Labuschagne, L., Remington, K., & Chen, P. (2008). Governance and support in the sponsoring of projects and programs. *Project Management Journal*, *39*(S1), S43-S55.

Crawley, E. F., Malmqvist, J., Lucas, W. A., & Brodeur, D. R. (2011). The CDIO syllabus v2. 0. An updated statement of goals for engineering education. In *Proceedings of 7th International CDIO Conference, Copenhagen, Denmark*.

De Graaf, E., & Kolmos, A. (2003). Characteristics of problem-based learning. *International Journal of Engineering Education*, *19*(5), 657-662.

Dietrich, S. W., & Urban, S. D. (1998). A cooperative learning approach to database group projects: integrating theory and practice. *IEEE Transactions on Education*, *41*(4), 14-pp.

Hamilton, A. (2006, May). Project management: turning engineers into team players. In *Proceedings of the Institution of Civil Engineers-Civil Engineering,* 159 (2), 82-87.

Heer, D., Traylor, R. L., Thompson, T., & Fiez, T. S. (2003). Enhancing the freshman and sophomore ECE student experience using a platform for learning/spl trade. *IEEE Transactions on Education*, *46*(4), 434-443.

International Project Management Association. (2015). Individual competence baseline for project, programme & portfolio management. Zurich: Author.

Kerzner, H., & Kerzner, H. R. (2017). *Project management: a systems approach to planning, scheduling, and controlling*. John Wiley & Sons.
Kolmos, A., & Kofoed, L. (2002, July). Developing process competencies in cooperation, learning and project management. In *Proc. 4th World Conference of ICED*.
Laloux, F. (2014). *Reinventing organizations: A guide to creating organizations inspired by the next stage in human consciousness*. Nelson Parker.
Louw, T., & Rwelamila, P. D. (2012). Project management training curricula at South African public universities: Is the balanced demand of the profession sufficiently accommodated? *Project Management Journal*, *43*(4), 70-80.
Pant, I., & Baroudi, B. (2008). Project management education: The human skills imperative. *International journal of project management*, *26*(2), 124-128.
Parry, S. B. (1996). Just What Is a Competency? (And Why Should You Care?). *Training*, *35*(6), 58.
Project Management Institute. (2017). *Project manager competency development framework* – Third edition. Newton Square, PA Author.
Schmidt, H. G. (1983). Problem-based learning: rationale and description. *Medical education*, *17*(1), 11-16.
Schmidt, H. G. (1993). Foundations of problem-based learning: some explanatory notes. *Medical education*, *27*(5), 422-432.
Takey, S. M., & de Carvalho, M. M. (2015). Competency mapping in project management: An action research study in an engineering company. *International Journal of Project Management*, *33*(4), 784-796.
Thomas, J. W. (1999). *Project based learning: A handbook for middle and high school teachers*. Buck Institute for Education.
Thomas, J. W., & Mergendoller, J. R. (2000). Managing project-based learning: Principles from the field. In *Annual Meeting of the American Educational Research Association, New Orleans*.
Turner, J. R., Keegan, A. E., & Crawford, L. (2002). Delivering improved project management maturity through experiential learning. *Project Management*, *8*(1), 72-81.
Van Rooij, S. W. (2009). Scaffolding project-based learning with the project management body of knowledge (PMBOK®). *Computers & Education*, *52*(1), 210-219.
Wearne, S. (2004). Professional engineers' needs for managerial skills and expertise. In *Proceedings of the Institution of Civil Engineers-Civil Engineering*, 157 (1), 44-48.
Zhou, C. (2012). Fostering creative engineers: a key to face the complexity of engineering practice. *European Journal of Engineering Education*, *37*(4), 343-353.

BIOGRAPHICAL INFORMATION

Luis Ballesteros-Sánchez is Professor in the Department of Industrial Management, Business Administration and Statistics at ETSI Industriales – UPM. He is focused on creating team procedures and on the resolution of conflicts in multidisciplinary teams, mentoring, and coordinating also the Management Engineering track.

Rocío Rodríguez-Rivero is Professor in the Department of Industrial Management, Business Administration and Statistics at ETSI Industriales – UPM. She is focused on systematic project management procedures, hence supporting both courses and mentoring the adequate progress of the different projects.

Andrés Díaz Lantada is Professor in the Department of Mechanical Engineering at ETSI Industriales – UPM. His research activities are aimed at the development of biodevices using modern design, modeling, and manufacturing technologies and he incorporates these results to subjects linked to product development. He is Editorial Board Member of the International Journal of Engineering Education and CDIO contact at UPM. He has received the “TU Madrid Young Researcher Award” and the “TU Madrid Teaching Innovation Award” in 2014 and the “Medal of the Spanish Academy of Engineering to Young Researchers” in 2015.

Jesús Juan Ruíz is Professor in the Department of Industrial Management, Business Administration and Statistics at ETSI Industriales – UPM. He supports both courses with experimental design expertise and statistical validation of implementation and operation results.

Rafael Borge García is Professor in the Department of Chemical Engineering at ETSI Industriales – UPM. He is our expert on sustainable engineering design and supports both courses with the systematic assessment of products’ life-cycles for enhanced selection and definition of geometries, materials, and processes.

Enrique Chacón Tanarro is Professor in the Department of Mechanical Engineering at ETSI Industriales – UPM. His research activities are linked to several fields of Mechanical Engineering, including most areas of tribology and contact phenomena, machine performance assessment and systematic product development.

Miguel Ángel Peláez García is Professor in the Department of Industrial Management, Business Administration and Statistics at ETSI Industriales – UPM. He supports these subjects by means of his expertise in medical device regulation towards optimized marketability processes.

Ana Moreno Romero is Professor in the Department of Industrial Management, Business Administration and Statistics at ETSI Industriales – UPM. She is currently Deputy Vice-Dean for Social Responsibility and is especially focused on the management of change in complex organizations and on professional development.

Rafael Ramos Díaz is Professor in the Department of Industrial Management, Business Administration and Statistics at ETSI Industriales – UPM. He supports both courses with innovative approaches to entrepreneurship.

Corresponding author

Prof. Dr. Luís Ballesteros-Sánchez
Industrial Engineering Department,
Universidad Politécnica de Madrid
c/ Jose Gutierrez Abascal 2,
28006 Madrid, Spain
luisignacio.ballesteros@upm.es