Promoting PBL Through an Active Learning Model and the Use of Rapid Prototyping Resources

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Abstract—This paper aims to present an active learning model for the implementation of innovative teaching-learning practices in Higher Education, based on Active Learning Methodologies by highlighting especially, PBL – Problem Based Learning using Rapid Prototyping devices. In order to apply PBL's methodology to the courses, an implementation model with four levels of implementation was developed. Each level has four class attributes, which are the problem's scope, student autonomy, teaching role and classroom space-time. The obtained results show that the students demonstrate higher levels of interest, participation, and involvement with classmates, motivation and content's perennial assimilation. With the application of these methodologies, skills required by job market, such as teamwork, relationship, collaboration, proactivity and entrepreneurship are also developed.

Keywords—PBL, Implementation Model, Active Learning, Rapid Prototyping

1 Introduction

Introducing active learning in Higher Education is challenging because it brings disruptive changes in the way that teaching and learning process traditionally occurs. Around the world, many institutions identified the need for a cultural shift in order to rescue the societal relevance, nature and protagonism of undergraduate engineering courses, which were based on traditional curriculum [1]. The shift involves the transition from an educational system based on teaching to a system based on learning, making the student the center of the educational process [2].

Until the advent of the Internet and its massification in the 1990's, the traditional method had been considered the only way to teach. However, from 2000 onwards, we witnessed the closure of information Era and the start of the knowledge Era and as a consequence, the traditional and stablished methods of teaching has been questioned and the need to promote learning in new spaces emerged. Especially because currently, we are experiencing the Fourth Industrial Revolution; that is, the merging of digital, physical and biological technologies in a cybernetic world. The 4.0 industry with the Internet of Things (IoT), cloud computing and manufacturing information are already part of our daily lives and the teaching model, which persists up to this day, is similar to one first stablished in the year of 1088, the year that Bologna's University was founded. Therefore, it is important to promote innovative teaching-learning practices to provide an education in engineering that is consistent with the needs of the 21st century. Thus, overcoming outdated teaching models.

Problem-Based Learning (PBL) is an educational approach that is learner-centered. The focus changes from a teacher-driven approach that leads the students to one that aims to empower students, promoting self-directed and perennial learning, developing also their cognitive and metacognitive skills [3]. When implementing PBL, at its highest level of implementation, the student is "mentored and encouraged to conduct research, integrate what is learned, and apply it to develop a viable solution to an ill-defined problem" as stated in ref. [4]. This methodology engages students in active learning, and in addition, it promotes and increases students' cognitive and practical abilities, as well as developing other important skills to professional life, such as collaboration, teamwork, creativity and proactivity to solve problems and face challenges. At this point, the materialization of solutions, made via Rapid Prototyping (RP) resources becomes the class' synthesis, promoting a perennial and meaningful learning.

Searching for innovation and reform of higher education in engineering courses via Active Learning implementation starts with the need to develop important abilities and skills, widely discussed in national and international scope [5],[6]. Furthermore, once problems have become more complex, achieving the highest level requires professionals of several fields to solve them, thus it is indispensable that engineers are able to work in multidisciplinary teams. Therefore, it is important that teachers experience and develop among their students' creativity, teamwork, decision-making, communication and problem solving.

Thus, the present work shows the development and application of a PBL model in engineering courses at SATC, a Brazilian College, which aims to integrate theory and practice by promoting learning through the integration of university and the demands of enterprises and bringing real life problems for students to solve. However, the methodological changes needed to attend the demands of the job market depend on a design that considers the need for a cultural transformation. Therefore, taking into the consideration how complex Higher Educational settings are and how difficult it is to implement new learning models; we propose to implement the PBL-based learning model gradually.

2 Problem-based learning model

Based on research of Problem-Based Learning (PBL) applications in engineering courses, in previous inquiries [4], [7], [8], [9], as well as having institutional visits to American universities (MIT and Olin College in November, 2016) and also through experiences we have had in our own institution, it was developed a PBL implementation model for engineering courses' curriculum (Fig. 1). For the development of this model, we have considered teachers and students' view of learning, infrastructure and the integration between academic work and the industrial needs. As a result, a model presenting four levels (PBL Levels, left side in Fig. 1) of implementation was devel-

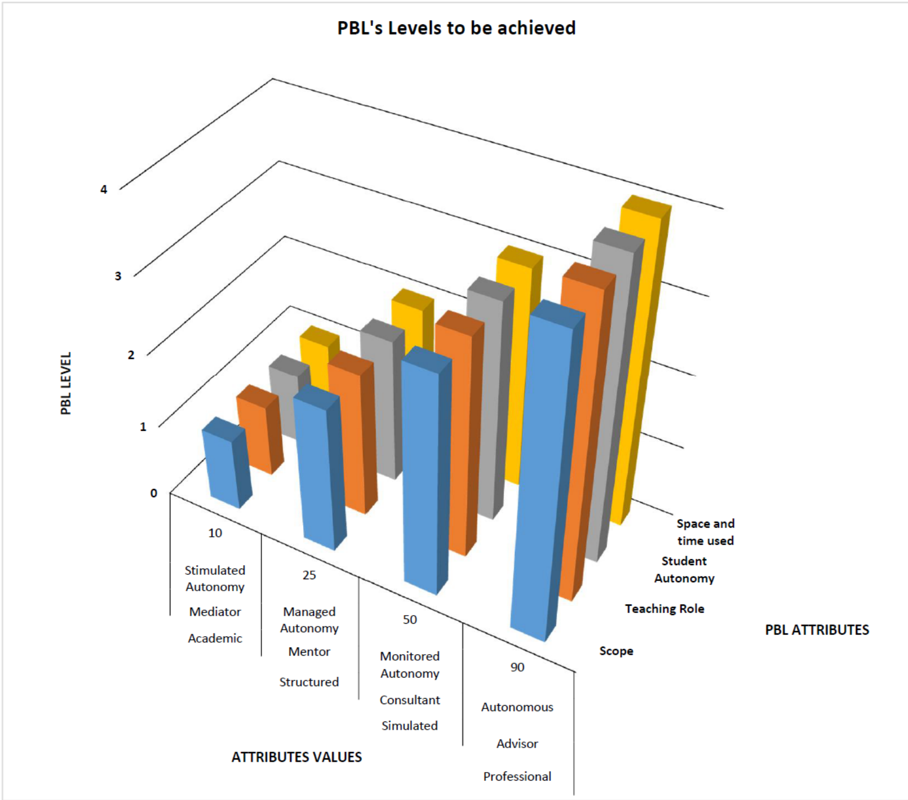

Fig. 1. PBL'S level of development

oped and each one cover four attributes (PBL Attributes, right side in Fig. 1). Following, each attribute has a four-degree scale (from Level 1 up to Level 4). Level 1 as the most basic, and the first to be applied; Levels 2 and 3 are intermediate ones and Level 4 is the most advanced, thus the last one to be applied.

The first attribute relates to the *space and time* needed. It is related to where PBL lessons occur and how long it takes to solve the problem. In Level 1, space and time are confined, respectively, to regular class time and physical classroom space, whereas Level 4 extrapolates both.

The second one is related to the development of *students' autonomy*. This attribute considers the required autonomy to lead students towards auto-learning. As pointed out before, students expected learning to resume in listening to lectures and resolving lists of exercises. The fact that students were unprepared to work with ill-structured problems led to the need of planning PBL considering students' autonomy and the teacher role in the process as interdependent. Therefore, the role of the teacher in creating the conditions for autonomy to be gradually developed is essential. While in the Academic level (Level 1), problems are well-defined and autonomy is stimulated, in Professional Level (Level 4), which is the final goal, students become autonomous and professors' role become more of an advisor.

The third aspect is the importance of teachers in the learning process and their *role* in the different levels. The implementation project of this model also takes into account the need to provide teacher development for the faculty in order to achieve the highest level of PBL. The first step is to review with professors the learning theory on which their practice is based on, and then promote their understanding of the need for changing as well as discussing principles of learning based on research. The attribute that considers Teaching Role is the one that describes the role of professors as mediator, mentor, consultant or advisor, which changes how the space and time of classes are used. That means that depending on the level of PBL that has been planned, the space-time also varies.

The fourth and final aspect covered in our learning implementation project is the *scope,* which is the problem itself. It can be from an academic perspective to a real problem. The scope can be named as *Academic, Structured, Simulated* or *Professional*, according to domain of the problem, as problems can vary from well-defined to ill-defined. Well-defined problems are the types of problems presented in a very structured way with usually only one possible solution and a well-known procedure whereas ill-structured problems are complex and not clear-cut. Thus, the problem-solving process in ill-defined problems depends upon the understanding of the problem situation, its nature and the conditions to solve it, leading to multiple possible solutions [10].

The need to implement PBL gradually rises from the need to consider different aspects of an educational setting and the ins and outs that affect the implementation of a new pedagogical model. In order to minimize the impact of ill-structured problems, it is important to consider the receptivity of students and professors and create the right conditions for change to become possible, therefore, the model presented below gives an overview of how the model aims to achieve its goal, that is, by considering each attribute. Further details of PBL's levels are presented in the following section. Then, a case showing how rapid prototyping resources can be used in a PBL class is discussed.

2.1 Level 1: solving an academic problem inside the classroom

Considering that the main practice at SATC College was lecturing students and giving lists of exercises, Level 1 was the first natural step towards the implementation of active learning. Most professors and students were used to the traditional model, which considers teaching as passing on knowledge from teacher to students while students' role would be to attentively listening to the lectures and doing lists of exercises. Therefore, the need for gradually preparing students and professors to work with problem-based learning by expecting it to be implemented through small projects where professors would stimulate a more autonomous student work was paramount.

In this level, the space-time attribute presented above with a value of 10 means, for example, that in a discipline with a semester of 60-hour workload (20 week-meetings with 3h for each class), 10% of time for the development of PBL's activity, which is equivalent to two meetings, about 6 hours. Due to the short period available for this level, which expected to be about two meetings at any time during the semester, the workspace is likely to be the classroom; however, other academic learning spaces such as the library, computer lab or hands-on labs could also be used.

Regarding developing student Autonomy, the Stimulated takes into consideration that students, on their first contact with PBL, have not experienced this kind of learning but the traditional one. Therefore, autonomy is encouraged and problem solving is constantly stimulated. Teacher Role attribute is that of a Mediator who needs to mediate the process of learning constantly. The mediator does not give the answer, but provokes the students with meaningful questions and constantly challenges them, recommends research sources and leads students in the process of finding solutions. This role requires that professor-mediator to give short lectures and intervene during the PBL activity. Thus, continually nurturing the learning process by monitoring and leading the teams of students.

The problem falls into the academic scope likely to focus on a specific discipline's topic. The students work in groups and the solutions are likely to be similar. It is less likely, therefore, to produce a work that is unique due to a few variables and the low complexity of the problem itself.

2.2 Level 2: solving a structured problem

The space-time attribute shows a value of 25, that is, we may need 25% of the discipline's total workload for the PBL activities. Considering again a discipline that has 60 hours in a semester (20 meetings of 3 hours each one), that would be 15 hours – equivalent to 5 meetings for class work. With more time, there are more possibilities to extrapolate the classroom's space and using other academic spaces (library, computing labs and practice or hands-on labs). There is also more flexibility. The professor can plan one activity, based on level 2 criteria, expecting to take up to five meetings to complete the PBL or two PBL activities of two and three meetings, respectively. The first one, perhaps, at level 1 and the second one, more elaborated, according to the criteria of level 2. The intention is to provide students and teachers the opportunity to become more familiar with the methodology, allowing a judicious evaluation of the progress as well as of the failures that occur during the implementation.

Regarding student autonomy (Managed Autonomy), considering that stimulation has occurred in the previous experiences, students should at this level show a discreet skill to self-learning and proactivity. Thus, rather than constant, the stimulation become frequent. As for the Teaching role, the professor in this level becomes a Mentor. The mentor, according to the dictionary, is an individual considered wise and inspiring, that drives, leads and encourages someone. The propositions presented in this level might be less structured and in an intermediate complexity. In the mentoring role, the professor will answer questions that students might have by pointing out possibilities ("and if…") and showing previous cases, nudging students to search and make new discoveries. However, teaching through short lectures to small groups will still occur on demand, and lecturing the whole group only when needed, but likely to be less frequent than in level 1. Even though this level aims to foster self-directed learning, constant group monitoring will occur, like in the first level.

The scope of the problem becomes "Structured". In this one, the resolution attends the medium complexity of the problem and may require content integration of two or more disciplines that are concomitants or pre-requirements. The PBL's activities in some cases can go beyond the academic and classroom spaces. In loco visits, where the problem is happening, is a real possibility, but not expected at this level. The final product, presented commonly in class, could be presented to the external community (liberal professionals, representatives and enterprise's CEOs). In this level, the solution to the problem must be validated by using structured scientific approach by including the references, justification, methods, results, discussion and conclusion.

2.3 Level 3: simulating a problem's solution

Here, 50% of total workload may be available to PBL's activities. Thereby, of the 60 reference-hours, 30 will be for implementing active learning, where students become protagonists of the learning process; they acquire more responsibilities and the outcomes more elaborated, as learning situations are more complex as well. These situations are obtained from professional observation of several places: shops, offices, agencies, factories, farms, inside a coalmine, means of public transportation, in-side a car, hospitals, at the bank, other schools, in their own house, etc…).

Based on the assumption that the designed problems in this level are embedded in situations that are part of professional or personal students' lives, the engagement is expected to be spontaneous, without the need to tap into students' intrinsic motivation or emphasize how meaningful the activity is. The professor, therefore, is not obliged to motivate constantly the student, since they are expected to have already developed some skills by level 3. Thus, student's autonomy is monitored as occasional stimulation to avoid deviations from the task might be needed. In this sense, the professor acts like a consultant, acting on demand.

The simulated scope means that the obtained solution to a real problem exposed at the start of PBL activity is validated and presented, but it is not in fact applied. An engineer designing a crane bridge can simulate and validate it using real data (constructive materials, dimensions, friction, lubrication, safety factor, energy consumption, ultimate tensions, etc…) without, in fact, the need to build one. Likewise, a discussion about drivers' aggressive behavior in sociology can be synthesized in an advertising campaign or a toll planning about defensive driving without having to pro-duce them.

As such, the resolution via problem's simulation will require concepts' integration and, consequently, will develop skills and abilities that are important for the job market.

2.4 Level 4: solving a professional problem

In the last level, while practically all the classroom time (about 90%) is dedicated to PBL activities, the classroom space itself is minimally occupied and restricted to meetings with professor-advisor. The learning itself develops on the space-time where the phenomena to be investigated occur. At this level, students are the main actors and become responsible for driving and accomplishing the pre-established goals and achieving their full autonomy. In this context, the crane bridge and the toll examples given above would be developed and the results evaluated according to professional criteria (costs, technical viability, ethics and safety) to attest or not the students' ability to solve a problem. There is no lecturing and the conversations that occur between advisor-student happens on an individual basis. This could be exemplified by the Course Work expected to be accomplished at the end of the engineering course (called TCC in Portuguese), which is similar to senior capstone projects where a student engages in a project as part of their senior year and is completed in close consultation of a faculty mentor. However, it is tacit and explicit that a great number of graduating students, educated in a traditional context, when enrolled in the last semester, do not show skills, abilities and attitudes needed to deal with the highest level of PBL. Consequently, the professor, who should act like an advisor, returns to level 1, mediating the process, stimulating the autonomy and assuming responsibilities about deadlines, fulfillment of goals and outcome's analysis. This is the reason by which TCC causes stressful situations and is uncomfortable for the students. We educate them during all the academic cycle in the passive, traditional, unilateral, and non-autonomous form and focuses mainly on theory. Suddenly, at the end of program, we insert them in an active process, which is contemporaneous, multilateral, fully autonomous and free to obtain knowledge based on real experiences. Consequently, the work presented to a faculty board council at the end of the course (TCC) is disorganized, lacks originality, texts bypassing the theme and oral presentations are discouraging, not to say disastrous. It is the right formula to create embarrassment to everyone involved, especially for the student.

3 The use of Rapid Prototyping (RP) Resources in the PBL levels

According to Orey [11], who based his levels of thinking in the 'Learning Pyramid' (Fig. 2) of Bloom's Taxonomy, in order to ensure cognitive development, it is important to work with all levels of thinking, from lower to higher order. Therefore, lecturing followed by memorization exercises are examples of a low-level learning; the listen-read-write-look activities can generate some medium-level learning but still not effective as an excellent student learns– and does not forget – around 40% to 50% of what is taught. Furthermore, desirable skills are not contemplated (teamwork, collaboration, creativity and proactivity). On the other hand, high levels of thinking are achieved when a professor provides discussion-evaluation moments and activities that foster creativity and hands-on work. Because of that, it is not enough for students to

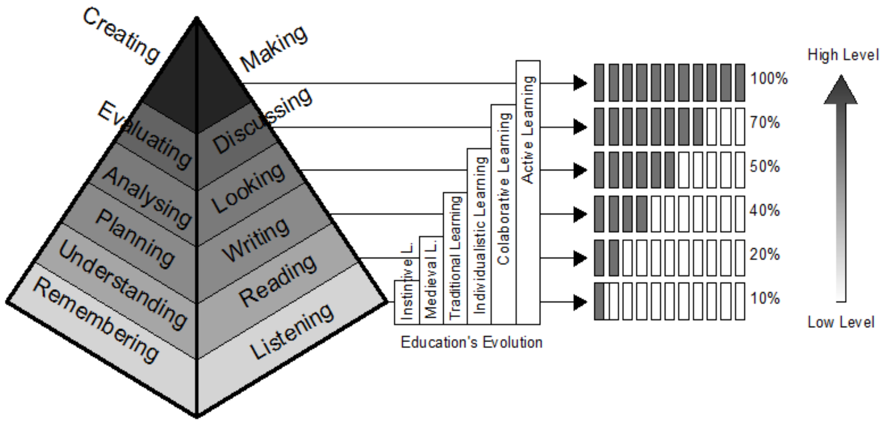

Fig. 2. Relation between the Bloom's Taxonomy, academic actions, education's historic evolution, perennial learning percent and thinking levels. Adapted and modified from [11].

listen to a lecture or understand a text. By creating, drawing and manufacturing a new product, students are working with a range of cognitive levels of thinking, especially higher-order thinking. Hence, using RP in the classroom provides the opportunities for students analyze, evaluate and apply knowledge.

PRONTO 3D – Laboratory of Prototyping and Digital Manufacture Oriented to 3D is part of the Brazilian labs network linked to the FAB Foundation, associated to MIT – Massachusetts Institute of Technology. The Fab Lab Network is an open, creative community of fabricators, artists, scientists, engineers, educators, students, amateurs, professionals, who has the mission to share and promote access to the tools for technical invention. This community is simultaneously a manufacturing network, a distributed technical education campus, and a distributed research laboratory working to digitize fabrication, inventing the next generation of manufacturing and personal fabrication. In each unit of PRONTO 3D there are 3D printers, router milling, laser cutting machines, computers and software (Fig. 3). There, it is developed CAD modeling, print 3D physical models, manufacture of prototypes, final products, complex structures, assemblies and installations. Several areas are attended, such as architecture, civil, mechanical, mechatronics and electrical engineering, industrial and graphic design, among others. The PRONTO 3D unit from SATC is composed by a coordinator (Professor-researcher) and students who receive scholarship, and provides services to internal customers (SATC undergraduate, high school and technical education courses) and external customers (companies and others PRONTO 3D units from Santa Catarina State).

Fig. 3. RP equipment to develop PBL classes (3D Printer, Laser cutting machine and Milling Router).

3.1 PBL's classes development in Level 1

An important aspect to implement the PBL is related to classroom layout, which allow to foster collaboration and interactive learning. Because of that, we designed our own active learning room (Fig. 4) We have whiteboards for students to share and express their ideas. We also have a mobile camera that allows students to showcase their work by streaming in the big screens.

Fig. 4. SATC Active Learning room.

The following is an example of a class where PBL was applied – Level 1, during the 2nd semester 2016 (Fig. 5). The project's aim was to promote cognitive activities that achieve higher order thinking, allowing students to become creative and problem solvers. Therefore, class was divided into groups of four student to solve a problem related to the subject of Technical Drawing. The PBL's task was to develop a Mini Baja's prototype by applying the discipline basic contents (dot, line, planes and graphics process to obtain distances and areas). Normally when implementing PBL, the classroom's layout is different from the traditional (rows of desks), so tables for four or more students to work together in this experience were used. In this case, several tools (scissors, pliers, stilettos, screws and other mechanical tools) were made available and raw materials (wood and acrylic sheets) were provide to manufacture the prototypes.

The professor (red shirt, seated next to students, left side of figure 5) does not stay seated in his chair - he remains very close to the teams, helping them to solve the proposed problem. There were short lectures, but most of the time was spent helping the groups. Not all groups delivered the complete task (incomplete assembly) but all groups performed drawings and used them to build the prototype. As can be seen, to plan and execute PBL class, it requires important changes (classroom layout, equipment, planning, and infrastructure adaptation). However, the main and most difficult change to be sought is in the professor's mindset, who needs to leave their comfort zone and adapt to provide the education of the XXI century.

Fig. 5. Left side: Active Learning classes (Level 1); 2nd semester 2016, SATC College, Mechanical Engineering Course. Subject: Technical Drawing. Right side: manufacture of prototypes using the basic concepts of the subject (design) and rapid prototyping resources (laser cut machine and 3D printer).

4 Conclusions

It is important to consider that the applicability of this PBL-based learning model to different disciplines needs to take into consideration the nature of each discipline, due to limitations imposed by course's current structure. Thus, it is plausible to expect professors to achieve level 2 when implementing in one discipline and level 3 in another, without moving up to next level. On the other hand, the incapacity to apply levels 1 and 2 indicated that there were structural problems, in which prevented defining the objective, importance, nature, protagonism and utility of the discipline itself. Furthermore, each attribute cannot occur in the same intensity even if it is in the same level of implementation. A problem of simulated scope (Level 3) can be solved through a mediator professor (Level 1). Actually, it is a possible situation but unlikely, in according to case studies observed. The integral application of PBL, contemplating every learning unit and every level, requires a revision of the curriculum for all the courses. However, the current proposition does not see this as a possibility.

PBL's curricular implementation requires change of teachers' consciousness towards teaching-learning process, the steeped application of each level, the radical change from content-based curriculum to skills-based curriculum, the immersion of universities on professional world and vice-versa. This immersion can be achieved via partnership between enterprise and the university, providing and fomenting research projects; scholarship and extra-curricular internship; university learning units inserted into the enterprises and enterprise laboratory units inserted into university.

Following, are displayed a resume of PBL-based learning model aspects (positives and negatives). On the positive side, we have seen the improvement in the engagement of teachers and students during PBL classes as well as a decrease in student dropout because students become more motivated. This active learning project, also promotes more recognition and differentiation from the job market. That also increase scientific production and external quality indicators. The negative aspects we have found is that engineering professors, specially, are more resistant to implement PBL, despite the fact that we have all the structure and provide all the conditions and support to plan and implement active learning. We also know that deep changes in the curriculum of each graduation course is needed. There is a need to make a financial investment because there are expenses with equipment maintenance, inputs and raw materials.

5 References

[1] Hasna, A.M. (2008). Problem Based Learning in Engineering Design, Proceedings of SEFI 36TH Annual Conference, European Society for Engineering Education.

[2] Rodríguez, J., Laverón-Simavilla, A., del Cura, J. M., Ezquerro, J. M., Lapuerta, V., & Cordero-Gracia, M. (2015). Project Based Learning experiences in the space engineering e ucation at Technical University of Madrid. Advances in Space Research, 56(7), 1319-1330. https://doi.org/10.1016/j.asr.2015.07.003

[3] Jamaludin, M. Z., Yusof, K. M., Harun, N. F., & Hassan, S. A. H. S. (2012). Crafting engineering problems for problem-based learning curriculum. Procedia-Social and Behavioral Sciences, 56, 377-387. https://doi.org/10.1016/j.sbspro.2012.09.666

[4] Hitt, J. (2010). Problem-based learning in engineering. Center for Teaching Excellence, United States Military Academy, West Point, NY.

[5] Belhot, R. V., Reflexões e propostas sobre o 'ensinar Engenharia' para o século XXI. (1991) Escola de Engenharia de São Carlos, Universidade de São Paulo.

[6] Drake, E., & Battaglia, D. (2014). Teaching and learning in active learning classrooms. The Faculty Center for Innovative Teaching: Central Michigan University.

[7] de Los Rios, I., Cazorla, A., Díaz-Puente, J. M., & Yagüe, J. L. (2010). Project–based learning in engineering higher education: two decades of teaching competences in real environments. Procedia-Social and Behavioral Sciences, 2(2), 1368-1378. https://doi.org/10.1016/j.sbspro.2010.03.202

[8] Esteban, S., & Arahal, M. R. (2015). Project Based Learning Methodologies Applied to Large Groups of Students: Airplane Design in a Concurrent Engineering Context. IFAC-PapersOnLine, 48(29), 194-199. https://doi.org/10.1016/j.ifacol.2015.11.236

[9] Hassan, S. A. H. S., Yusof, K. M., Mohammad, S., Abu, M. S., & Tasir, Z. (2012). Methods to study enhancement of problem solving skills in engineering students through coop-

erative problem-based learning. Procedia-Social and Behavioral Sciences, 56, 737-746. https://doi.org/10.1016/j.sbspro.2012.09.711
[10] Jonassen, D.H., (1997). Instructional design models for well-structured and III-structured problem-solving learning outcomes. Educational technology research and development, 45(1), pp.65-94. https://doi.org/10.1007/BF02299613
[11] Orey, M. (2010) Emerging Perspectives on Learning, Teaching and technology. Zurich, Switzerland: Jacobs Foundation.

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