Journal of Engineering Education Transformations ,
Volume 37 , No. 3 , January 2024 , ISSN 2349-2473, eISSN 2394-1707

10.16920/jeet/2024/v37i3/24002

The Impact of Cross-cutting Pedagogical Features Based on Neuroeducation Advances: Project-based Learning Vs. Traditional Lecturing in Engineering Education

Prof. Claudia Paciarotti[1], Dr. Gabriele Bertozzi [2]
[1,2] Industrial Engineering Department, Università Politecnica delle Marche, Ancona – Italy
[1]c.paciarotti@univpm.it,
[2]g.bertozzi@pm.univpm.it

Abstract— On the academic level of education, Traditional Lecturing represents the primary means of conveying information to the class. At the same time, Project-based learning is one of the major research subjects in engineering education, and literature claims it can offer more authentic and meaningful learning experiences. Supported by the most recent advances in syntheses of meta-analyses in education and neuroscientific-based educational sciences, the study presented compares Traditional Lecturing and two versions of Project-based learning implemented with variations in content and project typologies through a single-group variation on the two-group post-test-only randomized experiment. Two research hypotheses were investigated using three questionnaires and a test: I) the learning experience and outcomes are enhanced when attending Project-based learning lessons compared to Traditional Lecturing ones; II) effective cross-cutting instructional elements are more detectable in Project-based learning than in Traditional Lecturing and variations in contents and typologies of project do not lead to different outcomes within Project-based learning. The research was carried out in an Engineering course and involved 80 students. The results show that Project-based learning outperforms Traditional Lecturing and highlight the crucial role of some cross-cutting instructional features that are detectable or missing within the two methodologies. Derived from meta-analyses and neuroscientific-based educational sciences, these features represent a solid pedagogical core within the structure of the Project-based learning methodology. We argue they have a relevant role in the stability and enhancement of the results of Project-based learning in comparison with Traditional Lecturing. Indeed, despite variations in content and project typologies, Project-based learning produces similar results. Finally, for engineering teachers wishing to adopt Project-based learning, this study provides insights into the necessity to understand, consciously incorporate, support, and manipulate such particular features, especially through developing pedagogical competence based on scientific evidence.

Keywords : neuroeducation, engineering education, higher education, project-based learning, traditional lecturing

1. Introduction

Traditional Lecturing (TL) is also known as "recitation method", conventional-direct-recitation method or initiation-response-evaluation cycle [1]. It

Dr. Gabriele Bertozzi
Industrial Engineering Department,
Università Politecnica delle Marche, Ancona – Italy
c.paciarotti@univpm.it,

has little changed over the time and represents a sort of "grammar" of schooling [2].

Its most recognizable features belong to the teacher-centered approach. Teachers are in charge of both the choice of the contents and the pace of the lesson. As a consequence, the students work individually, listen, take notes and rarely get involved in discussions or answering questions [3]. Considering its long persistence, TL must indeed have some advantages. Firstly, it belongs to tradition, and it is easier to make it work. The cycle of requests and expectations is clear and largely predictable [1]. Through TL, teachers can manage the class and have control in terms of discipline, authority and, most notably on, content choice. As a result, they become the one and only source of knowledge. From this first analysis, it is clear that Traditional Lecturing represents a good compromise between authority and management [1]. Moreover, there is also a general reputation among people that TL has been somehow successful in building well-educated generations of students. In addition to the perception that competing methods and technological innovation have not reached a visible mutation or outstanding outcomes [1].

On the other hand, Project-Based Learning (PBL) is a pedagogical model aiming at enhancing learning through the development of projects. Many are the variations in its implementation as well as the overlapping areas between PBL and other teaching strategies, e.g., intentional learning, design experiments, problem-based learning, inquiry-discovery, and learning by doing, to mention a few [4]–[6]. Hence, a neat definition of what PBL is particularly difficult to derive. However, a specific definition of PBL is possible using some pedagogical concepts transversal to all constructivist activities. PBL is an essential part of what has to be learned; questions drive it, it allows knowledge construction [7]; it brings with it the idea of teachers as facilitators and students as responsible and autonomous actors; it deals with real-life scenarios and challenges [8]. The literature has identified some specific didactic elements to define it more practically. Demanding tasks, unsolved problems, active individual or collaborative work, research, and decision-making are among the most relevant. The final result often consists of a product strictly connected to real life [9], [10].

Through questionnaires and an achievement test, this study wants to investigate the following research hypotheses: I) the learning experience and outcomes are enhanced when attending PBL lessons compared to TL ones; II) effective cross-cutting instructional elements [11]–[17] are more detectable in PBL than in TL (prior knowledge, clarity of objectives and expected performance, meaningful learning as usefulness in a life-long perspective, motivation to commit, motivation to take part in classes, feedback opportunities, group work versus individual work, clarity of acquisition) and variations in contents and typologies of project do not lead to different outcomes within PBL.

2. Literature Review

Considering its long-time endurance and widespread implementation, TL has been the object of extensive research.

Especially for a non-expert student, evidence has shown that this methodology might result in a complex experience [18], [19]. In TL, the quality and quantity of questions teachers ask students are often limited to mnemonic levels [1]. They cannot generate complex answers or feedback dynamics and are hence unable to foster scaffolding strategies, teachers' guidance or detect the students' learning stages. Few of them have a chance to be actively involved and only seldom. It is passive the role played by students in the classroom. Learning turns into a repetitive task where being able to replicate someone else's ideas or show their retention becomes more important and valued than critically internalizing new knowledge [11]. Furthermore, the taught content is usually extraneous to the choice or interest of the class: a pre-packaged material, and the focus would shift from the process onto the outcomes (mostly summative evaluation). It is, in a way, as if "students come to lesson to watch teachers working" [20].

Nevertheless, TL still ranks first among the most employed teaching methods [21], [22]. As summarized by Regmi, there are still several pros when adopting this method. For example, it can deliver factual material directly and logically; it is appropriate to teach large classes; it represents an efficient and inexpensive approach; a teacher may be a 'role model' for students' learning; students develop listening and note-taking skills [23]. Moreover, TL maintains its position also because it is not easy for an untrained eye to spot the weak points of the cycle: racing through the contents; deep learning is negatively affected; not all of the students have a chance to be successful [2], [21].

Teachers certainly cover contents in such a context, but stimuli and "meaningfulness" [24] are missing, and this is not a marginal aspect. For example, a vast study [25] found that the chance to talk for students up is 5% and just 1% for more complex questions. This kind of involvement contradicts the founding mechanisms of our brain when it comes to learning: the strong connection between emotions and engagement /motivation / learning; attention time; images as the most favorite media [1], [14], [17], [26]–[28]. Furthermore, all that "chalk and talk" often turns into cognitive overloading [19]: an unmanageable quantity of inputs.

Within our engineering context, teaching seems equivalent to lecturing [21], [29]. Surprisingly, students tend to prefer TL [30], a model still valued as beneficial and not out-of-date by a large majority of them [31]. Nevertheless, lecturing shows low achievement [32]. This is why many papers have focused their attention on improving lecturing (e.g., a more interactive lecturing) [33], [34]. Research has searched for suggestions coming from engineering students too to make teaching more effective [31]: engagement/active learning environment; dynamic lesson with visual aids; having good notes to look during the lecture; going from global to details; referring to what is being taught might be asked in exams; creating a positive learning environment; allowing in-depth learning that's to say giving a chance for deeper understanding of the contents [31]. These are pretty interesting features since they show the dual nature of students' goals. On the one hand, they need more active and in-depth learning while, on the other hand, they focus on passing the exam as the main priority.

However, when it comes to engineers' professional life, the requested competencies go beyond core literacy [35]. They are far more complex than those TL approach can produce [1]. In the pyramid of learning [36], engineers are asked to develop "deep" learning, i.e., competencies related to analytical, critical, and creative thinking [11]. In addition, specific attitudes and mindset features need to be fostered and developed, i.e., motivation, engagement, learning in context, deliberate practice [37]–[39], soft skills, competent inventive capabilities and mentality [40]. As a consequence of these emerging formative demands, other methodologies have been looked into and especially those characterized by a more student-centered vision as PBL.

To define PBL, some identifying key features can be derived from the literature. A driving question [41] or request usually moves students to search and investigate fields containing the required knowledge. PBL is "crafted to make a connection between activities and the underlying conceptual knowledge that one might hope to foster." [42]. Hence, PBL is part of the curriculum, and it doesn't provide examples or additional enriching explanations to learning material that has already been taught beforehand by other didactic means. The way students are activated is that typical of a constructivist approach and, more precisely, of social constructivism with its collaborative and community-centered specificity. PBL expects learners to move from what is known to new skills and knowledge [43]. In doing so, they do not execute somebody else's instructions, follow predetermined paths or ready-made project boxes. A great deal of autonomy and active participation on the side of students characterize this methodology. So, even if the final result is declared, the how-to reach it or personalize it still belongs to the students' domain.

The learning object needs to be felt as meaningful, somehow useful and has to be experienced. It has to be as much realistic as possible and not theoretical. Working on real tasks or environments and being pushed to identify and solve problems make learning effective and deeper [44] and develop a much more flexible attitude. This kind of learning, which is found in problem-solving, has more chances to be retained and applied too [45].

PBL has shown some critical points too. For instance, there is no evidence that students with a low grade of achievements can become motivated and engaged learners [10]. Moreover, though claimed to be a valuable means of promoting both short-term and long-term learning, studies have not always produced the same results [46]. Moreover, difficulties encountered in implementing this method are: managing the amount of time that is needed; teachers' role; students' autonomy rates; support of student learning; management of the classroom; curriculum pace and priorities; control of the learning process; technology use and assessment; how students should interact [47]. Hence, PBL itself is not an easy model to assess since it depends on many interacting elements, and the long period required to develop it increases the chance of mistakes and interference in final results or data collection [47].

In order to take steps towards limiting the cons, it is possible to refer to a recent literature review study [48] and the list of six evidence-based recommendations that have been drawn up: student support; teacher support; effective group work; balance between didactic instruction with independent inquiry method; assessment emphasis on reflection, self and peer evaluation; student choice and autonomy. With regard to our study, all of the recommendations have been carefully followed, and the presence of other effective instructional elements have been investigated, selecting them from Hattie's meta-meta-analytic work [1], [11].

Being the concept of "project" a very familiar one in the field of engineering, most studies on PBL carried out in Higher Education are focused on engineering education [48]. In them, several topics are dealt with, e.g., motivation development [49], integral implementations, possible variations, information technology applied to this model [50], [51], different work modes [52]–[54], addressing emerging learning needs [55]. The capacity to grasp an idea in a competent and interiorized way appears to be one of the key consequences of PBL implementation. Other results are the improved rate of attendance, self-efficacy, and a better approach to learning on behalf of the students [8].

In comparative studies, research often focuses on PBL features, trying to evaluate its pros and cons or to determine whether it might represent a likely alternative to TL [56]. So, the latter appears in the background as if its inadequacy could be taken for granted. By providing an overview of the areas of interest PBL features are in, we can state that comparisons are usually concerned with personal perception elements such as satisfaction, motivation, clarity and critical thinking. PBL generally shows better outcomes in terms of perceptions (preference, the perception of efficacy, motivation), quality in the long term of learning (critical thinking, deeper understanding), and "soft skills".

3. Method

The research method employed in this study can be defined as a variation on the experimental design defined as “two-group post-test-only randomized experiment” [57]. The original version of it consists in comparing two groups randomly formed. The first group (R) receives the treatment (X), while the second - that is used for relative comparison - does not receive it or alternatively gets the standard or typical treatment. In this specific method, a post-test (O) only is submitted to students. In fact, the random group-formation makes it reasonable to assume that both experimental and comparison group satisfy the null hypothesis and, hence, a pre-test is not needed [57].

As to this research, a variation on the method has been implemented. In fact, the two randomized groups have been substituted with a single group that become both control and experimental group contemporarily. Moreover, it was decided that the treatment for the control/comparison group had to be that of the standard treatment, i.e., TL. Firstly, the authors argued that the implementation of a single-group research could well suit this study from an overall point of view. In fact, it is the typical approach carried out to assess the effectiveness of an educational intervention, and “can be used with smaller sample sizes with little or no error variance concerning individual differences between conditions” [58]. Moreover, it allowed the authors to avoid ethical issues due to random assignments [59]. The single group variation - representing both the experimental and the control group - brings with it several further advantages related to internal validity, too. In fact, a single group experiences the same testing and instrumentation issues, similar rates of attrition and regression to the mean too [60]. As to other common threats to internal validity related to single group designs, the severest ones are represented by maturation, history, and sequencing effects [58]. To manage them it is suggested to make the order of the treatments random, a practice also known as counterbalancing [58]. Accordingly, the authors decided to implement PBL1, PBL2 and TL contemporarily.

A test and questionnaires represent the means by which quantitative data of the students’ learning outcomes and their perception of the learning experience have been derived. The study was conducted within a Management Engineering course of 80 second year undergraduate students: “Industrial plants design”. The study was set up to compare TL with PBL. The latter in two different implementations. The industrial plants class has been regarded as particularly suitable since characterized by little interconnection among the contents and low dependence from students’ prior-knowledge.

The whole course was divided into 3 modules:

- Section n.1 The didactic model was PBL1. Students had to develop a project to optimize a production.
- Section n.2 TL teaching style.
- Section n.3 The didactic model was PBL2. Students had to design a project in order to teach their course mates contents earlier assigned to them.

In Section n.1 and Section n.3, the students worked in groups of about 6 students each randomly formed; while throughout Section n.2, work was carried out individually.

1) Instruments

The instruments used to derive data were:

- Three 5-point scale questionnaires;
- A test: 42 questions.

The questionnaires

The three questionnaires (8 items each) investigated through equivalent parallel questions students' perception of the learning experience within PBL1, TL, and PBL2. It allowed the students to graduate their answers in a range that goes from 1 to 5. Accordingly to PANAS scale grades were [61] 1 not at all, 2 a little, 3 moderately, 4 quite a bit, 5 extremely. As mentioned above, each question was repeated for each teaching method (with inevitable trivial formal adjustments) to provide a direct comparison between PBL1, TL and PBL2. The comparison between the two differently implemented PBL versions offered a chance to declare statistically significant results as a consequence of the methodologies rather than of the variations in their contents and projects. The questionnaires investigated to what extent specific effective instructional elements [11] were detected in students' learning experience. Answering the questions needed no pedagogical familiarity from the students. In fact, it relied only on their experience as learners or university attendees. The theoretical grounding of the questionnaires has to be firstly found in the reliable capability of learners to assess quality teaching [62]. Strictly related to effective teaching as well as to a life-long educational perspective, quality teaching is defined and specified through several research steps in literature [11], [63]–[67]. The questionnaires asked the students to grade to what extent the following features had been perceived in the lessons: prior knowledge, clarity of objectives and expected performance, meaningful learning as usefulness in a life-long perspective, motivation to commit, motivation to take part in classes, feedback opportunities, group work versus individual work, clarity of acquisition. Before its utilization, the capacity of the items of the questionnaires not to be misunderstood was checked by two researchers with experience in Likert questionnaires and an expert in statistics. An exploratory factor analysis (see Tables I, II, III) was carried out to validate the questionnaires. In Tables I, II, III factor loadings and scree plots of PBL1, TL, and PBL2 are displayed, respectively.

Table 1: Items factor loadings and scree plot of PBL1

Chi-squared Test

	Value	df	p
Model	30.487	20	0.062

Factor Loadings

PBL1	Factor 1	Uniqueness
1	0.473	0.776
2	0.357	0.872
3	0.490	0.760
4	0.439	0.807
5	0.435	0.811
6	0.344	0.881
7	0.559	0.687
8	0.622	0.614

Note. Applied rotation method is promax.

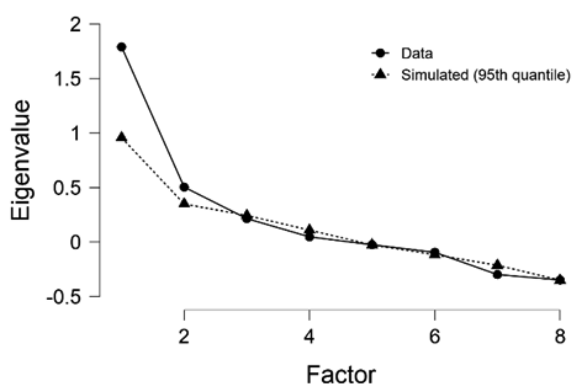


Table 2: Items factor loadings and scree plot of TL

Chi squared Test

	Value	df	p
Model	28.073	20	0.108

Factor Loadings

TL	Factor 1	Uniqueness
1	0.469	0.780
2	0.468	0.781
3	0.617	0.619
4	0.786	0.383
5	0.418	0.825
6	0.694	0.518
7	0.530	0.719
8	0.574	0.671

Note. Applied rotation method is promax.

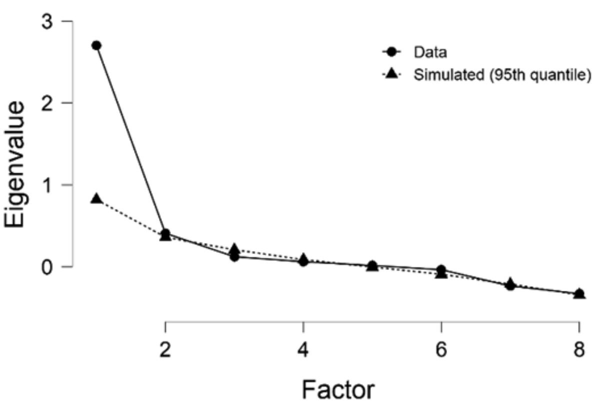


Table 3: Items factor loadings and scree plot of PBL2

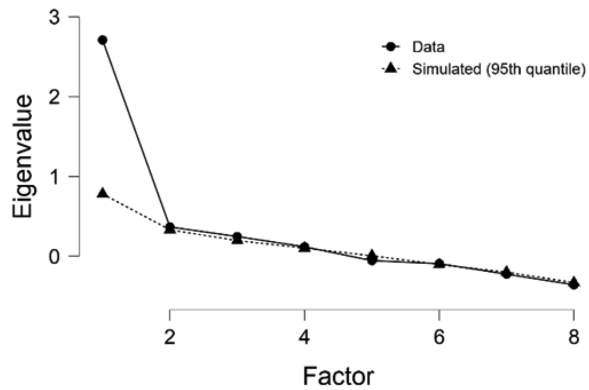
Chi-squared Test

	Value	df	p
Model	36.883	20	0.012

Factor Loadings

PBL2	Factor 1	Uniqueness
1	0.391	0.847
2	0.561	0.686
3	0.517	0.732
4	0.806	0.350
5	0.507	0.743
6	0.521	0.729
7	0.795	0.369
8	0.408	0.834

Note. Applied rotation method is promax.



KMO and reliability of the questionnaires follow.

Table 4 : KMO test & reliability of the questionnaires

Teaching method	KMO	Cronbach's alpha
PBL1	0.68	0.69
TL	0.79	0.81
PBL2	0.75	0.79

KMO test and Cronbach's alpha computation confirmed that both the suitability of data for factor analysis [68], [69] and reliability [59] were acceptable.

Being the case of one group measured on different occasions, data collected from the questionnaires were statistically analyzed utilizing the Friedman test with a Bonferroni correction. The Friedman test is the non-parametric alternative to the one-way ANOVA with repeated measures and is used to test for differences between groups when the dependent variable being measured is ordinal. Once differences occurred ($p<0.05$), the Post-hoc Wilcoxon signed-rank tests were run on the different combinations of related groups. Post-hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction. Using the first correction, we obtain the result of checking the type I error for each question in the questionnaires, so the likelihood of a false positive for every question is checked at 0.05. With the second correction, we get a probability of committing a type I error controlled at level 0.01 among all the performative tests.

In the questionnaires, each student answered parallel questions for the three modules and, therefore, for the respective teaching methods (PBL1, TL, PBL2). The object of the analysis will be the descriptive display of the answers given by each student and the comparison among the three teaching methods by means of the median. The following data filtering criteria apply: for every parallel triplet of questions or pairs (see Figures 12 and 13), the data of the students who didn't give all of the answers have been removed.

The test

The test consisted of 42 questions. Since questions covered the course syllabus (both learned through PBL1, TL and PBL2), the test offered the opportunity to match students or groups with specific answers. The ANOVA test for repeated measures has been deployed, being the dependent variable quantitative. Once significant results had been obtained ($p<.05$), a multiple comparison Post-hoc Test was run. The analysis of the data was meant to highlight significant differences between methodologies. The overall Effect Size was then calculated between specific pairs of methodologies through Cohen's d.

4. Discussion

1) Item 1- Prior knowledge

A learning process only occurs when students' prior knowledge can incorporate new information. The latter allows the learner to make sense of new ideas and advance toward new material [1], [26], [70], [71]. By disregarding learners' prior knowledge, students usually experience a cognitive overload [19], i.e., an incapacity to make sense of the new information. Already foreseen by Vygotsky [71], this dynamic of the progressive and consequential process has been later confirmed by neurosciences and their study on how the brains learn [14], [72]. Moreover, it activates different detrimental dynamics within the learning process. For instance, it prevents teachers from giving students more focused and effective feedback [73] or turns out in a lack of motivation. Checking for prior knowledge is among the features that identify highly effective methodologies such as Direct Instruction and Mastery Learning [11]. The questionnaires ask the students to evaluate the level of prior knowledge fostered by teachers to progress into the methodologies and their contents.

Results - From the analysis of the parallel comparisons, PBL outperforms TL (see Figure 1), and no significant difference between PBL1 and PBL2 is shown. It has to be noted that for PBL, fostering prior knowledge was part of the methodology itself, and a satisfying level of information was perceived by the learners. On the other hand, teachers in TL didn't assess or provide prior knowledge, and in doing so, it was shown how TL doesn't naturally take into account this aspect.

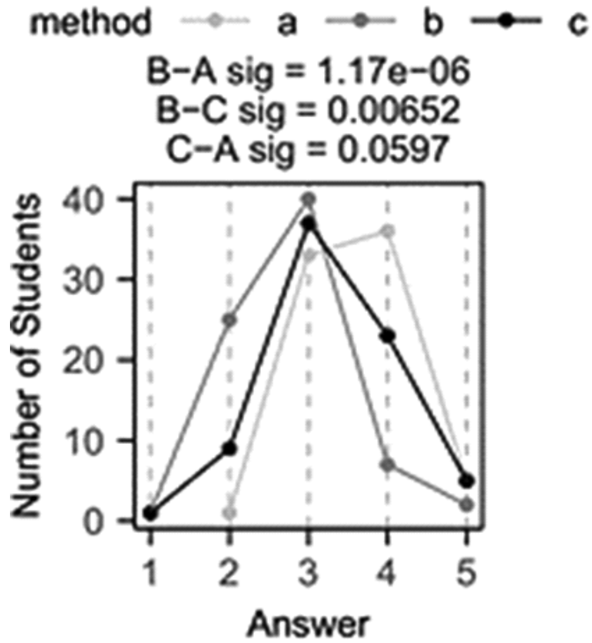


Fig. 1 : Post-hoc Wilcoxon signed-rank tests - Prior knowledge.

2) Item 2 - Clarity of objectives and expected performance

Connecting students' attention to the actual goals without letting them be confused by irrelevant information plays an essential role in the learning process. Setting goals and declaring the level of performance expected makes the study more efficient and develop a higher level of awareness [1], [11], [19], [26], [74]. Neurosciences support this thesis too. In fact, the literature shows how attention processes are very limited in duration and focus [28], [75]. Attention cannot multitask, and clarifying objectives and expected performance allows students to dodge useless or distracting inputs/information [26]. These features typically belong to the pedagogical tradition of Mastery Learning and Direct Instruction where a more guided approach is used and can produce its best results with novices in terms of outcomes and motivation [1], [19], [74], [76], [77]. Metacognitive processes are also trained and enhanced. We refer to metacognitive aspects and attitudes highly valued for engineers-to-be as self-evaluation, autonomy, self-efficacy, and higher levels of thinking [1], [40]. The questionnaire item asks students to rate how clear the objectives and performance expected were made by teachers.

Results - In the clarity of objectives and expected performance, again, PBL outperforms TL (see Figure 2). With its unilateral transmissive nature, TL seems to be able to do without specifying the goals, as the role of the student is that of a passive recipient of information [2], [11]. On the other hand, it appears that PBLs call for clear goals and success criteria, despite the differences in contents or nature of the projects.

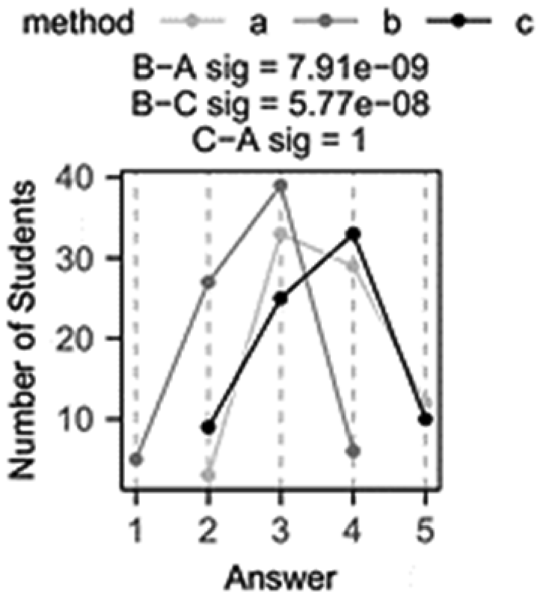


Fig. 2: Post-hoc Wilcoxon signed-rank tests - Clarity of objectives and expected performance.

3) Item 3 - Meaningful learning as usefulness in a life-long perspective

The questionnaires ask the students to which extent they thought they could derive useful skills from the different methodologies from a life-long perspective. This question is supported in the literature by the "Meaningful Learning" theory [24]. The perception of meaningfulness in students can boost motivation in its most self-determined forms, i.e., intrinsic motivation and identified regulation [78], [79]. Both of them are key to success in learning. In addition, motivation can activate some learners' attitudes as engagement, persistence, self-esteem, and self-regulation leading to improved learning outcomes [80]. This is even more crucial in contexts like Higher Education, where students' age collocates them between pedagogy and andragogy [81]. Hence, an age where a strong connection between learning and real-life/profession is highly valued by students [67]. Synthesis of meta-analytic research also confirms how meaningfulness in learning represents a substantial positive influence on outcomes [11] and finds its neuroscientific support in those studies that underlie the essential link between learning, emotions and attention [28].

Results - A statistically significant difference is not strictly correlated to a specific pair or methodology (see Figure 3). It emerges in TL - PBL1, and PBL1 - PBL2. The descriptive nature of the analysis and research does not allow for causal links to be derived. Therefore, these data are open to interpretation. In this case, it is possible to argue that it was not the specific methodology that created statistically significant differences. Assuming that working on some content rather than others could have made a difference in future perspective seems more realistic.

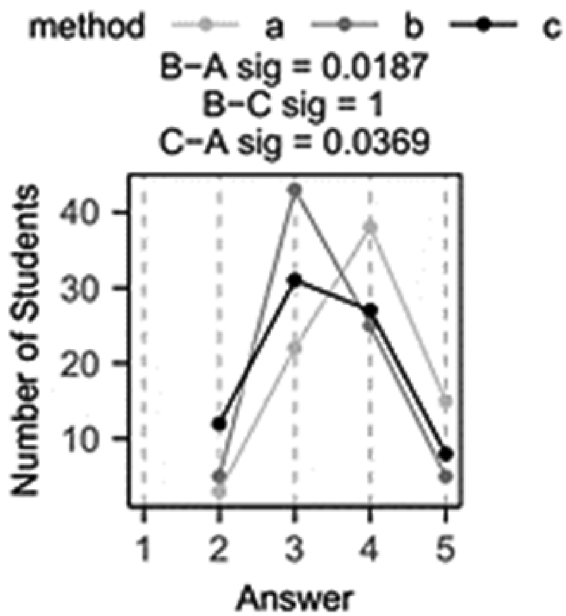


Fig. 3: Post-hoc Wilcoxon signed-rank tests – Meaningful learning as usefulness in a life-long perspective.

4) Item 4 - Motivation to commit

Motivation, intrinsic motivation, in particular, is a key element as it is the driving force toward a proactive mindset [78], [82], [83]. Through motivation, not only commitment is promoted, but also an attitude of curiosity, research, learning and not least, a wide range of metacognitive (e.g., self-regulation, awareness) and psychological features (e.g., self-esteem, sense of effectiveness) [80], [84]. Motivation might trigger during different phases of a lesson. What this question investigates specifically refers to motivation to commit to the project in an early phase.

Results - PBL1 and PBL2, in comparison with TL, show similar results (see Figure 4). Moreover, in the comparison between PBL1 and PBL2, a significant difference does not emerge. It can be argued that the variations (contents and project differences) in their implementation do not appear to cause differences in results. This concept will not be repeated but will be taken for granted during the following discussion anytime the study states that a comparison between PBL1 and PBL2 has shown no statistically significant differences.

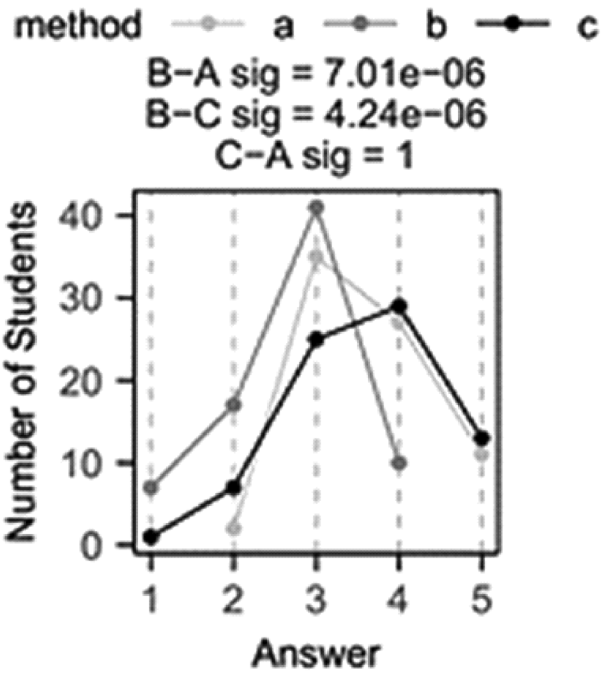


Fig. 4: Post-hoc Wilcoxon signed-rank tests – Motivation to commit.

5) Item 5 - Motivation to take part in classes

This questionnaire item investigates how strong students perceived their motivation to take part in classes. Again, this item is related to the literature focused on motivation [78], [82], [85] and investigates the particular level of self-determined motivation. In our case, the latter can be defined as the motivation to take part in classes for its own sake because the activity is perceived as pleasurable or depending on one's own free choice and for one's good [78].

Results – PBL performs better than TL. (see Figure 5). A comparison between PBL1 and PBL2 shows no significant difference. Motivation represents one of the strongest features that characterize PBL when compared with TL. Indeed, the literature values active learning and social learning as essential triggers for motivation, and the results of this question seem to be in agreement with it [86], [87].

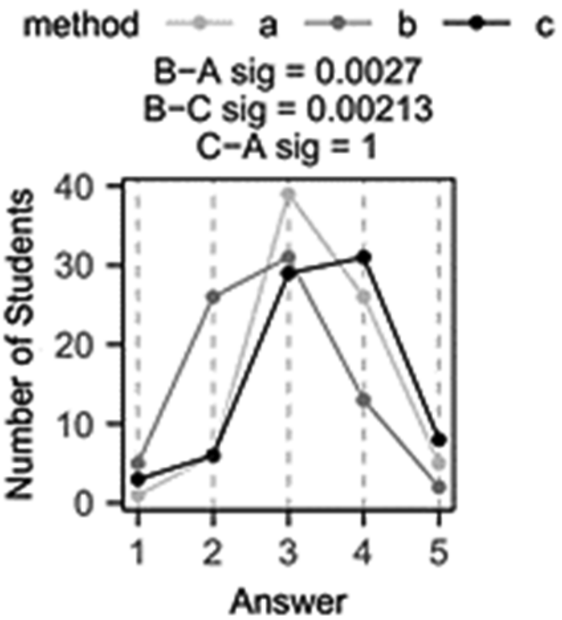


Fig. 5: Post-hoc Wilcoxon signed-rank tests – Motivation to take part in classes.

6) Item 6 - Feedback opportunities

Feedback represents "the" transversal feature in effective teaching methodologies. Its influence on learning outcomes is remarkable [73]. Its importance has been widely stated and confirmed in education [73], [88], [89] and neurosciences [1], [26], [28]. It is also among the instructional elements rated by engineering students as most relevant to their academic satisfaction [90]. Feedback can come from instructors to learners and vice versa, from peers and the self. It allows students to develop awareness and fruitfully and effectively guide their course of study [73], [76], [89]. Feedback connects prior knowledge to learning goals and learning intentions [73], [74], [89], [91]. It is a return of specific information that shows the learning gap that must be filled [11]. Moreover, it allows students to focus on what is relevant rather than dispersing time and intellectual energies on marginal topics [19], [26], [73]. The questionnaires ask to what extent the students perceived the possibility of receiving feedback (from peers or teachers).

Results - Comparing the answers statistically significant differences. PBL outperforms TL, and more importantly, the difference between the two is independent of the variations adopted in PBL implementations (see Figure 6).

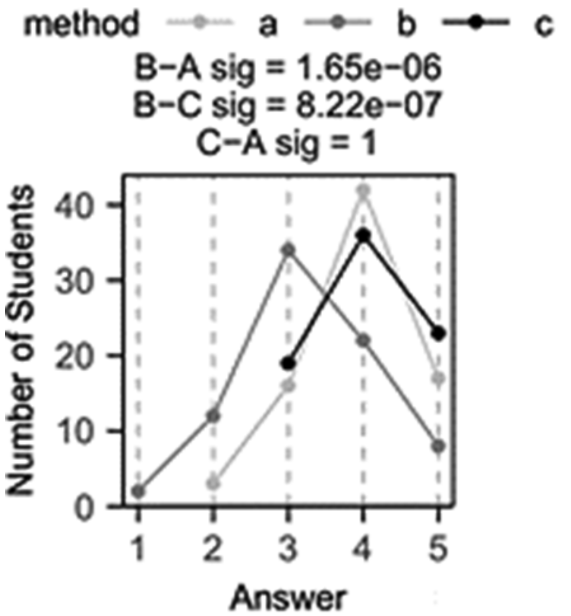


Fig. 6: Post-hoc Wilcoxon signed-rank tests - Feedback opportunities.

7) Item 7 - Group work versus individual work

In literature, particular effectiveness is attributed to group work in terms of in-depth learning, motivation, and acquisition of soft skills [87], [92]–[94]. Hence, effectiveness in all those competencies that distinguish and characterize the engineer profession [7], [35], [40], [85], [95]. However, it is important to notice that group work is also often criticized for being difficult to manage in terms of customization, time management and assessment, as well as equality in students' commitment and workload distribution [92], [93], [96]. Despite the practical issues that teachers could come across, it is not just pedagogy assessing as positive the presence of group work when learning. In fact, by confirming the social nature of the brain, neuroscientific studies also emphasize the relevance of this didactical element within learning processes [1], [28]. This specific questionnaire item asks students to what extent group work for PBL1 and PBL2, and individual work (for TL) represented valuable features within the specific learning process of the study presented.

Results - The comparison between PBL and TL shows a statistically significant difference. Furthermore, the data state the perceived importance of group work, regardless of the variables between PBL1 and PBL2 (see Figure 7). This analysis does not allow us to understand in detail the reasons (social, cognitive, active learning-wise, feedback-wise, Etc.) why PBL got better outcomes than TL. Nonetheless, we can state that group work is perceived as more valuable than individual work.

8 I e) t

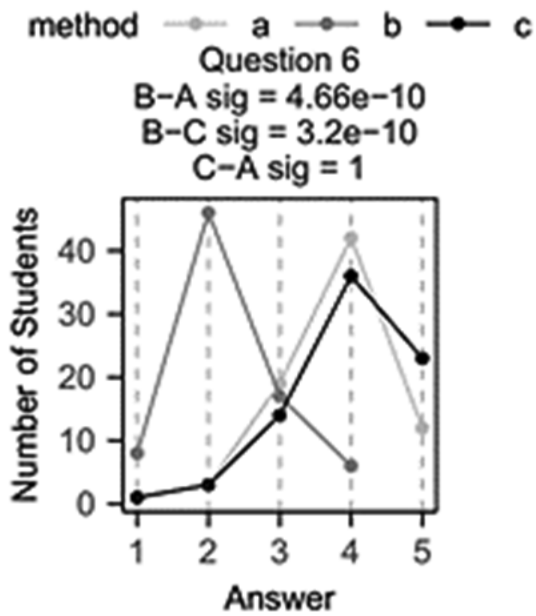


Fig. 7: Post-hoc Wilcoxon signed-rank tests - Group work versus individual work.

m 8 - Clarity of acquisition

The final question asks the students to value how clearly they perceived the contents related to each methodology they had been exposed to.

Results - In terms of perception, the null hypothesis is supported. There is no statistically significant mean difference among the methods; hence the Post-hoc test was NA, i.e., not available (see Figure 8). Furthermore, since the answers to the questionnaires were anonymous, it is impossible to prove the existence of a correlation between the clarity of acquisition and the learning outcomes. Nevertheless, these data seem to contradict the test results (see Table V). In literature, this finds support in the students' capability of self-assessment that is directly proportional to their level of expertise [11]. Regarding PBL, studies in engineering education report mixed results in learning depending on the presence or lack of specific competencies/enablers in the learners (e.g., self-management) [48]. Other explanations behind this result might be found in the cultural view of TL, often valued as a sort of real grammar of schooling [1], [2], [29]. In fact, in TL, what is to be learned is implicitly certified by an external authority (i.e., teachers) rather than through personal evaluation within a more constructivist context as in PBL.

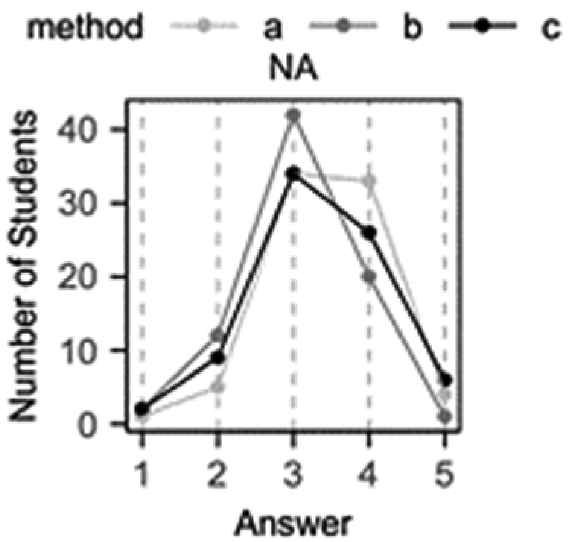


Fig. 8: Post-hoc Wilcoxon signed-rank tests - Clarity of acquisition.

9) Learning outcomes

Table V displays the learning outcomes of the research. Both PBL1 and PBL2 show results that are significantly (Sig.<0,05) higher than TL. Comparing PBL1 and PBL2 non-statistically significant difference is shown in the test results. Effect Size has been then calculated between PBL1 and TL (= 0.65), PBL2 and TL (= 0.7), and PBL1 and PBL2 (= 0.08). According to Cohen's interpretation - 0–0.20 = weak effect; 0.21–0.50 = modest effect; 0.51–1.00 = moderate effect; >1.00 = strong effect - effect sizes are moderate, moderate, weak, respectively [59]. The effect size analysis shows similar levels of efficacy both for PBL1 and PBL2.

Table 5: One-way Anova for repeated measures and Post-hoc test - Learning outcomes

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1,504	2	,752	7,621	,001
Within Groups	27,828	282	,099		
Total	29,332	284			

Dependent Variable: testresults

	(I) topylearning	(J) topylearning	Mean Diff. (I-J)	SE	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Tukey HSD	PBL1	TL	,14035(*)	,04558	,006	,0330	,2477
		PBL3	-,02456	,04558	,852	-,1320	,0828
	TL	PBL1	-,14035(*)	,04558	,006	-,2477	-,0330
		PBL3	-,16491(*)	,04558	,001	-,2723	-,0575
	PBL3	PBL1	,02456	,04558	,852	-,0828	,1320
		TL	,16491(*)	,04558	,001	,0575	,2723

* The mean difference is significant at the .05 level.

The results show how the two forms of PBL implementation produced similar learning outcomes and statistically non-significant differences. This is interesting because it occurs despite differences in the content covered and differences in the type of design. A causal link between the presence of effective science-based elements detectable more in PBL than in TL and results is not feasible. Still, it is important to notice the stability of results that the two versions of PBL show across questionnaires and tests.

5. Conclusions

Neuroeducation is an educational approach that utilises neuroscience and transforms the results of neuroscientific research into effective educational practises and methods. Incorporating the most recent findings from neuroscience, psychology, and cognitive science into educational models, it is intended to give teaching and learning a true scientific basis. Neuroeducation is the framework for this paper that deals with a single-group variation on the two-group post-test-only randomized experiment carried out in the context of an engineering course. PBL variations vs. TL have been looked into and compared. The two research hypotheses and related data-based conclusions follow.

- RH1) The learning experience and outcomes are enhanced when attending PBL lessons compared to TL ones.

PBL outperformed TL in fostering: prior knowledge, clarity of objectives and expected performance, motivation to commit, motivation to take part in classes, feedback opportunities, and group work versus individual work. However, TL is perceived as substantially equal in its ability to promote clarity of acquisition. It produces not neat results when coming to the meaningfulness of learning related to the perception of usefulness from a life-long perspective.

- RH2) Effective cross-cutting instructional elements are more detectable in PBL than in TL, and variations in contents and typologies of the project do not lead to different outcomes within PBL.

Didactic features belonging to the set of the most evidence-based effective ones are much more detectable and perceived in PBL. Moreover, these elements seem to be as intrinsically connected to the PBL approach as a fondant structure, despite the variations in contents and project typologies, and are reasonably considered as part of the determinant factors for the overall better and stable performance of PBL vs. TL. The didactical frame was the same in both PBL1 and PBL2 implementations. Apart from "meaningful learning as usefulness in a life-long perspective", the results supported the research null hypothesis. Indeed, it appears that implementation of PBL consistent with the definition given in this study and containing the detected specific didactic features determines a solid didactical structure capable of generating similar results and non-significant differences among PBL implementations, overcoming differences in content and typologies of projects. This study provides insights into the need for engineering teachers to understand, knowingly integrate, provide, and manipulate specific features based on scientific evidence when adopting Project-based learning. The study also suggests a different approach to the professionalization of engineering teachers, who generally lack specific training or pedagogical expertise [97]–[99]. Indeed, in light of the results, it would seem more realistic and functional to address the cross-cutting pedagogical competence of teachers. By mastering the foundational and most effective elements of any learning process, teachers would have more teaching tools capable of responding to the specific needs of individual educational contexts and a solid foundation to specialize more quickly and thoroughly in any specific teaching methodology.

References

[1] J. Hattie and G. C. R. Yates, Visible learning and the science of how we learn. Routledge, 2013.

[2] L. Cuban, "Persistence of the inevitable: The teacher-centered classroom," Educ. Urban Soc., vol. 15, no. 1, pp. 26–41, 1982.

[3] J. Hattie, "Visible Learning. A Bradford Book." Routledge, London, 2009.

[4] M. Scardamalia and C. Bereiter, "Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media,"J.Learn. Sci.,vol.1,no.1,pp.37–68, 1991.

[5] A. L. Brown, "Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings," J. Learn. Sci., vol. 2, no. 2, pp. 141–178, 1992.

[6] S. A. Gallagher, W. J. Stepien, and H. Rosenthal, "The effects of problem-based learning on problem solving," Gift. Child Q., vol. 36, no. 4, pp. 195–200, 1992.

[7] M. J. Prince and R. M. Felder, "Inductive teaching and learning methods: Definitions, comparisons, and research bases," J. Eng. Educ., vol. 95, no. 2, pp. 123–138, 2006.

[8] J. W. Thomas, "A review of research on project-based learning. Autodesk Foundation," Retrieved April, 2000.

[9] J. W. Thomas, Project based learning: A handbook for middle and high school teachers. Buck Institute for Education, 1999.

[10] B. F. Jones, C. M. Rasmussen, and M. C. Moffitt, Real-life problem solving: A collaborative approach to interdisciplinary learning. American Psychological Association, 1997.

[11] J. A. Hattie, "Visible learning: a synthesis of 800+ meta-analyses on achievement. Abingdon." Routledge Abingdon, 2009.

[12] J. Hattie, "Visible learning plus: 250+ influences on student achievement," Visible Learn. plus, 2017.

[13] M. S. C. Thomas, D. Mareschal, and I. Dumontheil, Educational neuroscience: development across the life span. Routledge, 2020.

[14] T. N. Tokuhama-Espinosa, "The scientifically substantiated art of teaching: A study in the development of standards in the new academic field of neuroeducation (mind, brain, and education science)," Capella University, 2008.

[15] M. S. Schwartz, V. Hinesley, Z. Chang, and J. M. Dubinsky, "Neuroscience knowledge enriches pedagogical choices," Teach. Teach. Educ., vol. 83, pp. 87–98, 2019.

[16] M. S. Amran, S. Rahman, S. SURAT, and A. Y. A.

B. U. BAKAR, “Connecting neuroscience and education: Insight from neuroscience findings for better instructional learning,” J. Educ. Gift. Young Sci., vol. 7, no. 2, pp. 341–352, 2019.

[17] E. Jensen and L. McConchie, Brain-based learning: Teaching the way students really learn. Corwin, 2020.

[18] liz McDowell, “Effective teaching and learning on foundation and access courses in engineering, science and technology,” Eur. J. Eng. Educ., vol. 20, no. 4, pp. 417–425, 1995.

[19] J. Sweller, P. Ayres, and S. Kalyuga, “Measuring cognitive load,” in Cognitive load theory, Springer, 2011, pp. 71–85.

[20] J. Hattie, Visible learning for teachers: Maximizing impact on learning. Routledge, 2012.

[21] S. Schrage, “Massive study finds lectures still dominate STEM education,” Fac. Focus, pp. 1–13, 2018.

[22] L. Van Dijk, G. C. Van Der Berg, and H. Van Keulen, “Interactive lectures in engineering education,” Eur. J. Eng. Educ., vol. 26, no. 1, pp. 15–28, 2001.

[23] K. Regmi, “A Review of Teaching Methods--Lecturing and Facilitation in Higher Education (HE): A Summary of the Published Evidence.,” J. Eff. Teach., vol. 12, no. 3, pp. 61–76, 2012.

[24] S. L. Bretz, “Novak’s theory of education: Human constructivism and meaningful learning.” ACS Publications, 2001.

[25] J. I. Goodlad, A place called school. Prospects for the future. ERIC, 1984.

[26] J. Geake, The brain at school: Educational neuroscience in the classroom: Educational neuroscience in the classroom. McGraw-Hill Education (UK), 2009.

[27] A. Guida, F. Gobet, H. Tardieu, and S. Nicolas, “How chunks, long-term working memory and templates offer a cognitive explanation for neuroimaging data on expertise acquisition: a two-stage framework,” Brain Cogn., vol. 79, no. 3, pp. 221–244, 2012.

[28] T. Tokuhama-Espinosa, The new science of teaching and learning: Using the best of mind, brain, and education science in the classroom. Teachers College Press, 2015.

[29] W. Jochems, “Good practice, wat is de praktijk en wat is goed?[Good practice, what is the teaching practice and what is good?],” Onderz. van Onderwijs, vol. 25, pp. 4–5, 1996.

[30] R. K. Chowdhury, “Learning and teaching style assessment for improving project-based learning of engineering students: A case of United Arab Emirates University,” Australas. J. Eng. Educ., vol. 20, no. 1, pp. 81–94, 2015.

[31] J. Fitzpatrick, K. Cronin, and E. Byrne, “Is attending lectures still relevant in engineering education?,” Eur. J. Eng. Educ., vol. 36, no. 3, pp. 301–312, 2011.

[32] E. Bales, “Corporate Universities versus traditional Universities. Keynote at the Conference on innovative practices in business education.” Orlando, Florida, December, 1996.

[33] J. Rutkowski and K. Moscinska, “ICT supported engineering course--case study and guidelines,” in Proc. 12th IASTED Int. Conf. on Computers and Advanced Technology in Education (CATE), 2009, pp. 129–136.

[34] L. A. Van Dijk and W. M. G. Jochems, “Changing a traditional lecturing approach into an interactive approach: Effects of interrupting the monologue in lectures,” Int. J. Eng. Educ., vol. 18, no. 3, pp. 275–284, 2002.

[35] W. E. Forum, “The Future of Jobs Report 2020,” 2020.

[36] D. R. Krathwohl, “A revision of Bloom’s taxonomy: Krathwohl, D. R. (2002). A revision of Bloom’s taxonomy: An overview. Theory into Practice, 41(4), 212–218.An overview,” Theory Pract., vol. 41, no. 4, pp. 212–218, 2002.

[37] K. Alanne, “An overview of game-based learning in building services engineering education,” Eur. J. Eng. Educ., vol. 41, no. 2, pp. 204–219, 2016.

[38] Y.-Y. Tang, Brain-based learning and education: Principles and practice. Academic Press, 2017.

[39] I. Mayer, H. Warmelink, and G. Bekebrede, "Learning in a game-based virtual environment: a comparative evaluation in higher education," Eur. J. Eng. Educ., vol. 38, no. 1, pp. 85–106, 2013.

[40] C. A. Bodnar, D. Anastasio, J. A. Enszer, and D. D. Burkey, "Engineers at play: Games as teaching tools for undergraduate engineering students," J. Eng. Educ., vol. 105, no. 1, pp. 147–200, 2016.

[41] P. C. Blumenfeld, E. Soloway, R. W. Marx, J. S. Krajcik, M. Guzdial, and A. Palincsar, "Motivating project-based learning: Sustaining the doing, supporting the learning," Educ. Psychol., vol. 26, no. 3–4, pp. 369–398, 1991.

[42] B. J. S. Barron et al., "Doing with understanding: Lessons from research on problem-and project-based learning," J. Learn. Sci., vol. 7, no. 3–4, pp. 271–311, 1998.

[43] C. Bereiter and M. Scardamalia, "Process and product in PBL research," Toronto Ontario Institutes Stud. Educ. Toronto, 1999.

[44] J. S. Brown, A. Collins, and P. Duguid, "Situated cognition and the culture of learning," Educ. Res., vol. 18, no. 1, pp. 32–42, 1989.

[45] J. Boaler, "Open and closed mathematics: Student experiences and understandings," J. Res. Math. Educ., pp. 41–62, 1998.

[46] M. Prince, "Does active learning work? A review of the research," J. Eng. Educ., vol. 93, no. 3, pp. 223–231, 2004.

[47] R. W. Marx, P. C. Blumenfeld, J. S. Krajcik, and E. Soloway, "Enacting project-based science," Elem. Sch. J., vol. 97, no. 4, pp. 341–358, 1997.

[48] D. Kokotsaki, V. Menzies, and A. Wiggins, "Project-based learning: A review of the literature," Improv. Sch., vol. 19, no. 3, pp. 267–277, 2016.

[49] C. Zhou, A. Kolmos, and J. F. D. Nielsen, "A problem and project-based learning (PBL) approach to motivate group creativity in engineering education," Int. J. Eng. Educ., vol. 28, no. 1, pp. 3–16, 2012.

[50] J. P. T. Mo and Y. M. Tang, "Project-based learning of systems engineering V model with the support of 3D printing," Australas. J. Eng. Educ., vol. 22, no. 1, pp. 3–13, 2017.

[51] A. M. Ruiz-Ortega, J. J. Gallardo-Rodr\'\iguez, E. Navarro-López, and M. del Carmen Cerón-Garc\'\ia, "Project-led-education experience as a partial strategy in first years of engineering courses," Educ. Chem. Eng., vol. 29, pp. 1–8, 2019.

[52] M. Gibbes and L. Carson, "Project-based language learning: an activity theory analysis," Innov. Lang. Learn. Teach., vol. 8, no. 2, pp. 171–189, 2014.

[53] R. A. Stewart, "Investigating the link between self directed learning readiness and project-based learning outcomes: the case of international Masters students in an engineering management course," Eur. J. Eng. Educ., vol. 32, no. 4, pp. 453–465, 2007.

[54] P. T. Terenzini, A. F. Cabrera, C. L. Colbeck, J. M. Parente, and S. A. Bjorklund, "Collaborative learning vs. lecture/discussion: Students' reported learning gains," J. Eng. Educ., vol. 90, no. 1, pp. 123–130, 2001.

[55] R. G. Hadgraft and A. Kolmos, "Emerging learning environments in engineering education," Australas. J. Eng. Educ., vol. 25, no. 1, pp. 3–16, 2020.

[56] M. Frank, I. Lavy, and D. Elata, "Implementing the project-based learning approach in an academic engineering course," Int. J. Technol. Des. Educ., vol. 13, no. 3, pp. 273–288, 2003.

[57] W. M. K. Trochim and J. P. Donnelly, Research methods knowledge base, vol. 2. Atomic Dog Pub., 2001.

[58] W. A. Edmonds and T. D. Kennedy, An applied guide to research designs: Quantitative, qualitative, and mixed methods. Sage Publications, 2016.

[59] L. Cohen, L. Manion, and K. Morrison, Research methods in education. routledge, 2017.

[60] K. J. Flannelly, L. T. Flannelly, and K. R. B. Jankowski, "Threats to the internal validity of experimental and quasi-experimental research in healthcare," J. Health Care Chaplain., vol. 24, no. 3, pp. 107–130, 2018.

[61] D. Watson, L. A. Clark, and A. Tellegen, "Development and validation of brief measures of positive and negative affect: the PANAS scales.," J. Pers. Soc. Psychol., vol. 54, no. 6, p. 1063, 1988.

[62] L. M. Aleamoni, "Student rating myths versus research facts from 1924 to 1998," J. Pers. Eval. Educ., vol. 13, no. 2, pp. 153–166, 1999.

[63] P. Ramsden and E. Martin, "Recognition of good university teaching: Policies from an Australian study," Stud. High. Educ., vol. 21, no. 3, pp. 299–315, 1996.

[64] K. Trigwell, M. Prosser, and F. Waterhouse, "Relations between teachers' approaches to teaching and students' approaches to learning," High. Educ., vol. 37, no. 1, pp. 57–70, 1999.

[65] K. Trigwell, "Judging university teaching," Int. J. Acad. Dev., vol. 6, no. 1, pp. 65–73, 2001.

[66] S. Bradley, E. Kirby, and M. Madriaga, "What students value as inspirational and transformative teaching," Innov. Educ. Teach. Int., vol. 52, no. 3, pp. 231–242, 2015.

[67] Y. Hill, L. Lomas, and J. MacGregor, "Students' perceptions of quality in higher education," Qual. Assur. Educ., 2003.

[68] H. F. Kaiser, "An index of factorial simplicity," Psychometrika, vol. 39, no. 1, pp. 31–36, 1974.

[69] J. F. Hair Jr, "Black, WC/Babin, BJ/Anderson, RE & Tatham, RL (2006): Multivariate Data Analysis," Auflage, Up. Saddle River, 2006.

[70] Y. L. Shing and G. Brod, "Effects of prior knowledge on memory: Implications for education," Mind, Brain, Educ., vol. 10, no. 3, pp. 153–161, 2016.

[71] T. Harland, "Vygotsky's zone of proximal development and problem-based learning: Linking a theoretical concept with practice through action research," Teach. High. Educ., vol. 8, no. 2, pp. 263–272, 2003.

[72] E. Gozuyesil and A. Dikici, "The Effect of Brain Based Learning on Academic Achievement: A Meta-Analytical Study.," Educ. Sci. Theory Pract., vol. 14, no. 2, pp. 642–648, 2014.

[73] J. Hattie and S. Clarke, Visible Learning: Feedback. Routledge, 2018.

[74] P. A. Kirschner, J. Sweller, and R. E. Clark, "Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching," Educ. Psychol., vol. 41, no. 2, pp. 75–86, 2006.

[75] D. Sloan and C. Norrgran, "A neuroscience perspective on learning," Chem. Eng. Educ., vol. 50, no. 1, pp. 29–37, 2016.

[76] G. L. Adams and S. Engelmann, Research on direct instruction: 25 years beyond DISTAR. ERIC, 1996.

[77] T. R. Guskey and T. D. Pigott, "Research on group-based mastery learning programs: A meta-analysis," J. Educ. Res., vol. 81, no. 4, pp. 197–216, 1988.

[78] R. M. Ryan and E. L. Deci, "Intrinsic and extrinsic motivation from a self-determination theory perspective: Definitions, theory, practices, and future directions," Contemp. Educ. Psychol., vol. 61, p. 101860, 2020.

[79] D. P. Ausubel, "The Adquisition and Retention of Knowledge. Dortrecht, Netherlands," Kluwer, vol. 10, pp. 978–994, 2000.

[80] E. L. Deci and R. M. Ryan, "Human autonomy," in Efficacy, agency, and self-esteem, Springer, 1995, pp. 31–49.

[81] V. McGrath, "Reviewing the Evidence on How Adult Students Learn: An Examination of Knowles' Model of Andragogy.," Adult Learn. Irish J. Adult Community Educ., vol. 99, p. 110, 2009.

[82] M. R. Lepper, “Motivational considerations in the study of instruction,” Cogn. Instr., vol. 5, no. 4, pp. 289–309, 1988.

[83] T. W. Malone, “Making learning fun: A taxonomic model of intrinsic motivations for learning,” Conative Affect. Process Anal., 1987.

[84] E. L. Deci and R. M. Ryan, “Intrinsic motivation and self-determination in human behavior: Springer Science & Business Media,” 1985.

[85] B. Galand, B. Raucent, and M. Frenay, “Engineering students’ self-regulation, study strategies, and motivational believes in traditional and problem-based curricula,” Int. J. Eng. Educ., vol. 26, no. 3, pp. 523–534, 2010.

[86] S. R. Hall, I. Waitz, D. R. Brodeur, D. H. Soderholm, and R. Nasr, “Adoption of active learning in a lecture-based engineering class,” in 32nd Annual frontiers in education, 2002, vol. 1, pp. T2A--T2A.

[87] L. S. Vygotsky, Mind in society: The development of higher psychological processes. Harvard university press, 1980.

[88] A. N. Kluger and A. DeNisi, “The effects of feedback interventions on performance: A historical review, a meta-analysis, and a preliminary feedback intervention theory.,” Psychol. Bull., vol. 119, no. 2, p. 254, 1996.

[89] D. R. Sadler, “Formative assessment and the design of instructional systems,” Instr. Sci., vol. 18, no. 2, pp. 119–144, 1989.

[90] R. W. Lent, D. Singley, H.-B. Sheu, J. A. Schmidt, and L. C. Schmidt, “Relation of social-cognitive factors to academic satisfaction in engineering students,” J. Career Assess., vol. 15, no. 1, pp. 87–97, 2007.

[91] M. J. S. Gan and J. Hattie, “Prompting secondary students’ use of criteria, feedback specificity and feedback levels during an investigative task,” Instr. Sci., vol. 42, no. 6, pp. 861–878, 2014.

[92] A. C. Alves, D. Mesquita, F. Moreira, and S. Fernandes, “Teamwork in Project-Based Learning: engineering students’ perceptions of strengths and weaknesses,” in Proceedings of the Fourth International Symposium on Project Approaches in Engineering Education (PAEE’2012), 2012, pp. 23–32.

[93] B. A. Oakley, D. M. Hanna, Z. Kuzmyn, and R. M. Felder, “Best practices involving teamwork in the classroom: Results from a survey of 6435 engineering student respondents,” IEEE Trans. Educ., vol. 50, no. 3, pp. 266–272, 2007.

[94] K. J. Chua, W. M. Yang, and H. L. Leo, “Enhanced and conventional project-based learning in an engineering design module,” Int. J. Technol. Des. Educ., vol. 24, no. 4, pp. 437–458, 2014.

[95] S. Chandrasekaran, A. Stojcevski, G. Littlefair, and M. Joordens, “Learning through projects in engineering education,” 2012.

[96] J. Hattie, Visible learning: A synthesis of over 800 meta-analyses relating to achievement. Routledge, 2008.

[97] All ENTER Consortium members, “Engineering Educators’ Pedagogical Training in Europe, Russia and Kazakhstan: background, best practices, challenges and opportunities,” 2019. http://erasmus-enter.org/files/r_1.3_-_best_practices_of_pedagogical_education_for_engineering_teachers__(e-book).pdf

[98] U. A. Kazakova and I. A. Alekhin, “Psychological and pedagogical training of teachers of engineering universities in the framework of additional professional education,” in Proceedings of the Conference “Integrating Engineering Education and Humanities for Global Intercultural Perspectives,” 2020, pp. 569–577.

[99] S. Kersten, “Approaches of engineering pedagogy to improve the quality of teaching in engineering education,” in Vocational Teacher Education in Central Asia, Springer, Cham, 2018, pp. 129–139.