Engineering Students' Self-regulation, Study Strategies, and Motivational Believes in Traditional and Problem-based Curricula*

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Is problem-based learning (PBL) really effective? Evidence focusing on achievement provides mixed results, but a growing body of research indicates that PBL fosters students' academic engagement. However these studies are limited to the education of health professionals and do not include measures of implementation. The aim of the present study is to compare perceptions of the learning environment, motivational beliefs (self-efficacy and goal orientations), self-regulation strategies, study strategies, and satisfaction among engineering students before and after the shift from a lecture-based to a problem- and project-based (PBL) curriculum. The last cohort of students who attended the traditional curriculum and the first cohort of students who attended the new PBL curriculum participated to a questionnaire survey. Results of multivariate analyses show that PBL students perceived stronger academic support and weaker organizational structure. They also report more frequent use of adaptive self-regulation and deep processing strategies, less frequent use of surface processing strategies, lower satisfaction, higher attendance and longer study time. No differences were found for motivational beliefs and collaboration between students. Moreover, perceived learning environment mediates most of the observed differences between cohorts. Implications for attempts to improve student academic engagement are discussed.

Keywords: higher education; problem-based learning; project-based learning; self-regulation; motivation; learning strategies

1. INTRODUCTION

A SHIFT FROM elite to mass education together with a growing emphasis on contribution to graduate employability is nowadays one of the major challenges faced by higher education institutions [8]. To cope with these challenges, more and more universities foster the implementation of more student-centred and competencies driven curricula. Problem-Based Learning (PBL) is one of the most renowned approaches inspiring these changes [17, 20]. Within PBL environments, instruction is built around complex real-world problems. Students are usually asked to work in team to understand these problems under the supervision of a tutor [12, 27, 48]. However, is this approach really effective?

Evidence about the effectiveness of PBL is mainly focused on achievement, and provides mixed results [1, 11, 43]. Several scholars call for a larger perspective on the evaluation of PBL effectiveness, arguing that the various outcomes fostered by PBL are not well captured by standardized achievement test [13, 34]. Among other advantages, PBL is assumed to foster self-directed learning, critical thinking, theory-practice relation-

ships, and problem solving [31]. These outcomes could be difficult to assess, but they are close to other constructs largely studied in educational psychology, such as goal orientations (i.e. reasons for engagement and criteria of success), self-efficacy beliefs (i.e. beliefs in one's agentic capacities), self-regulation strategies (i.e. how students regulate their time, effort, attention, etc.), and study strategies (i.e. how student process information to learn).

Contrary to many concepts usually used in PBL research—like 'self-directed learning' and 'lifelong learning'—these motivational beliefs and (meta-) cognitive strategies have been clearly operationalized, and many studies document their importance for the quality of students' learning and for achievement [3, 6, 65]. For these reasons, we chose to use them in this study.

1.1 The effects of PBL on motivation and engagement

The claim about the superiority of PBL over traditional learning to sustain students' motivational beliefs (goal orientations and self-efficacy) and cognitive engagement (self-regulation and study strategies) is consistent with several theoretical approaches, like situated learning [19], coop-

erative learning [55], and self-determination theory [52] for instance. Further, a growing body of empirical research supports this claim [18]. Regarding motivation, some studies found that students perceived PBL to be more enjoyable and challenging that traditional programs [18]. PBL students report more positive attitude toward their learning environment [29] and a more positive evaluation of the program [62]. PBL students are less confident in their knowledge base than 'conventional' students [1], but more confident in their ability to search information and management of uncertainty skills [40]; see also [53]. A few studies also indicated that PBL enhances intrinsic interest in the subject matter [46].

Regarding cognitive engagement, PBL students use more information resources and libraries, they rely less on memorization and try more to give meaning to the material [5, 39]. In medicine, PBL students also display a different mode of clinical reasoning than 'conventional' students [47], but it is hard to say which mode is more effective [1]. In randomized field experiments, PBL was found to foster critical thinking compared to traditional lecture—and discussion-based learning [54, 58].

Some studies took a more global stance and investigated student's approaches to learning in PBL and traditional curricula. Approaches to learning refer to distinctive patterns of motivation, self-regulation and study strategies. A deep approach is characterized by an interest in the learning task, a search for meaning in the task and integration of various sources of knowledge, while a surface approach is characterized by an extrinsic motivation (ex. reward, paper qualification), and a focus on memorization and mere reproduction of material [16]. Results of these studies indicated that, compared to students from traditional curriculum, students from PBL curriculum report a higher level of deep approach to learning and a lower level of surface approach [10, 42]. More recently, another study indicated that PBL students engage more in self-regulation strategies and endorse more a constructivist model of learning than 'conventional' students [33].

1.2 Limitations of previous studies

However, all those evidence are strictly limited to the education of health professionals. The question of the generalizability of these findings to other disciplines in Higher Education is still open [43]. Actually, a study in business found the opposite effect than in medicine: students from the PBL course reported less deep approach and more surface approach than the other ones [45]. Even among health professional, McParlant, Noble and Livingstone [35] found no differences in learning styles and attitude between student in PBL or in a traditional course of psychiatry. The question of generalizability of the effects is complicated by the broad variety of practices included under the label 'PBL' and the large differences in program design or implementation that could appear [14, 18]. This is especially true when moving from medical education to engineering education, which typically includes problem solving, design, and project completion. Unfortunately, most available studies provide only a very limited description of program design and no measure of implementation [43].

Consequently, it is difficult to relate students' outcomes to changes in specific curriculum features or instructional practices, and to know how PBL affects student learning [5, 45, 57].

Therefore, despite the volume of literature on PBL, our knowledge about the effects of PBL on different outcomes, in different contexts and in different instructional designs is still limited. The present study wants to extend this knowledge by comparing students' motivational beliefs, self-regulation and study strategies, and satisfaction among engineering students before and after the shift from a lecture-based curriculum to a problem- and project-based curriculum. Besides, we wanted to compare students' perceptions of their learning environment before and after this shift and to assess if differences in student outcomes could be mediated by differences in student perceptions [45]. A growing number of studies indicate that perception of the learning environment is an important factor in students' academic engagement [32, 36]: on the one hand, workload, emphasis on performance and inappropriate assessment were found to be associated with a surface approach to learning, on the other hand, teacher support and emphasis on understanding were found to be related to a deep approach to learning. Collaboration between students is another component of the learning environment that could be important in PBL, but its relationships with approaches to learning has not yet been thoroughly investigated. Student perceptions of the learning environment could also provide an indicator of several aspects of PBL implementation [25]. If no differences appear in perceived learning environment, the probability to find any effect on student engagement should be very low. Moreover, analysis of the perceived learning environment could provide more detailed information about the dimensions of PBL that are related to different effects.

1.3 Aims of the present study

More specifically, the first aim of this study was thus to check if differences coherent with the introduction of a PBL curriculum could be observed in students' perceptions of their learning environment. We expected that PBL students would perceived more teacher support, more focus on understanding, more contextualization, and more collaboration between students and heavier workload.

The second aim of this study was to compare students' motivational beliefs, self-regulation and study strategies use, and satisfaction before and after the introduction of the PBL curriculum. From research reviewed above, we expected

students who completed the PBL curriculum to be more mastery oriented, to use more adaptive self-regulation strategies, more deep processing strategies, and less surface processing strategies, and to be more satisfied toward their program than students who completed the traditional curriculum. No clear prediction emerges from the literature for self-efficacy beliefs. Attendance and study time were also measured, because PBL implies a large change in time allocation between lectures, teamwork and individual study. We expected that PBL students will report higher attendance and study time.

The third aim of this study was to see if observed differences in students' outcomes could be explained by differences in students' perception of the learning environment. We expected that perceptions of learning environment mediate the effects of curriculum on students' engagement. Evidence of a mediation effect of perceived learning environment would support the attribution of outcomes differences to curriculum change, and could contribute to the identification of key practices associated with increased students' academic engagement.

1.4 Description of the curricula

In 2000, the School of Engineering of our university shifted the curriculum of the first two years of its undergraduate program (common to all engineering programs) from a 'traditional' curriculum, to a problem- and project-based curriculum. This new curriculum was inspired by the experience of the universities of Sherbrooke, Maastricht and Aalborg. In this curriculum, problems and projects were situated in realistic professional contexts and incited students to build upon existing knowledge to acquire new knowledge.

Communities of learners were fostered through teamwork to stimulate individual learning. The role of staff moved from teachers and assistants into tutors and facilitators. Each year of this new curriculum was based on three 11– week trimesters, followed by three weeks of final examinations. Each trimester relied on a multidisciplinary project and included about 10 single discipline problems. Projects were used mostly to develop interdisciplinary and longer-term (11 weeks) approaches, while problems were used mostly within a single course and over a shorter time span (one week). In this new curriculum, a typical student week contains between 15 and 18 hours of scheduled contact hours (including four to six hours of lectures), compared to 22 to 24 hours in the previous curriculum (including 12 to 14 hours of lectures). Most of the scheduled time was devoted to supervised group work on problem and project. Groups of six or eight students were randomly constituted at the onset of each trimester. In each subject matter, a trained tutor was in charge of three groups of students. Group work was supported by some lectures, exercises or labs, articulated with problems and projects groups had to deal with. Non scheduled time was extended to allow more unsupervised individual and group work. In the previous curriculum, most of the scheduled time was devoted to lectures, there was no interdisciplinary project, and lectures, exercises and labs could progress at different pace. Group work was rare, limited in time and scope, and not tutored.

The staff of this school decided to combine problem-based and project-based learning, thinking that both models exhibit strong qualities and that their conjunction would fit better to engineering education. A more detailed description of these curriculum changes, their design and planning, and the decision-making process could be found in Frenay, Galand, Milgrom, and Raucent [21], in Milgrom and Raucent [38], and in Raucent, Braibant, de Theux, Jacqmot, Milgrom, Vander Borght and Wouters [50].

2. METHOD

2.1 Participants and procedure

As part of a larger study, 170 students of the last cohort who completed the traditional curriculum were surveyed in October 2001, and 133 students of the first cohort who completed the new PBL curriculum were surveyed in October 2002. All the students were in the 3rd year of their training when they participated in the study. This timing provides an opportunity to assess the impact of mid-term (two years) enrolment in a PBL or traditional environment on motivational beliefs, self-regulation and study strategies. Participants completed a questionnaire during regular lecture time. This questionnaire was administered by members of the research team to insure the confidentiality of the answers. The students were 19 to 23 years old (mean = 20 years) and 85 % were male. Age and gender distributions were similar among cohorts, as were participation rates in the survey (57 % vs. 53 %). To be admitted at the School of Engineering, all students had to pass a math entrance test. The admission process remained the same during the curriculum change and there were no differences in performance on the entrance test between the two cohorts. Grades of the two cohorts of participants did not differ significantly at the end of their 2nd and 3rd year.*

2.2 Measures

The questionnaire was constructed on the basis of a compilation and translation of various scales that were selected from an extensive review of the literature. Priority was given to scales already validated in French when available. The selected items were submitted to a panel of experts and to

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* This comparison must be taken cautiously, because the two cohorts were partially graded on different of criteria [23].

another panel of faculty members from the School of Engineering. This stage resulted in some changes in the original draft (change in the wording of some items, addition or removal of some items). This second draft was submitted to individual and group pretests among students from another faculty to check for proper understanding of the items. The remaining items were then grouped into scales on the basis of factorial analyses, and the internal consistency, discriminant validity and predictive validity of those scales were examined. More details about the validation of this questionnaire are presented in Bourgeois, Galand and Frenay [9], and Galand and Frenay [23].

All scales are based on first order factorial analysis (PCA). Number of items and internal consistency coefficient (Cronbach alphas) of those scales are presented below. For all items, a 5-point scale Likert type response format was used (anchors: 1 = strongly disagree, 5 = strongly agree; except for self-regulation and learning strategies: 1= never, 5 = very often). For the items about perceived learning environment, participants were instructed to refer to their experience of the last two academic years. For all other items, participants were instructed to refer to what they were doing now. Two examples of items for each scale are shown in the appendix.

Perceived learning environment. Items assessing perception of the learning environment were adapted from Ames and Archer [2], Galand and Philippot [25], Ramsden [49], Roeser, Midgley and Urdan [51], and Vallerand, Fortier and Guay [59]. We selected items reflecting pperceived instructional practices rather than students' assessment of the courses. The final version included 37 items divided into six subscales. Students reported their perceptions of the extent to which their teachers provided them cognitive and emotional support (*coaching,* 9 items, alpha = 0.82), promoted authentic learning and transfer of learning to 'real-life' context (*linking theory and practice*, 6 items, alpha = 0.80), emphasized comparison and competition among students (*emphasis on competition,* 6 items, alpha = 0.70). They also reported the extent to which they experienced work overload in their study (*work overload,* 4 items, alpha = 0.60) and the learning assessment practices (tests and exams) were fair and consistent with instruction (*assessment fairness,* 5 items, alpha = 0.71). Finally, perceived emotional and cognitive support between students was assessed (*collaboration between students*, 7 items, alpha = 0.73). In order to build stronger and more synthetic indicators, a second order factorial analysis was performed on the six perceived learning environment subscales. Results showed that two factors account for the majority of the variance. These two factors were *academic support*, including coaching and linking theory and practice scales, and *organizational structure*, including assessment fairness, work overload (negative loading) and emphasis on

competition (negative loading) scales. Factorial scores on those two factors were used in the following analyses. The collaboration between students scale loaded slightly on both factors and was analyzed separately.

Motivational beliefs. Items assessing motivational beliefs were adapted from Bouffard, Boisvert, Vezeau and Larouche [7], Galand and Philippot [24], Midgley, Kaplan, Middleton, Maehr, Urdan, Anderman et al. [37], and Nicholls [44]. The final version included 21 items divided in three subscales. Students were asked to report the extent to which two different types of goals guide them in their study. More specifically, they answered questions referring to *mastery goals*, i.e., focus on learning, understanding and mastery (6 items, alpha = 0.74), and *performance goals*, i.e. focus on demonstrating competence (5 items, alpha = 0.70). Students also answered questions about their perception of their own ability to succeed in their learning tasks (*self-efficacy*, 10 items, alpha = 0.82).

Self-regulation strategies. Items assessing students' self-regulation strategies were adapted from Bouffard et al. [7], Dupeyrat [15], Entwistle and Ramsden [16], Vermunt [61], and Weinstein, Goetz and Alexander [63]. Students completed 19 items about the frequency of their use of five self-regulation strategies: (a) supervising oneself when going about a learning task (*supervision*, 6 items, alpha = 0.66), (b) controlling one's progress in learning tasks (*monitoring*, 3 items, alpha = 0.69), (c) facing difficulties in managing potential distractions from learning (*distraction vulnerability*, 3 items, alpha = 0.53), (d) managing content-related information, like, for instance, searching for other sources of information when a part of the textbook is not understood (*information search*, 4 items, alpha = 0.71), and (e) low persistence when facing problems (*lack of persistence*, 3 items, alpha = 0.55). In order to build stronger and more synthetic indicators, a second order factorial analysis was performed on the five self-regulation subscales. Results showed that two factors account for the majority of the variance. These two factors were *adaptive strategies*, including supervision, monitoring and information search scales, and *maladaptive strategies*, including distraction vulnerability and lack of persistence scales. Factorial scores on those two factors were used in the following analyses.

Study strategies. Items assessing students' study strategies were adapted from Bouffard et al. [7], Dupeyrat [15], Entwistle and Ramsden [16], Vermunt [61], and Weinstein et al. [63]. Students completed 21 items about the frequency of their use of five learning strategies: (a) making links between different pieces of information (*relating*, 6 items, alpha = 0.81), (b) searching the relevance of learning material for real-life situations (*contextualizing*, 4 items, alpha = 0.79), (c) having a critical stand toward learning material (*criticizing*, 4 items, alpha = 0.67), (d) underlying and summar-

izing learning material (*organizing*, 4 items, alpha = 0.60), and (e) memorizing and rehearsing learning material (*rehearsing*, 3 items, alpha = 0.61).

In order to build stronger and more synthetic indicators, a second order factorial analysis was performed on the five learning strategies subscales. Results showed that two factors account for the majority of the variance. These two factors were *deep processing*, including relating, criticizing and contextualizing scales, and *surface processing*, including rehearsing and organizing scales. Factorial scores on those two factors were used in the following analyses.

Satisfaction. Ten items assessed students' satisfaction toward the content of their curriculum and the way it is delivered (alpha = 0.77).

Attendance and study time. Students were asked which percent of lessons they usually attended (10 point scale, from 10 % to 100 %) and how many hours per week they usually worked besides the lessons (9 point scale, from 0–5 to 41 and more).

3. RESULTS

3.1 Cohorts comparison

Several MANOVAs were then performed to compare the answers of the two cohorts of students on each category of variables. Omnibus test were significant ($p < 0.01$) for all categories of variables except for motivational beliefs. Detailed results for each variable are presented below. Means, standard deviations and effect-sizes are presented in Table 1. Mean comparisons could be visualized graphically in Figs 1 and 2.

Perceived learning environment. Students from the PBL curriculum report more academic support than students from the traditional curriculum ($F_{(1, 303)} = 54.34$; $p < 0.001$), but they consider organizational structure more negatively ($F_{(1, 303)} = 35.99$; $p < 0.001$). No significant differences were found for collaboration between students ($F_{(1, 303)} = 2.55$; $p = 0.11$).

Motivational beliefs. Analyses indicate no significant difference between cohorts regarding self-efficacy ($F_{(1, 303)} = 0.02$; $p = 0.90$), mastery goals ($F_{(1, 303)} = 0.27$; $p = 0.60$), and performance goals ($F_{(1, 303)} = 2.93$; $p = 0.09$).

Self-regulation strategies. Students from the PBL curriculum report using more adaptive strategies than students from the traditional curriculum ($F_{(1, 302)} = 9.63$; $p < 0.01$). No significant differences between cohorts appear for maladaptive strategies ($F_{(1, 302)} = 1.85$; $p = 0.18$).

Study strategies. Students from the PBL curriculum report using more deep processing strategies ($F_{(1, 301)} = 3.54$; $p < 0.05$) and less surface processing strategies ($F_{(1, 301)} = 6.53$; $p < 0.01$) than students from the traditional curriculum.

Satisfaction. Students from the PBL curriculum report to be less satisfied than students from the traditional curriculum ($F_{(1, 301)} = 5.20$; $p < 0.05$).

Attendance and study time. Students from the PBL curriculum report more attendance ($F_{(1, 300)} = 11.59$; $p < 0.01$) and more study time ($F_{(1, 300)} = 19.22$; $p < 0.001$) than students from the traditional curriculum.

3.2 Mediational effect of perceived instructional practices

As differences emerged on all outcome variables except motivational beliefs, the next step was to test if perceived learning environment mediates these effects. Following Baron and Kenny [4], three conditions need to be met to allow a test of mediation: (1) the independent variable must be

Table 1. Means, standard deviations, and effect-sizes.

	Range	Traditional (n = 170)		PBL (n = 133)		Cohen's d
		M	SD	M	SD	
Perceived learning environment						
Academic support[a]	–3.5 to 3.5	–0.34	*0.98*	0.44	*0.83*	0.86***
Organizational structure[a]	–3.5 to 3.5	0.29	*1.01*	–0.37	*0.87*	0.70***
Collaboration between students	1 to 5	4.27	*0.55*	4.36	*0.41*	0.18
Motivational beliefs						
Mastery goals	1 to 5	3.98	*0.53*	4.02	*0.55*	0.07
Performance goals	1 to 5	2.23	*0.73*	2.37	*0.70*	0.19
Self-efficacy	1 to 5	3.60	*0.59*	3.59	*0.55*	0.02
Self-regulation strategies						
Adaptive[a]	–3.5 to 3.5	–0.16	*1.00*	0.20	*0.96*	0.37**
Maladaptive[a]	–3.5 to 3.5	0.07	*0.95*	–0.09	*1.05*	0.16
Study strategies						
Deep processing[a]	–3.5 to 3.5	–0.11	*1.02*	0.12	*0.97*	0.23*
Surface processing[a]	–3.5 to 3.5	0.13	*1.03*	–0.16	*0.94*	0.28**
Satisfaction	1 to 5	3.74	*0.49*	3.62	*0.42*	0.26*
Attendance	1 to 10	8.09	*1.75*	8.68	*1.12*	0.40**
Study time	1 to 10	3.20	*1.51*	4.01	*1.63*	0.51***

Note. PBL: problem- and project-based learning; a: factorial score (standardized); ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.
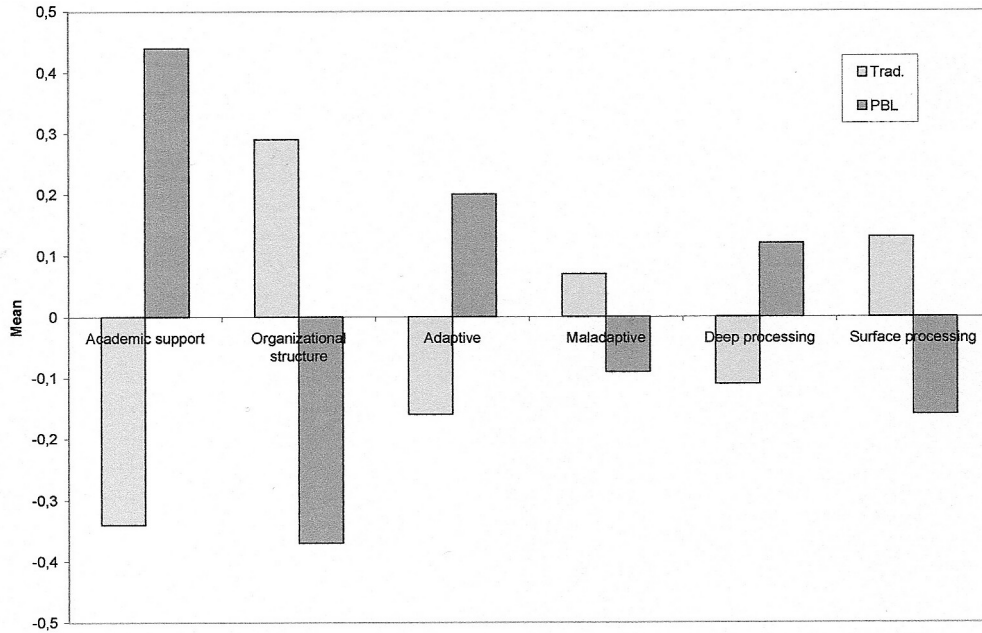
Fig. 1. Comparison between traditional and PBL curriculum for learning environment, self-regulation strategies and study strategies (factorial scores).
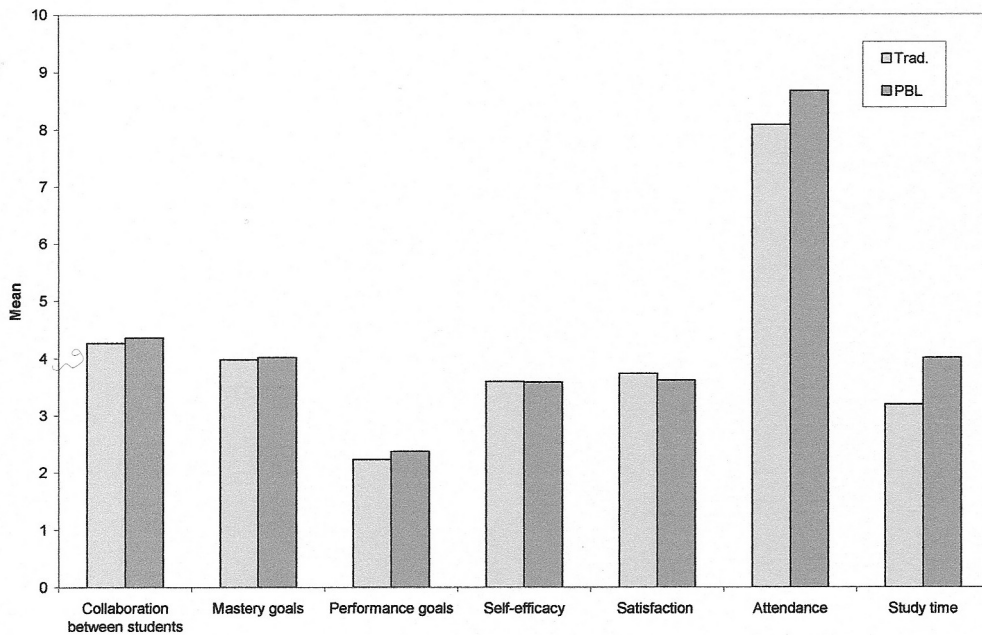

Fig. 2. Comparison between traditional and PBL curriculum for collaboration between students, motivational beliefs, satisfaction, attendance, and study time.

related to the dependent variable, (2) the independent variable must be related to the potential mediator, and (3) the potential mediator must be related to the dependant variable. Results of the MANOVAs presented above show that the first two conditions are met for academic support and organizational structure (but not for collaboration between students) and for most dependant variables: they are related to the independent variable curriculum (traditional vs. PBL). The correlations between the outcome variables presented in Table

2 indicate that academic support is significantly associated with all other variables affected by curriculum change (condition 3): adaptive strategies, deep processing, surface processing, satisfaction, attendance, and study time. Organizational structure is only associated with satisfaction and study time.

Consequently, academic support was introduced as a covariate in the comparisons between cohorts for adaptive strategies, deep processing, surface processing, satisfaction, attendance, and study

Table 2. Correlations between the outcome variables of the study

	1	2	3	4	5	6	7	8	9	10	11	12
1. Academic support	–											
2. Organizational structure	0.12*	–										
3. Collaboration between students	0.25**	0.27**	–									
4. Mastery goals	0.27**	0.19**	0.15**	–								
5. Performance goals	0.03	–0.10	–0.14*	–0.08	–							
6. Self-efficacy	0.15**	0.33**	0.25**	0.24**	0.21**	–						
7. Adaptive strategies	0.28**	–0.01	0.22**	0.44**	0.06	0.23**	–					
8. Maladaptive strategies	–0.13*	–0.07	–0.20**	–0.21**	–0.09	–0.13*	–0.28**	–				
9. Deep processing	0.41**	0.08	0.21**	0.44**	0.04	0.34**	0.68**	–0.19**	–			
10. Surface processing	–0.14*	–0.10	0.01	–0.01	–0.01	–0.14*	0.12*	–0.12*	0.03	–		
11. Satisfaction	0.33**	0.40**	0.36**	0.33**	–0.12*	0.31**	0.25**	–0.21**	0.31**	0.09	–	
12. Attendance	0.26**	–0.05	0.05	0.10	0.05	0.00	0.11	–0.32**	0.13*	0.14*	0.11	–
13. Study time	0.12*	–0.25**	0.01	–0.05	0.17**	–0.13*	0.17**	–0.33**	0.05	0.14*	–0.01	0.32**

Note. N = 299; *p < 0.05; **p < 0.01.

time. Organizational structure was introduced as a covariate only for satisfaction and study time. MANOVAs were performed again on those variables and changes in *F*- and *p*-values (compared to the above results) were examined. Results of these new analyses indicated that PBL students no longer differ from 'conventional' students on adaptive strategies (F (1, 299) = 1.99; p = 0.16), deep processing (F (1, 299) = 0.96; p = 0.33), and attendance (F (1, 299) = 3.60; p = 0.07) when academic support is controlled, while results remained almost unchanged for surface processing (F (1, 299) = 6.82; p < 0.01). Difference in satisfaction is magnified when academic support is controlled (F (1, 299) = 33.01; p < 0.01), but does not remain significant when organizational structure is controlled (F (1, 299) = 0.01; p = 0.91). Academic support is not a significant covariate of study time (p > 0.10), and difference in study time is reduced but remains significant when organizational structure is controlled (F (1, 299) = 10.33; p < 0.01). In other words, most differences in engagement between conventional and PBL students could be explained by differences in perceived learning environment, because these effects are no longer detectable when perceived learning environment is taken into account.

4. DISCUSSION

In this study we wanted to assess the impact of PBL on engineering students' perception of their learning environment and academic engagement. A cohort of students who followed a two-year lecture-based curriculum was compared with a cohort of students of the same faculty who followed a two-year problem- and project-based curriculum. Results of this comparison indicate large differences in the way students perceive their learning environment. Students who attended the PBL curriculum report more supportive teacher-student relationships and more practices making links between theory and applications. This effect suggests modifications in instructional

practices that are consistent with the principles of PBL [17].

However, students from the PBL program also report more work overload and less coherence between instruction and assessment. These results seem to reflect some difficulties in the implementation of the new PBL curriculum, maybe due to insufficient coordination among teachers [45]. However, qualitative data collected in another part of our research program suggested that coordination among teachers increased with the implementation of the PBL curriculum [23]. But it seems, at least from the student point of view, that it was not sufficient to deal with all the changes implied by the shift to PBL. The absence of difference between cohorts regarding collaboration between students is surprising, given that PBL implies much more cooperative interaction between students. However, collaboration between students was already very high in the traditional curriculum (see table 1), so this null result maybe reflects a ceiling effect. On the other hand, it could be that the PBL curriculum investigated in this study did not success to set up the conditions allowing groupwork to foster engagement and learning [22, 55].

A surprising result of the present study was that no significant difference appeared between the two groups of students on motivational beliefs (goal orientations and self-efficacy). Maybe the implementation problems mentioned above could have counterbalanced the expected positive effect of PBL [46]. As goal orientations and self-efficacy become more stable with age [64], it could be also that undergraduates' quality of motivation is less sensitive to contextual factors than secondary school students [36]. Anyway, other differences between the cohorts of students cannot be attributed to variation in motivational beliefs.

Regarding cognitive engagement, results of this survey show that students from the PBL curriculum get better outcomes than students from the traditional curriculum: as expected, they report using more adaptive self-regulation strategies, more deep processing strategies and less surface processing strategies. Results for study time are

consistent with change in time allocation between the two curricula. Reduction in scheduled time was compensated by an increase in unsupervised individual and group work. Moreover, results for attendance indicate that this reduction in scheduled time was accompanied by higher attendance.

No negative effect of the PBL curriculum was found on the indicators of student engagement assessed in this study, except for satisfaction: contrary to our expectations, PBL students report slightly less satisfaction toward their program than 'conventional' students. It should be noted however than student satisfaction is very high in both curricula. This last effect put apart, results of the present study are very consistent with previous studies in the education of health professionals [5]. Effect-sizes for student engagement are small to moderate; those for perceived learning environment are large.

Consistently with our expectations, most of the above differences between students from PBL and traditional curricula are no longer significant when perceived learning environment is introduced as a covariate. More precisely, differences in adaptive strategies, deep processing strategies and attendance disappear when academic support is controlled. In other words, these differences could be explained by changes in perceived instructional practices that are consistent with PBL guidelines. On the other hand, the difference in satisfaction disappears when organizational structure is controlled. These results support the idea that the implementation of PBL impacts on students' academic engagement through their perception of the learning environment [45].

Moreover, as positive effects are mainly associated with the coaching and transfer facilitation scales, they suggest that contextual learning and tutoring are key factors in PBL effectiveness [14]. They also suggest that student workload and alignment between instruction and assessment could be particularly problematic in PBL implementation [41], and impair students satisfaction. These results underscore the importance of a careful monitoring of innovation during its implementation period [28]. Nevertheless, some differences between PBL and conventional students in surface processing and study time remain even when perceived learning environment is controlled. It could be that our measure of perceived learning environment did not capture all the differences in the way students experienced conventional and PBL curriculum.

A major limitation of this study is that the students were not randomly assigned to each group and that the measurement is cross-sectional (all the variables are measured at the same time). With such a study design, we could not be sure that the findings are related to curriculum change rather than to other, unmeasured factors.

Even if we controlled for grades, gender and age, and despite the rapidity of the curriculum change, we could not exclude selection or historical bias.

However, the consistency of our results with previous research and with what could be expected from a shift from traditional to PBL curriculum supports the idea of a curriculum effect. Nevertheless, these results do not imply that PBL is the most effective way to increase student academic engagement. Maybe other guidelines for instructional design, more structured, e.g. case-based learning [56], or with greater faculty input, e.g. team learning [30], could be more efficient than PBL. The main implication of our results is that curriculum change can increase student academic engagement.

Another limitation of the study is that all variables were measured through self-report. Combining these measures with other sources of information would add to the validity of the findings. Regarding this point, it should be noticed that results for practices reported by teachers parallel those for students' perception of instructional practices [23]. Nevertheless, other dimensions of the perceived learning environment not included in this study—e.g. modalities of group work [31]—could be worth to assess in order to understand more thoroughly the effects of PBL on student learning. Finally, students' conceptions of learning and teaching or expectations regarding instruction at university—that could have mediated the effect of curriculum on engagement—were not taken into account in the present study [60].

Finally, one could wonder if the differences found in this study are really relevant for student knowledge and skills, given that those were not directly assessed. Fortunately, in another part of our research program, based on another sample of four student cohorts, we found that PBL students displayed better knowledge and problem-solving skills that conventional students on an achievement test [26]. These results suggest that differences in cognitive engagement documented in the present study translate into learning differences.

The assessment of a 'natural' curriculum shift from lecture-based learning to problem- and project-based learning in engineering education presented in this paper is just one step in a better knowledge of the effects of PBL on various outcomes, in various contexts and designs. Clearly, more research in a larger variety of contexts is needed if we want to understand how and in which conditions different forms of PBL—or combination of PBL and projects like in the present study—affect student engagement in learning. It should be noted that the methodological choices made in this study were in line with the aim of assessing the outcomes of a curriculum change toward PBL. Other research aims, like for instance a fine grain understanding of differences in student learning experience in the two cohorts, would probably fit better with other methodological approaches (e.g. observations, interviews).

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APPENDIX

Sample items (free translation from French)

Perceived learning environment

Coaching. 'In this faculty, teachers provide regular feedback about our progress.' 'In this faculty, teachers encourage us to learn from our mistakes.'

Linking theory and practice. 'In this faculty, teachers show us the possible practical applications of what they teach.' 'In this faculty, teachers use concrete examples to explain concepts.'

Emphasis on competition. 'In this faculty, teachers publicly compare students one another.' 'In this faculty, teachers favour especially students who are successful.'

Assessment fairness. 'In this faculty, the grades we get do reflect fairly the students' level of mastery.' 'In this faculty, the content of tests and exams are consistent with the learning objectives.'

Work overload. 'In this faculty, the requested amount of work doesn't allow us any free time.' 'In this faculty, the various teaching activities are well articulated' (reverse score).

Collaboration between students. 'My relationships with other students happen in a climate of confidence.' 'We help one another between students.'

Motivational beliefs

Mastery goals. 'In my study I seek primarily to deepen my knowledge.' 'Understanding the subject-matter is more important to me than the grades I get.'

Performance goals. 'In my study, I seek competition because I find it stimulating.' 'It's important for me to have better grades than other students.'

Self-efficacy. 'Compared to other students, I feel my abilities are lower' (reverse score). 'I am sure to be able to understand the subject-matter in those courses.'

Self-regulation strategies

Supervision. 'When I am facing a difficulty to understand a part of the content, I try to analyse finely the nature of the problem.' 'Before I begin to study a subject-matter, I plan in which order I will study it.'

Monitoring. 'To test my progress in my study, I try to answer questions I ask myself about the subject-matter.' 'To check whether I master a subject-matter, I try to think of other examples than those we have had in the class.'

Distraction vulnerability. 'Most of the time, I wait till the last moment to do my work.' 'When I attend lessons, I make sure my attention is totally focused on it' (reverse score).

Information search. 'I tend not to read more than what is expected for the exams' (reverse score). 'If I don't understand a part of the subject-matter, I try to find relevant information from other sources.'

Lack of persistence. 'If I don't understand something, I give up and do something else.' 'I do an effort even when what I'm studying is not interesting' (reverse score).

Study strategies

Relating. 'I try to find the similarities and the differences between notions presented separately.' 'I try to see the connections between the content of several courses.'

Contextualizing. 'I try to find the relevance of what I learn in my courses in my daily life.' 'I use what I learn at university in my activities outside university.'

Criticizing. 'I draw my own conclusions from the data presented by the teachers.' 'I compare my own point of view with those presented in the courses.'

Organizing. 'I make a list of the main points to memorize.' 'I summarize the main ideas of my courses.'

Rehearsing. 'I repeat the main parts of the matter until I know it by heart.' 'I try to learn word by word the content of the courses.'

Satisfaction. 'I am satisfied with the content of my curriculum.' 'This program helps us to develop a strong knowledge base.'

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