# Problem Based Learning and the Development of Professional Competences: An Experience in the Field of Biomedical Engineering

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## ABSTRACT
In recent decades, one important objective in higher education has been developing professionals who can display competences in their specific work fields. Hence, the development of such competences and skills has been a widely discussed, highlighting that the use of active pedagogical initiatives might be the best approach to fulfill this requirement. In this study we analyze the students' perspective of the implementation of a hybrid curriculum between Problem-based Learning and Project Oriented Problem-based Learning in a course called introduction to biomedical engineering. In addition, we discuss different aspects of how competences are developed through this hybrid curriculum that was designed using course objectives and competences. Furthermore, data from 78 students from 7 different cohorts is analyzed and discussed from a qualitative approach developed from a critical and hermeneutic perspective. The results show that students are able to identify and understand differences between a passive pedagogical strategy that is centered in the teacher, and an active pedagogical strategy, centered in the student. Moreover, they acknowledge the changes from one strategy to the other as drivers for participation and development of competences in the field of engineering -namely ethics and professional responsibility, effective communication, and understanding the impact of solutions proposed in the field on local and a global contexts.

## INTRODUCTION
Recently, various aspects have changed the demands on the development of competences in the field of engineering. Different authors have attributed this change to complex phenomena such as globalization, technological advances, development of new specializations in the field, need for interdisciplinary work, among others (Becker, 2006, Galloway, 2007). Unfortunately, those changes have also revealed inconsistencies between the competences developed in engineering as part of the educational programs and the competences required by an engineer in the actual world.

Competences in engineering education can be classified into two main groups: general competences and engineering competences. The former, are those competences needed in all disciplines such as oral and written communication, teamwork, leadership, emotional intelligence, problem solving and ethical aspects. The latter are competences required by any engineer to succeed in their field, namely innovation, design and understanding of complex systems, theory-practice application and business management (Wakas, 2001; Male, Bush & Chapman, 2009). The need to develop competences is so important that specialized institutions like the Accreditation Board for Engineering and Technology (ABET) have gradually included evaluation processes related to the development of competences in engineering, science and technology programs. In the specific case of biomedical engineering -where life sciences and medicine are combined with engineering to improve the health of individuals and communities- the development of competences as interdisciplinary and collaborative work must be part a critical part of the curriculum (Cruz, 2016).

Nowadays, traditional education based on lectures and on a teacher-centered educational perspective has proven to be unsuccessful in the development of general and specific competences (Ribas et al, 2009). Additionally, freshmen engineering students are not familiar with the characteristics of the engineering career, which could lead to a poor performance or dropout in emerging engineering programs, such as biomedical engineering (Cruz, 2016). In response, re-design of introductory courses to engineering in companion with several active pedagogical strategies –student-centered approaches- must emerge, aiming at modifying and enhancing traditional curricula, emphasizing on student's engagement and the development of competences.

Problem Based Learning (PBL) is an active pedagogical strategy commonly used in some disciplines to develop general and specific competences. PBL is a curricular model in which a problematic situation is presented initially, encouraging the students to find and understand the problem to be solved. Later, students and teachers identify the learning objectives together with relevant literature and information research. Finally, the students go back to the problem and build a possible solution to the situation (Capon, 2004). This model is a deviation from the traditional education, given that students are participant and responsible for their learning; on the other hand, the teacher acts as a guide in the process (Ribas, 2004). The problem situation is addressed by teams that build knowledge using previous experiences, reflecting about the problem and understanding its context. At the same time, they develop teamwork, oral and written communication, leadership, decision making, creativity and interdisciplinary work competences (for further information about PBL we recommend Capon, 2004; Ribas et al, 2009; Wood, 2003; Ribas, 2004 y Savery y Duffy 1995).

Another active pedagogical strategy for competence development related to PBL is the Problem Oriented Problem Based Learning (PO-PBL). This curricular approach involves the students in the process of developing a research project. In this process, the students outline a relatively wide problem to be solved within the framework of the class objectives, and they try to solve it in small teams, usually in a full term semester (Hernandez, 2014; Vithal et al, 1995). Throughout the semester, the students are able to build knowledge and develop competences such as learning to learn, work in teams, outline complex problems, use theory and resources to propose a solution to a given problem, critical thinking and interdisciplinary work (Hernandez, 2015; Vithal et al, 1995).

According to De Graaf and Kolmos (2007), PBL and PO-PBL strategies share at least 3 pedagogical and curricular principles in their foundation. First, the learning approach is based and organized by means of problems, which –rather than simply looking for a solution- encourages motivation, curiosity, in-context learning processes and the use of learning experiences by those involved. Second, there is a social approach in the learning teams, which implies that learning processes are mediated by dialogue and communication. As such, students not only learn from themselves but from their mates, determining the direction of their learning process and taking crucial decisions to fulfill their goals. Lastly, there is a clear interdisciplinary approach to the content that enables stakeholders to modify their traditional vision of teaching and learning based on contents and methods in specific subjects.

On the other hand, the biomedical engineering program is one of the newest programs of the engineering faculty. One of the main goals in its curricular design is taking advantage of the accumulated knowledge in recent curricula reforms in the faculty, in order to generate environments that favor the development of general and specific competences in students. In particular, the first semester course of introduction to biomedical engineering seeks to promote in the students the identification, explanation and application of basic principles and tools of biomedical engineering to solve biological and medical problems. Besides, the course is intended to develop communication, team work, critical thinking and problem solving competences. The curricular reform is one of the main concerns of several teachers considering the difficulty of students to understand various topics, and the lack of general and specific competences in upcoming professionals. Additionally, the students that participate in the course described above are encouraged to participate in an open symposium by the end of the semester. In this experience, first semester students in together with professors, researchers and businessmen, show innovative products and processes developed throughout the semester.

Given the characteristics, objectives and goals of the curriculum course, the active pedagogical strategies of PBL and PO-PBL were incorporated in the introduction of the biomedical engineering course. This research presents an analysis from the perspective of the students, in terms of the contribution of the PBL/PO-PBL hybrid curriculum to the development of competences.

## METHODS

*Research approach*

This research is based under a qualitative perspective grounded in a critical and hermeneutical approach, which makes possible a general and particular comprehension of the reality (Alvesson & Skoldberg, 2009; Goetz &

Lecompte, 1988). In this type of research perspective, the researcher does not look for objectivity in the process; on the contrary, its role, participation and characteristics as an active member of the research are taken into account. This perspective moves away from the positivistic perspective usually used in the natural sciences, in which the researcher is always trying to be as more objective as possible (Fassinger & Morrow, 2013). Furthermore, the study of perceptions in this research refers to our interpretations of reality as humans. From a phenomenological point of view, perceptions are strongly associated to a direct apprehension of reality, in which interpretation is different from sensations and intuition (Husserl, 1995). In other words, interpretation goes beyond the reception processes and is not limited by external impressions. On the contrary, perceptions have to do with the awareness of the physical world and are manifest as an intentional experience (Poza, 2005).

*Data gathering*
Systematizing the student's perceptions was the main source for data collection. Two different qualitative instruments were used for this purpose: an on-line survey (Appendix 1) and semi-structured interviews (Appendix 2). The former was sent via E-mail to students from different cohorts; the latter, was applied to 20 students at the end of each academic semester during four consecutive semesters. These instruments were designed aiming to inquire for competence development through the PBL and PO-PBL strategies implemented during the course. Informed consents and disclaimers were used as required in the data collection. Furthermore, questions were design to retrieve information about the personal reflection processes, providing qualitative data about the personal vision from the students about the matter of research Alvarez-Gayou (2009).

The information was analyzed via descriptive statistics and a process of triangulation of the information collected through the instruments. Two pre-established categories for the analysis of professional training of students were established: (a) training experience and (b) development of competences and skills.

*Implementation of the PBL and PO-PBL curricular model*
PBL was implemented so as to address different fields of biomedical engineering (Epidemiology, mathematics, cardiovascular dynamics, biomaterials, tissue engineering, signals and biomedical instrumentation) through common problems in these fields. The students were encouraged to analyze each of the problems given in 3 sessions of the course, by making an adaptation of the 7-steps PBL approach proposed by Savery and Duffy (2005)

Typically, in the first session of the course a problem situation was presented. Later in this session, students teamed up and discussed different approaches to solve the problem and different information search strategies. At the end of this session, instructions regarding the final report were given with a period of time to answer questions. In the second session, an expert in the specific PBL-subject of work offered a conference to share theoretical principles and application examples of the given theory. In the third session, the main goal for students was to deliver the report. During all the PBL sessions, professors from the biomedical engineering department, teacher assistants and research assistants were available to guide the process. These facilitators assisted the students in the route to find the solution for the problem. At the end of every experience, reports were evaluated and feedback was given to each team.

It is important to clarify that not all the sessions in the course were devoted to PBL experiences. For instance, some lecture classes were given on subjects such as imaging analysis and processing, protein design and clinical logistic. Moreover, there were workshops about anatomy, physiology, written skills development, ethics, business management, intellectual property and specialized software handling. Figure

The PO-PBL strategy was developed simultaneously throughout the semester. By facilitating interaction among small groups during the first weeks of the semester, the students had the chance to know each other. Then, they established a permanent work group and defined a specific research topic. The main objective of the PO-POBL experience was to offer a solution to a problem identified in the field of biomedical engineering in our country. The teams devoted 9 hours every week in to develop their projects, distributed in two face-to-face sessions of 1.5 hours each, a laboratory session of 1.5 hours, and 4.5 hours for research and development.

A fundamental element in the PO-PBL strategy is to define the problem that will guide the research. In order to promote motivation and context-related exploration of topics, the students were encouraged to define their own problems through negotiation processes in their teams, and they were given specific guidelines to facilitate this process. The viability of the proposals presented by the students was assessed by the teachers considering their novelty and their feasibility in terms of time and resources.

Once the research problem was defined, each work group developed their project by consulting technicians and professionals from different fields. This aimed at promoting communication skills, given that the students had to establish effective communication with experts. Habitual lecturers of the class had the opportunity to become facilitators, by guiding and giving feedback in different projects. The final results of the projects were presented in form of prototypes and designs in the symposium at the end of each semester.

**RESULTS**

The online survey was sent to the students from seven different semesters, gathering information from a total of 78 students who answered the survey. All the participants in the data collection were students who experienced the educational initiative subject of this research. The sample comprised students from all the semesters; however, most of the students claimed to have taken the course during the 2015-10, 2015-20 and 2016.10 semesters, as illustrated in Figure 2. The results related to the perspectives of the students about the outcomes of the educational experience are presented in two pre-established categories for analysis: training experience and development of competences and skills.

*Perceptions of training experience*

The perceptions related to this category were analyzed from three different points of view: i) personal and academic growth, ii) course structure and design; and iii) general learning experience throughout the course.
For the category of personal and academic growth, the questions in the survey categorized the perception using a 1 to 5 scale, being 5 the highest and 1 the lowest value. Most of the students pointed out that the implemented proposal was of great value in terms of academic and personal growth, as illustrated in Figure 3.

Some of the arguments given by the students are:

Stud1: *"This is a multidisciplinary course; I learned a lot, which makes me enthusiastic about the upcoming semesters of biomedical engineering"*

Stud26: *"This course enables me a vision about each of the research areas in this career, offering a clear perspective of biomedical engineering"*

Stud 56: *"Activities in this course strengthen not only academic skills, but communication and teamwork"*

Stud34: *"This course fosters the skills needed to develop projects and drive innovation"*

Stud4: *"This course helps me to understand the biomedical engineering career"*

On the other hand, some of the arguments of a low-ranked experience are the following:

Stud15: *"There were very complicated ideas for a first semester course"*

Stud24: *"I realized that the creation of a product or design is not easy and needs too much research, on the other hand, I think professors expect very complicated and difficult products"*

Stud59: *"At the beginning you don't have much knowledge, then, what we can achieve in the project is not what is expected"*

In terms of the structure of the course, most students stated that the structure proposed was highly adequate. Besides, they manifested that the PBL and PO-PBL approaches have become an interesting learning opportunity, since they constantly apply concepts and knowledge. Some of the arguments are the following:

Stud33: *"I think it is a very good strategy; learning is more evident than in lecture classes, we can learn more through problems because we can easily apply the knowledge"*

Stud17: "*The course is excellent. Projects and workshops are of great help to understand the insights of the career"*

Stud20: *"I consider that PBL is a good tool that allows us to deepen in class topics"*

Stud68: *"I found it very good because we can work from different career perspectives"*

Stud71: "*It is a good methodology that allows us to develop teamwork and to know about sub fields of the career"*

The data shows that the perceptions of the students are consistent with the PBL objectives described by different authors (Capon, 2004, Wood, 2003 y Ribas, 2004). As a recommendation, some students suggested that they need more supervision moments. Sometimes they feel that supervisions are extremely short:

Stud14: *"…however, better supervision processes must be applied to offer extra help in the development of the projects"*

Stud60: *"I feel that PBL experiences could be somehow shallow, feedback moments should be present after the grade process"*

Finally, the students were asked about the general learning experience throughout the course. The answers were organized in 4 qualitative categories: (a) Poor, meaning that no contribution was perceived; (b) Regular, meaning that no significant contribution was perceived; (c) Good, meaning that a significant contribution was perceived; and (D) Excellent, meaning that a very significant contribution was perceived. As shown in the Figure No 4, a considerable percentage of students perceived that “Good” (23.4%) and “Excellent” (62.3%) contributions were experienced throughout the development of PBL and PO-PBL exercises.

*Perceptions of professional development competences*
Specific questions regarding the development of 7 competences internationally accredited by the ABET were included in the survey. In this sense, the answers were tabulated in a 1 to 5 scale, being 5 the highest and 1 the lowest value. Figures 5 and 6 show the distribution of the results obtained.

In general, the responses state that this course offers major contributions to the development of competences. The answers according to the students' semester show how the PBL and PO-PBL approaches have gained the position of key developers of such competences. Some examples of these statements are the following:

Stud7: *"I consider that –PBL and PO-PBL- are good strategies as compared to lecture classes. We can learn and apply our knowledge more through study cases. However, I feel that PBL could have a better feedback process"*

Stud 16: *"We are still getting used to it, but in the end it is a good methodology"*

Stud30: *"I think it is good to get involved in project development, because you can gain experience in innovation"*

Stud38: *"These approaches keep the students thinking throughout the semester"*

Stud 65: *"I think it is a good methodology because it makes the students not only conduct a research, but also give a real result"*

It's important to mention that additional competences were developed by means of the PO-PBL strategy. Technical and economic feasibility as well as ethical and intellectual property aspects were addressed by the students. Additionally, teamwork and oral and written communication were developed/reinforced during this process.

**DISCUSSION**
The arguments posed in section 4.1 are evidence of how the curricular changes based on PBL and PO-PBL enable the development of knowledge by means of motivation and inquiry. An interesting aspect identified in the process was noticing there were different ways in which the students addressed the problems: based on personal or family experiences, consulting medical doctors or professionals in the field, or consulting non-profit organizations. Undoubtedly, those different approaches are drivers for motivation as suggested by Wood (2003). Moreover, the use of active pedagogical approaches not only developed theoretical concepts, but also promoted general competences in the students as proposed by Ribas (2004). Additionally, the students could experience a wide vision of the professional areas and sub-fields in biomedical engineering, meeting the main of objectives of the introduction to biomedical engineering course.

On the other hand, some of the students seem to have very high expectations -or think the teachers have it- in relation to the PO-PBL strategy. This leads to the perception in first semester students that “it is extremely difficult”. We consider that this sort of perceptions results from the comparison with a traditional education and a content-centered curriculum, in which the students are used to being exposed to contents first and apply these contents afterwards. Hence, we consider that some of the students were biased to a massive inclusion of contents as the main objective of the course, rather than an active pedagogical experience.

On these grounds, we consider that reinforcing the role of the professors in upcoming courses is extremely important. In particular, teachers should understand that they have the role of facilitators that stimulate debate by formulating indirect questions and by defying and questioning the student's arguments in the feedback process (Ribas, 2004). Moreover, The information collected suggests that this kind of curriculum design encompasses different learning dimensions that range from concepts to reflective learning processes. Additionally, the students fulfilled one of the main objectives of the PBL and PO-PBL approaches suggested by Capon (2004) and Vithal et al (1995) by putting in practice specific contents and theories of the subject area, connecting theory with practice.

As shown by the results in section 4.2, most of the students perceived a comprehensive development of all the competences evaluated. However, the perception of the development changed among some students. For example, ethics and responsibility, effective communication and understanding of the social impact in engineering solutions were perceived as the most developed during the course. As described by Male (2007), these competences are of major importance for the development of general and specific engineering competences.

On the other hand, the system, component or process design was the competence perceived to be the least developed. This is an important two-fold finding. First, the development of this set of competences could be a complicated task to develop in a single course; hence, we suggest a continuous use of active pedagogical approaches throughout the undergraduate program. Second, the students' awareness of the complexity of these approaches suggest high levels of reflection processes in the course, which is not common in courses based on traditional approaches.

In addition, it has been rewarding to know that some of the work groups have been constantly working in their projects beyond the course. Some of the teams have shown their results in biomedical engineering seminars and congresses. Furthermore, meetings have been scheduled with the "Innovation department of the institution" to persist and legally protect the inventions made by the students. One specific example of these experiences is the design and elaboration of a repletion clamp prototype. This clamp reduces the procedure time of researchers and technicians and increases the quality of tissue preservation. This project was born in the first semester of 2015 and presented in the First Peruvian Congress of Morphologic Science/Fourth Pan-American Congress of Anatomic Technics at the end of the same year.

This proposal still has opportunities and challenges subject of research. For instance, the opinions, perspectives and reflections of professors and assistants need to be considered. The analysis of this information could increase the impact of the program in terms of competence development, and shed light on failures in teaching and learning procedures.

Finally, one major challenge is the identification and improvement of the relationships between PBL exercises and projects developed to be presented in the symposium. This could offer a better understanding of how to strengthen competence development in the course. Likewise, this study also revealed flaws in the feedback in PBL. Hence, better feedback procedures will be designed and implemented in the future.

## CONCLUSIONS

Given that professional careers related to the engineering field are getting complex with time, engineers require different sets of skills and competencies in order to fulfill expectations and success in the area. The development of skills and competences generally is not easily accomplished by traditional teacher-centered strategies, in which the transfer of knowledge is the main purpose. On the contrary, several examples has shown that student-centered strategies, in which the students are actively involved in their learning process, are the best way to develop high-level skills as well as specific-career competences. As such, the redesign and improvement of our introductory course to biomedical engineering using the PBL and PO-PBL approaches, has promoted a student-centered approach for competence development. We consider that these strategies enable a general vision of the biomedical engineering career in the students, and give them a viewpoint on their future role as professionals in society.

It is important to clarify that further iteration and more robust reforms in other engineering courses must be executed to fully validate the findings exposed in this study, as well as include a higher number of participants in this process. Nonetheless, perspective evaluation framed in a hermeneutic vision of evaluation stimulates the transformation of traditional practices, making a shift from content memorization processes. This sort of proposals generates invaluable knowledge regarding competence development, enhancing professional education in students; hence, this research extends an open invitation to researches to set in motions initiatives as this one, in order to generate pertinent and contextualized engineering programs to face today's world necessities.

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**Appendix No 1**

Survey: perception about the curriculum model implemented in introduction to biomedical engineering

Dear student,

This survey aims to know your perception regarding the course “introduction to biomedical engineering” and EXPOANDES. This information will be valuable in order to improve teaching and learning processes in the future. We guarantee that all information provided will be used for improvement. Please answer all the questions in the most honest and sincere possible way.

If you decide to participate, please fill the present survey, otherwise close this window. Thanks for your collaboration.

1. Point out the academic period in which the introduction to biomedical engineering was taken: (i.e. 2015-10)
2. In a 1 to 5 scale, being 5 the maximum value, indicate to what extent this course was valuable for your academic growth.
    a. Please explain your answer
3. In a 1 to 5 scale, being 5 the maximum value, indicate to what extent this course was valuable for your personal growth.
    a. Please explain your answer
4. In a 1 to 5 scale, being 5 the maximum value, indicate to what extent this course develops the following professional competences.
    a. Systems, component or process design
    b. Multidisciplinary work performance
    c. Ethics and responsibility
    d. Effective communication
    e. Understanding of the social impact in engineering solutions
    f. Awareness of the importance of learning to learn
    g. Knowledge of contemporary issues
5. How do you categorize your experience throughout the course
    a. Excellent
    b. Good
    c. Regular
    d. Bad
6. In comparison with other methodologies applied in other courses, how do you categorize the implemented methodology in this course?
    a. Worst
    b. Equal
    c. Better
    d. Can’t categorize it
        i. Please explain tour answer
7. Indicate to what extent the activities developed in this course develops teamwork
    a. Totally agree
    b. Agree
    c. Disagree
    d. Totally disagree
        i. Please explain your answer
8. In a 1 to 5 scale, being 5 the maximum value, indicate to what extent EXPOANDES was valuable for your academic growth
    a. Please explain your answer
9. What is your opinion about the structure of the course (PBL and PO-PBL exercises)
10. Additional comments or suggestions can be described in this question.

**Appendix No 2**

Interview: perception about the curriculum model implemented in introduction to biomedical engineering

This interview aims to know your perception regarding the course “introduction to biomedical engineering” and EXPOANDES. This information will be valuable in order to improve teaching and learning processes in the future. We guarantee that all information provided will be used for improvement. Please answer all the questions in the most honest and sincere possible way.

Would you like to continue with the interview?

1. How valuable does the Introduction to Biomedical Engineering course was to your growth and career? Why?
2. Do you consider that the introductory course to biomedical engineering contributes to the development of engineering skills? Why?
3. Compared to the work methodology used in other courses, what do you think about the methodology implemented in this course?
4. What do you think about your learning experience during the course?
5. What aspects do you think would improve the course?