Work-in-progress: Pedestrian bridge application in a fundamentals of structural analysis course inside an architecture bachelor program

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***Abstract*— The paper presents an application of the Problem-Based Learning (PBL) methodology in a structural analysis course taught in English of the third year Architecture bachelor program at Politecnico di Torino (Italy). This experimentation regards a class which is composed mostly of international students, that is, a heterogeneous audience with different background. In general, students struggle with the technical aspects typical of structural analysis course. PBL has been found as a possible solution to this problem in Engineering programs. The aim of redesigning the course is to support students' learning while evaluating the PBL application in a non-technical context with an international audience. This work-in-progress article explains its implementation with the first observations. In particular, the participation has increased compared to the previous academic year in terms of presence during the lectures, interest in the subject and interaction between the lecturer and the students. These preliminary results are encouraging and confirm the validity of the PBL methodology as actually applied.**

Keywords—Structural Analysis, PBL, Architecture bachelor program, Pedestrian bridge

I. INTRODUCTION

The course of Fundamentals of Structural Analysis (FSA) is a third year mandatory course of the Architecture bachelor program at the Politecnico di Torino (PoliTo). This bachelor's degree has two different tracks: one taught in Italian, with around 450 students, and one in English with almost 75 students. While in the Italian path students are mostly coming from Italy, in the English one there is an international audience with students coming from different countries, in particular from Asia and South America.

Due to its nature, the FSA course has a high technical and engineering content and usually, architectural students struggle in understanding both the theoretical aspects and the manual and numerical solution procedures. One of the aspects that not technical students usually find hard is the shift from the theoretical concepts to the qualitative evaluation that this topic requires. This "translation" is unusual for students in general, but even more for the architectural one that in their study are not comfortable with this approach. This is even more evident in the English track in which students' backgrounds are very heterogeneous since they came from different nations with a variety of school systems, although the courses in the first two years helped to fill the previous educational gap.

In the past years, the methodology used in this course has been following a traditional face-to-face teaching model with a single lecturer supported by slides with some exercises at the blackboard. In the meantime, at the end of the course, only a few students succeeded in passing it. For example, in academic year (a.y.) 2018/19 of the 55 enrolled only 5 of them were successful at the final exam in the winter call (first call available). Moreover, the students' level of engagement during the course has been critical both in term of presence during the lectures and in term of interaction with the lecturer.

Data from several studies suggest PBL (Problem-Based-Learning) methodology as a good solution to approach the learning difficulties typical of a structural analysis content inside technical schools [1, 2, 3, 4]. The present research explores the effects of this methodology in a non-technical context, the Architectural bachelor degree, with an international audience.

To redesigning the course, in the planning stage, the three objectives (overall subject framework, themes and types of problems, and proposal for PBL work) are been chosen as a reference point. Moreover, referring to the typical theoretical learning principles that De Graaff and Kolmos identified [5], the course framework has been defined as reported in Table 1.

Table 1 Course design based in the typical theoretical PBL learning principles (first column refers to [5])

Typical PBL theoretical learning principles	**FAS redesign framework**
Problem-based learning: the problems are based on real-life problems which have been selected and edited to meet educational objectives and criteria	The chosen problem is the design of a pedestrian bridge and its structural analysis.
Participant-directed learning processes: students have the opportunity to determine their own problem formulation within the given subject area guidelines	The teacher will provide the students a detailed guideline to support the problem approach and to help them in identifying a feasible solution.
Experience learning: to link the formulation of the	Each group of students can choose the location, the

problem to the individual's world of experience increases motivation	shape and the material to be used for the bridge design
Activity-based learning: requiring activities involving research, decision-making and writing	Students will need to periodically submit reports. Moreover, in the initial design stages they will need to make decisions based on personal research; while in the structural analysis they will need to critically review the results obtained and make proper changes
Inter-disciplinary learning: teachers do not just consider objectives within the known subject-oriented framework, but also consider problems or real situations	In order to solve the pedestrian bridge problem, students need to consider the mechanical properties of materials, the esthetical aspects and the environmental constrains that they have learnt in previous courses
Exemplary practice: The students must acquire the ability to transfer knowledge, theory, and methods from previously learned areas to new ones	Teacher will foster the ability to generalize the learning knowledge
Group-based learning: whereby the majority of the learning process takes place in groups or teams	The students will work in groups of 3-4 people each

The chosen reference project for the PBL implementation deals about a preliminary design of a small/medium size footbridge following and applying the topics given in the course. This is simple enough to be examined with the tools provided during the lessons, and it can be partially solved manually and by using a structural software. For this course, the software used is Nòlian, an Italian FEM analysis application [6]. This tool is frequently used by the Italian professionals but is not available in English and this represents a partial problem for the international audience of this course. Besides, each team of students can locate the bridge somewhere in Italy or in their country of origin as well as they can choose as building material one typical of their region.

To boost students' participation, a collaboration with the DC Structures Studio of Cambridge (NZ) is been established and, at the end of the course during the final presentation, the best projects and related reports will be voted by a commission of academic lecturers and experts in the field. Then, the best ideas will be published on the studio's website.

II. Background

In the international context, the difficulties typical of the structural analysis have been addressed with a PBL implementation. While solving the problem students learn how to compute the calculation and how to address metacognition. In a qualitative analysis research, which measures the impact of the PBL in this topic, Justo et al. highlight as main strengths the teamwork, self-directed learning, continual assessment, practical approach and faculty involvement. Although, in the meantime, the study identifies some drawback points such as the disorientation experienced by the students at the beginning and the different involvement and workload of team members. These findings suggest the importance of the tutorship both in approaching the project and on the orientation and evaluation of equal task distribution inside the team [1]. Moreover, the role of tutoring activities is been identified as key also for the improvement of a conceptual understanding of students. However, a significant improvement in conceptual understanding of bending moment distribution seems to be hard to reach with only the tutors' support [2].

Then, another important aspect becomes the integration of the project into the course topics. Morgan and Barroso suggest creating an explicit tie between the project tasks, outcome and the course contents. Establish this clear link helps the students to understand that the project itself is a way in which they can personally put together the different concepts [3].

A. New course design context and purpose

At the beginning of the course, a sketch of a reference bridge and the full details are presented to the students (Fig. 1) [7]. Moreover, as personal deepening, other sources of inspiration are also been given to the students [8, 9, 10, 11].

The purpose of this new design of the course is to support students learning, in particular, the technical aspects of the structural analysis. Applying the PBL methodology, a sort of a preliminary and elastic design will be examined, taking care of some parts of the building regulations. Complete exams of the appropriate technical standards, load combinations, elastoplastic design, seismic actions, structural details will be covered in detail in following Structural Engineering courses during the Master degree.

B. Objectives of the study

This study will analyse two different relationships with the PBL:

- How can the PBL favour the learning of a technical subject in an architectural program?
- How can the PBL favour the learning of a class composed of international students with a heterogeneous background?

To answer those questions, different qualitative aspects are collected and analysed, thanks to direct observation, structured project revision, presentations and final survey.

III. Project implementation

In order to implement the PBL methodology, the entire course needed to be reviewed. First of all, the content of the project that the students need to develop has to be defined taking into consideration the traditional content of the course.

For this reason, it needs to have the characteristics of a preliminary study with simple calculations. In the meantime, although the goal of the course is not to do a full standard-compliant design, the project needs to take into consideration the national regulation to help the students to understand the

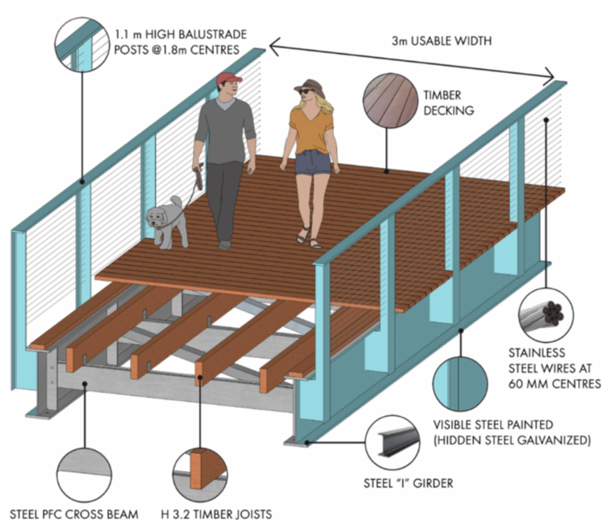


Figure 1 - New Zealand standard footbridge design (basic 18 m pedestrian bridge) [7].

complexity of real-life structural analysis. Following these characteristics, a small/medium size footbridge (span of about 15 m to 20 m) is been chosen as a project theme.

The reference project is been identify in the pedestrian bridge developed by the DC Structures Studio [7], which introduce the project by saying:

If you find these designs useful or have any improvements, please leave us a comment. Our team is driven by a passion for bridge design (we love bridges!). Hence, we are very proud of this set and hope to see it used throughout NZ. We would really appreciate hearing any feedback you might have: Is this standard bridge useful? What changes would make it better? Would you consider using it? What updates or additions would you like to see?

Thanks to the interaction with the DC designers, the full project was made available for the course. Students can design and imagine possible variation to improve the architectural and structural aspect of this original project, or to create a new one with similar characteristics. In general, the project needs to follow the KISS principle, that is, Keep It Simple Stupid [12].

Then, while the key technical aspects of the project have been identified, the course material has been reviewed according to them. In particular, the contents strictly related to the project have a yellow background and contain comments, exercises, data and suggestions useful for the designing of the bridge. This has been made to help students to immediately identify the steps they need to carry out to successfully complete the project [13].

To enrich the soft skills such as teamwork, communications, organization, and leadership, the students will work in teams with a maximum of 4 people.

At this point, the course calendar has been divided into (i) lecture, (ii) tutoring, (iii) presentation. The lectures amount to 60% of the entire course and consist of face-to-face traditional lessons, computational exercises and propaedeutic content for the project. The tutoring sections represent 30% of the course and consist in sections of 15 minutes each in which every team can personally discuss its project with one tutor. The tutors are civil engineer master students, selected through a call, available for a maximum of 60 hours each during the entire course. For this a.y., 3 tutors have been assigned to the FSA course which guarantees a strong interaction in term of time with the teams. The remaining 10% is dedicated to 4 presentations in which each team is required to explain the progress of the design. The first 3 presentations need to last 3 minutes each. Concurrently students are expecting to deliver a well-structured, one-page description of the work in progress of the project. Instead, the final team presentation last 10 minutes and will be in video conference with DC Structures Studio. Finally, a complete project report should be delivered to the lecturer.

During the first lesson, the restructured course has been explained to the class with a deep look into the project request. This includes the content that each team needs to present inside the 3 minutes speech. During the first presentation, students should present a basic structural scheme, materials, load, design and location of the bridge. During the second presentation, they should explain the deformability and stability. Then in the following speech, they need to show the strength, the effect of horizontal loads and bracing, and the 3D numerical model. While, for the final 10 minutes presentation the project must be fully presented.

Looking deeply on the information needed to be reported in the one-page description that the team necessitate delivering at each presentation, the following aspects need to be considered. To define the material properties, one must consider the building regulation that varies country by country. If the national regulation is not easily available the lecturers with the tutors can decide to use the Italian and EU regulation as a reference [14, 15]. The building regulation chosen as reference for each project needs to be used also for the loads' calculation, that includes dead load, live load, self-weight, snow, a horizontal force on the balustrade. While wind and earthquake loads are neglected. The structure calculation entails being partially solved manually by using equilibrium equations for which the structure should be statically determined. Only after this manual approach, the structure is solved using the structural software Nòlian.

In this stage, students should evaluate the numerical results comparing the analytical solution in terms of stress (strength), displacements (stiffness), instability (stability) and the numerical solution. Moreover, they need to discuss the horizontal bracing by applying horizontal forces (10% to 15% of the vertical forces). If the team chooses as location an Italian area, the national regulation is already present inside the FEM software; otherwise, it needs to consider manually the national restrictions.

For the final report (about 5-10 pages long) a detailed guideline has been made available to the students and cover the following points:

1. summary (description of the problem)
2. introduction (overview and main issues)
3. problem description (assumptions, drawings, solution procedures, theory assumptions)
4. results (presentation, explanation, supporting theory, numerical results, implications)
5. conclusions and recommendations

6. references (technical standards, other useful material)
7. appendices

Moreover, some insight references have been given to further support the students in the writing process [16, 17].

As part of the redesign, also the assessment has been modified. In particular the final exam will be composed by a multiple answers test (18 points) and the case study solution (12 points). The test will include 12 theoretical questions and 6 items related to the software application. It is considered passed if 12 over 18 are answered correctly, independently on the type of questions. Regarding the project evaluation, the entire team evolution of the solution will be considered (the three minutes presentations, the material delivered, and the tutoring sections) as well as the final presentation. For those students that didn't deliver any final solution, the assessment will remain as it was: a 30 questions multiple answers quiz.

IV. Discussion of the partial result

After 9 months of course revision and material preparation, the revised FSA started in October 2019 and will last until the end of January 2020. This a.y. there are 74 students enrolled in the course; with only 4 of them coming from Italy, while the others are mainly from Asia and South America.

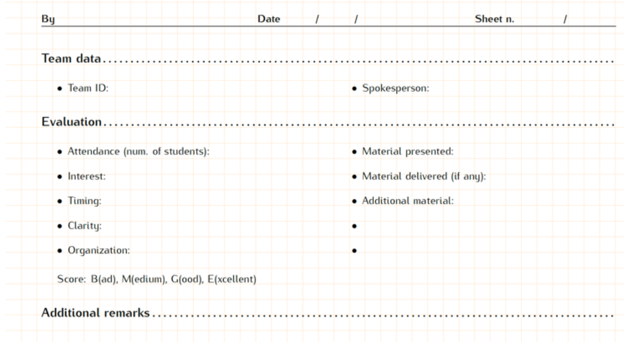
Considering the fact that the literature review highlighted as fundamental for a successful PBL implementation the tutoring support, before the starting of the course the main lecturer organized a meeting with the three assigned tutors. During this session, it has been explained the new approach and pointed out the key role they play in the learning process. In order to collect all the information and properly support each team, it has been required to fill a simple form for each team revision, like a diary (Fig. 2).

The reference of the spokesperson and the attendance were included to track the possible uneven distribution of workload inside the team. Thanks to this weekly report, at the end of the course a relation between those aspects and the goodness of the learning can be analysed.

During the first lesson, the new structure has been presented to the students and they autonomously organize in 20 teams. During the second week of lessons, the first revision section took place with 13 teams involved. Unless one, all the teams involved were in their complete formulation and the spokesperson was not limited to one for each team. Typically, each member exposes his/her idea of the design and materials previously discussed with the other colleagues. The interaction was profitable and the 7 teams that decided to not have a direct interaction with the tutors were physically present in the class doing brainstorming activities.

During the third week of the course, before the first presentation, another revision section took place. This time 14 teams were present, some of them were already at their second revision, while for others was the first meeting with the tutors.

At the first presentation, 17 teams publicly presented their idea. The quality of the presentation was well responding to the request. Although 4 teams' idea showed possible coming up problems in the following steps of the project. For this reason, the tutors were informed about the possible structural issues to help the teams on the structure design and materials during the next revision sessions.


By Date / / Sheet n. /

Team data

- Team ID:
- Spokesperson:

Evaluation

- Attendance (num. of students):
- Material presented:
- Interest:
- Material delivered (if any):
- Timing:
- Additional material:
- Clarity:
-
- Organization:
-

Score: B(ad), M(edium), G(ood), E(xcellent)

Additional remarks

Figure 2 - Form that the tutor needs to fill after each team revision.

Each of the bridges presented has a simple but different design. Considering the location, some of them chosen a spot in their country of origin (China, Colombia, Vietnam, Indonesia, Italy, …), others prefer a country external to the team such as Sweden or Nederland. Looking at the materials, some team chosen unusual one like containers and bamboo while others employed more standard elements, like wood and steel.

At the following revision, 10 teams interact with the tutors in order to solve the first calculation.

In general, the course participation has increased compared to the previous a.y. both in term of presence during the lessons that in interest about the subject. In particular, the interaction between the lecturer and the students increase mostly through email communication. Mostly the students' requests are addressing discussion about alternative computational solutions and particular material characteristics. Moreover, some active learning activities have been also implemented in theoretical lessons.

V. Partial conclusion

These initial results suggest that a positive relationship can exist between PBL and FSA in an Architecture program. Students are used to working in teams and to develop a project inside a course. In this way also the technical aspects, that usually are found to be the hardest one, are better understood by students thanks to the tutoring activities and the peer-to-peer learning. This cannot be ensured to all the students because the PBL has a degree of freedom in the involvement and participation in the proposed activities (lessons, revisions and presentation).

Considering the second research question, the possibility to locate the bridge all around the world and to choose materials which are more familiar for them is a positive aspect of this new methodology. Indeed, this freedom acts as leveraging on personal interests reinforcing and supporting the learning process. Another important aspect related to the heterogeneity of the class is the increase of peer-to-peer activities that are been registered since the first weeks. This informal and spontaneous interaction support not only the computational side but include in some cases also a theoretical discussion and study support activity.

Acknowledgement

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