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Research Article

Problem-based learning and metacognition

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Abstract

This research replicates an earlier study undertaken by the author, with a new and larger sample of first year undergraduates from two programmes at a Hong Kong University (N=132). One programme uses an entirely problem-based approach to learning and teaching, whilst the other uses more traditional methods. Using the Learning and Study Strategies Inventory (LASSI) as a measure of metacognition, it explores differences in metacognitive development between each group of students between the beginning and end of their first fifteen months in each programme. Despite significantly weaker entry scores on the LASSI, the mean final scores, taken after fifteen months and three semesters of study in the different curriculum environments demonstrate dramatic improvements in metacognition for the PBL group of undergraduates. The paper argues that, in addition to the formal learning context, everyday challenges emerging from the additional new social contexts provided by problem-based curricula provide fertile environments for the development of metacognition. In other words, when we are faced with finding solutions to a problem whether posed by the teacher as part of a problem-based curriculum or a new social environment, we are more likely to develop generic, as well as subject specific skills.

Keywords: Problem-based learning, A-level results, LASSI, will, skill, metacognition.

Introduction

Constructivist and social constructivist approaches to learning and teaching have become increasingly influential concepts over the past few decades as attention has increasingly focused on how we learn, as well as what we learn [1]. Some of the processes involved in acquiring new knowledge and skills, together with the ability to later apply these in novel situations, have long been recognised as key components in terms of intellectual, social, and cultural development [2]. However, the relationship between these concepts is not uni-directional and even Piaget [3] acknowledged the impact of social factors and peer interaction on cognitive development. Whilst more recent studies have generally confirmed this view [4], relatively few have attempted to evaluate the impact of PBL approaches outside the field of medicine, particularly the impact of problem-based approaches on the development of metacognition in university students, with most recent research tending to concentrate on the impact of 'Learning to Learn' type courses upon the development of undergraduates [5]. In those studies undertaken outside medicine [6, 7], a variety of different measures, which have not always focused on the development of metacognitive abilities, have been used to assess the impact of PBL approaches. Using the Learning and Study Strategies Inventory (LASSI) as a measure of metacognition, this study replicates an earlier study undertaken by the authors (N=66) with a new and larger sample (N=132), and explores differences in metacognitive development between two groups of students from the beginning to the end of their first fifteen months as undergraduates in two knowledge-similar programmes. Consequently, this study confirms significant differences in metacognition between students taking first year building and construction courses, which have adopted a problem-based approach to learning, and those taking similar building and construction courses in a non-PBL environment.

Metacognition

Metacognition can be most simply defined as 'thinking about thinking' [8, 9, 10], but this process also involves knowing how to reflect and analyse thought, how to draw conclusions from that analysis, and how to put what has been learned into practice. Kluwe [11] developed the concept of metacognition by noting two characteristics which echo Piaget's [12] notion of decentration: the thinker knows something about his or her own and others' thought processes, and the thinker can pay attention to and change his or her thinking. Kluwe calls this type of metacognition 'executive processes'. Stressing the importance of learning more about thinking, Hacker [13] elaborates the concept still further, identifying a difference between cognitive tasks (remembering things learned earlier that might help with the current task or problem) and metacognitive tasks (monitoring and directing the process of problem solving).

The role of learners' beliefs about thinking is emphasised by Cornoldi [14] who argues that if students feel confident that they can solve problems, they tend to do better work. Weinert [15] also defines metacognition as 'thinking about thinking' or 'second-order cognition', but acknowledges that purpose, conscious understanding, ability to talk or write about tasks, and generalisability to other tasks are also crucial factors in determining whether a given task can be regarded as metacognitive. Brown [16] supports this viewpoint agreeing that metacognition requires the thinker to use and describe the process of mental activity, whilst Allen and Armour-Thomas [17], also make the point that metacognition is best defined by acknowledging that it is both knowledge about, and control over thinking processes. Vadhan and Stander [18] make the distinction between ordinary thinking and awareness, and understanding of thinking, and this theme is developed by Hacker [13] who divides metacognition into three types of thinking:

- Metacognitive knowledge: What one knows about knowledge.
- Metacognitive skill: What one is currently doing.
- Metacognitive experience: One's current cognitive or affective state.

A good summary statement is provided by Marchant [19], who argues that whilst cognition focuses on solving the problem, metacognition focuses on the process of problem solving. Solving problems often requires undergraduate students to understand how their mind functions, and identify not just what they know, but how they perform important cognitive tasks such as remembering, learning and problem solving. Given the emphasis on the processes of learning in PBL approaches, rather than merely knowledge-based outcomes, it is logical to expect more significant metacognitive development from undergraduates engaged in problem-based learning when compared to those who learn through non problem-based approaches, which do not always require the same reflective performance.

Metacognition and PBL

Biggs [20] suggests that the aim of undergraduate education is to assist students to develop the functioning knowledge which allows them to integrate the academic knowledge base (declarative knowledge), the skills required for that profession (procedural knowledge), and the context for using them to solve problems (conditional knowledge). According to Hmelo *et al.* [21], problem-based learning by its very nature requires a different way of using knowledge to solve problems, and it is this 'functioning' knowledge that involves the metacognitive processes identified above. Consequently, because problem-based learning uses real world cases or problems as the starting point, the processes involved in solving these problems should lead to the development of the two characteristics of metacognition defined by Kluwe [11]. In addition to knowledge about how thoughts are applied [16], knowledge about how much can be learned, and what kinds of strategies to use [22, 23]; people also tend to have a set of general heuristics or 'rules of thumb' which involve how they plan, set goals, and process feedback [24]. The assumption is that these general heuristics may be highly generalised or specific, and can be either conscious or automatic [16, 25]. Problem-based learning comes in many forms, however they all require the successful student to monitor and direct the process of problem solving, and bring the memory of concepts and processes learned earlier to bear upon the current problem. In fact, in the general sequence of problem-based learning: the motivational context of learning is set up by a real-life problem; learners are activated through group, peer and facilitator interaction; a knowledge base of relevant materials is constructed and applied to deal with the case; and the case is then reviewed, all of which requires reflection upon declarative, procedural, and conditional knowledge. Therefore, problem-based learning should, in theory at least, be ideally tailored to the more rapid development of metacognition in undergraduates than non-problem-based alternatives.

Metacognition and the Learning and Study Strategies Inventory (LASSI)

Metacognition can be assessed in a number of ways but one of the most popular methods currently in widespread use is through the use of questionnaires which require students' to report their perceptions about their thinking and problem-solving skills and strategies. It is generally accepted that most students who struggle at university could improve their performance considerably if they understood the learning process better. Weinstein and Palmer [26] assert that learning is more effective when we engage in thinking about the process of learning, thinking, and problem-solving. As a result of her work in the field of strategic learning at the University of Texas at Austin, Weinstein [27] developed the Learning and Study Strategies Inventory (LASSI) which is now the most widely used learning inventory in the world. The LASSI measures student's perceptions of their study and learning strategies and methods. In other words, it is a measure of the students thinking about their thinking or metacognition. The second version [28] of the tool consists of ten scales, and eighty items which provide an assessment of students' awareness about and use of learning and study strategies related to skill, will and self-regulation components of strategic learning. Research has repeatedly demonstrated that these factors contribute significantly to successful study, and that they can be learned or enhanced through educational interventions such as learning and study skills courses [29, 30, 31, 32, 33]. The LASSI provides standardised scores for the ten different scales and provides students with a diagnosis of their strengths and weaknesses, compared to other students, in the areas covered. It measures three main areas of 'strategic learning':

Skill component of strategic learning

These scales examine students' perception (metacognition) of their learning strategies, skills and the thought processes related to identifying, acquiring and constructing meaning for important new information, ideas and procedures. The LASSI scales related to the skill component of strategic learning are:

- Information Processing-the ability to process ideas by mentally elaborating on them and organising them in meaningful ways.
- Selecting Main Ideas- the student's ability to identify the important information in a learning situation.
- Test Strategies-the student's ability to prepare effectively for an examination and to reason through a question when answering it.

Will component of strategic learning

These scales measure students' perceptions of their receptivity to learning new information, their attitudes and interest in college, their diligence, self-discipline, and willingness to exert the effort necessary to successfully complete academic requirements, and the degree to which they worry about their academic performance. The LASSI Scales related to the will component of strategic learning are:

- Attitude-the student's perceived motivation and interest to succeed in their study, and willingness to perform the tasks necessary for academic success.
- Motivation-the extent to which the student accepts responsibility for performing those tasks by using self-discipline and hard work.
- Anxiety-the degree of anxiety perceived by the student when approaching academic tasks.

Self-regulation component of strategic learning

These scales measure how students' perceptions of how they manage, or self-regulate and control, the whole learning process through using their time effectively, focusing their attention and maintaining their concentration over time, checking to see if they have met the learning demands for a class, an assignment or a test, and using study supports such as review sessions, tutors or special features of a textbook. The LASSI Scales related to the self-regulation component of strategic learning are:

- Concentration-the student's perceived ability to focus his or her attention, and avoid distractions, while working on school-related tasks like studying.

- Time Management-the student's perception of the extent to which they create and use schedules to manage their responsibilities effectively.
- Self-Testing-the student's awareness of the importance of self-testing and reviewing when learning material, and use of those practices.
- Study Aids-the student's perceived ability to use or develop study aids that assist with the learning process.

Method and Materials

Design

Starting from 2005-06 the LASSI was offered to all first-year undergraduate students at City University of Hong Kong in order to help them monitor and develop appropriate learning attitudes and strategies, and maximize the opportunity for students to enjoy a successful learning experience during university and beyond. Group A consists of undergraduate students on a degree programme in building who completed both entry and interim LASSI questionnaires in September 2006 and January 2008 respectively (N=33). This group was matched for age, gender and housing type with a sample from another building programme, composed of associate degree students (Group B), who completed LASSI at the same times as part of the institutional LASSI initiative. Matching for these particular variables was considered necessary in the light of previous published research conducted in Hong Kong which clearly suggested that age, gender, and housing type were significant variables in terms of LASSI score [4]. The undergraduates following the full degree programme in group A follow a course of study and assessment in their first year which is distinctly non problem-based learning (non-PBL), whereas the associate degree student group B from the second programme follow an exclusively problem-based approach which is described below. Therefore, this was an opportunity to compare the impact of PBL across two programmes in the same discipline. Given that the data from LASSI is ordinal, a related samples design using matched pairs and data is analysed using the Wilcoxon signed ranks test for related samples to ensure good inferential rigour [34].

Materials

The measure of Metacognition used for both entry and final tests is the Learning and Study Strategies Inventory (Second Edition) which is commercially available [28].

Participants

First year undergraduates from the building discipline at a Hong Kong university (N=132). Group A (n=66) were selected from full-time degree programme students embarking on their first year of study as undergraduates. Group B (n=66) were selected from full-time associate degree students also embarking on their first year of study. The participants were matched for age (the range for both groups was 20 to 25 years), gender (Table 1) and housing type. Housing type has proved a significant factor in academic performance in Hong Kong [4] so we included this in our matching criteria.

'A' level data for each group was also gathered because the entry requirements for each group of students are different given their admission to degree and associate degree programmes. 'A' level (AL) scores are calculated on a 'point' basis in Hong Kong with 2 AL subjects or 1 AL subject plus 2 Advanced-supplementary (AS) level subjects being counted. For AL subjects, grade A=10 points, B=8 points, C=6 points, D=4 points, E=2 points; whilst for AS level subjects, grade A=5 points, B=4 points, C=3 points, D=2 points, E=1 points. Thus, the maximum score for each student should not exceed 20 points. Table 2 shows the 'A' level scores for each group on entry to their respective programmes. The non-PBL degree programme students not surprisingly score significantly higher than their associate degree programme counterparts in terms of 'A' level achievement on entry.

Table 1. Gender distribution/matching.

	Male	Female
Group A (Non-PBL)	44	22
Group B (PBL)	44	22

Table 2. 'A' level points for each group on entry.

	Mean AL Score
Group A (Non-PBL)	9.67
Group B (PBL)	4.95

Learning contexts

The problem-based curriculum involved students working in small tutorial groups of between five and six trying to understand, explain and solve problems set by the tutor. The commonly used 'seven-jump' approach [35] was adopted in which PBL is systematically structured into seven broad steps: (1) clarifying terms and concepts not readily understood; (2) defining the problem; (3) analysing the problem; (4) summarising the various explanations of the problem into a coherent model; (5) formulating learning objectives; (6) individual study activities outside the group and; (7) report and synthesise the newly acquired information. Students have approximately 3 hours per week of tutor contact time at their disposal over a 13 week semester but this is organised flexibly according to student need. Therefore, some groups might wish to meet for longer tutorials early in the semester whereas others chose to meet for shorter periods on a weekly or twice weekly basis. In the early tutor groups students analyse the problem(s), formulate learning outcomes, and identify questions to which they should find answers through individual study. When the individual study is complete, the tutor group meets again to present what they have learned about the problem(s). At this stage, the tutor clarifies and analyses the acquired information and ideas with the intention of assisting students to integrate their knowledge. Throughout the semester the tutor's main task is one of facilitating learning and providing timely and appropriate scaffolding when required by the tutorial group.

In the non-PBL group a more traditional approach is taken whereby the subject matter is determined largely by the lecturer and the focus is on declarative and procedural knowledge, rather than functioning problem-based knowledge [20, 36]. Contact time is again 3 hours per week over a 13 week period but this is organised into a two hour lecture and one hour tutorial per week for each of the 13 weeks. In lectures, students are presented with clarifications and explanations of the subject matter, and weekly tutorials are used to deepen understanding of the acquired knowledge, clarify individual problems and provide feedback on formative and summative assessments. Subject matter, learning outcomes assessment and feedback remain largely in the hands of the lecturer or tutor although students are free to choose their own learning strategies and approaches.

Results and Discussion

Entry and interim score comparisons of the two groups are shown in Figures 1 to 4, pre- and post-test mean LASSI score differences are shown in Figures 5 and 6. We have presented statistical *p*-values for the t-tests beneath the column labels on the x-axis of each graph for easy visualisation. Mean LASSI scores observed at entry and interim phases for the two gender groups are also shown in Table 3, with t-test results for group comparison shown alongside.

Entry scores for the two groups

The results for the LASSI entry scores for groups A, (non-PBL degree students) and B, (PBL associate degree students) demonstrate that the degree entrants with higher 'A' level scores also score significantly higher on the LASSI entry test than their associate degree counterparts, and that this statistically significant difference is evident across all ten items of the LASSI questionnaire. In fact the overall means demonstrate a difference of about seven or eight percentiles between the two groups (see Figures 1 and 2).

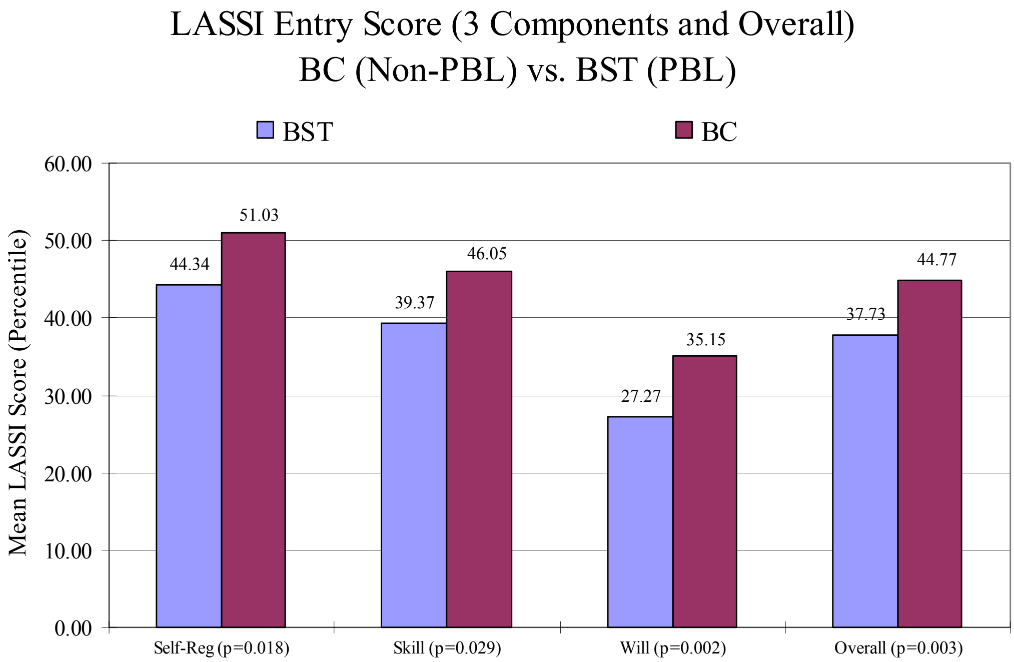

Figure 1. LASSI Entry Scores (3 components and overall) of Group A (non-PBL) and Group B (PBL) students.

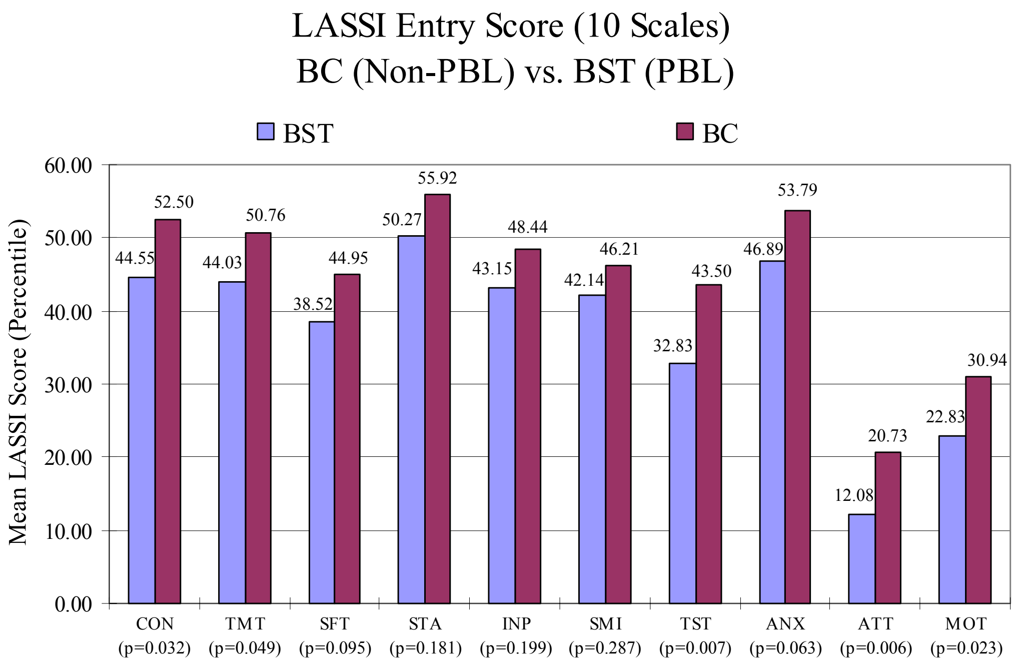

Figure 2. LASSI Entry Scores (10 scales) of Group A (non-PBL) and Group B (PBL) students.

Final scores for the two groups

The mean final scores, taken after fifteen months and three semesters of study in the different curriculum environments (shown in Figures 3 and 4) demonstrate a dramatic reversal of this situation with the associate degree students, who experienced the PBL curriculum, scoring significantly higher on all ten items of the LASSI. Overall they added 16 percentiles to their entry score and overtaken the non-PBL group in terms of their self-perceived metacognitive abilities.

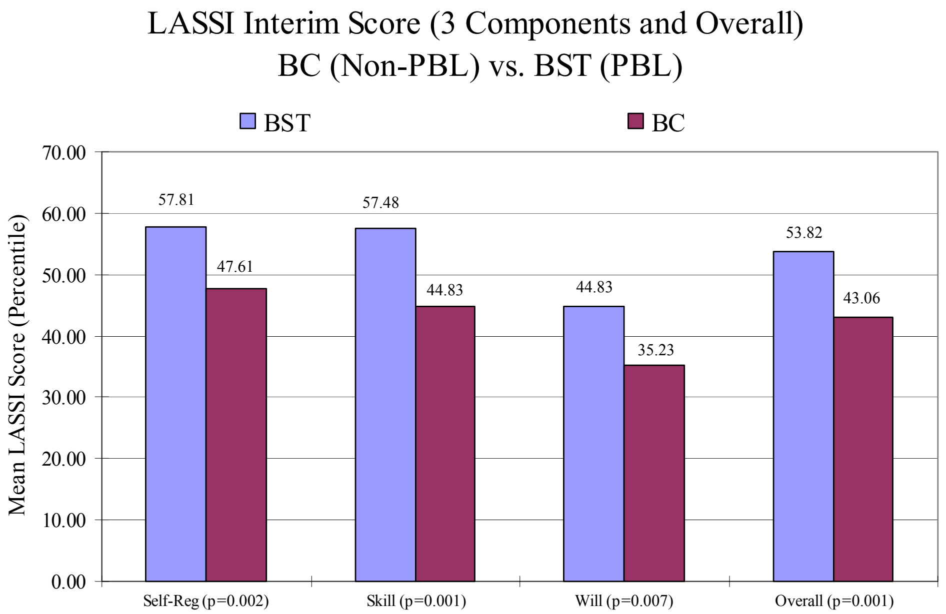

Figure 3. LASSI Final Scores (3 components and overall) of Group A (non-PBL) and Group B (PBL) students.

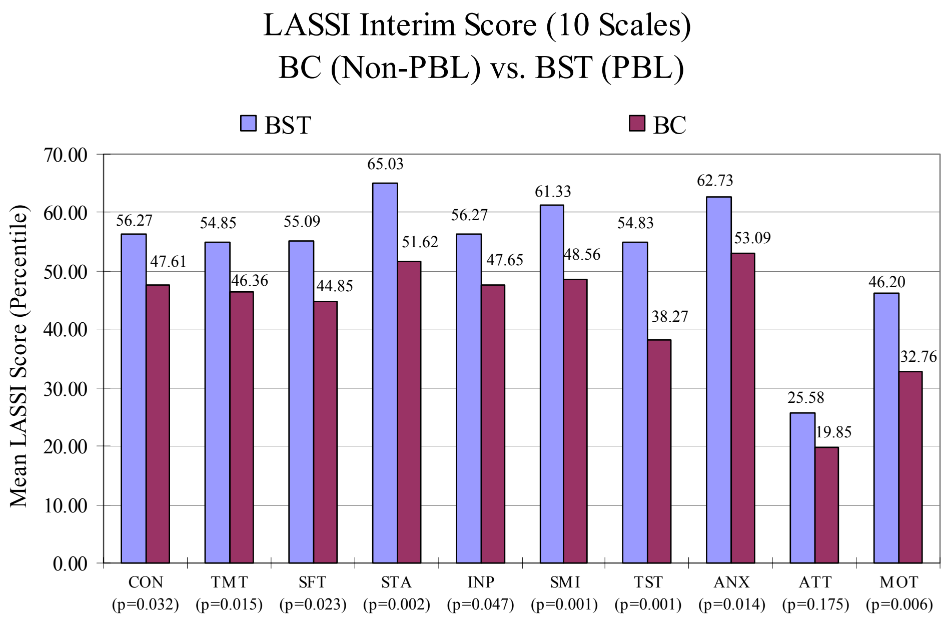

Figure 4. LASSI Final Scores (10 scales) of Group A (non-PBL) and Group B (PBL) students.

The mean difference between the entry and final scores on the LASSI for both groups is shown in figures 5 and 6 and these demonstrate the significant differences over the fifteen month period between the non-PBL and PBL students. The results in Figures 1 to 6 were all statistically significant at $p < .01$ or below.

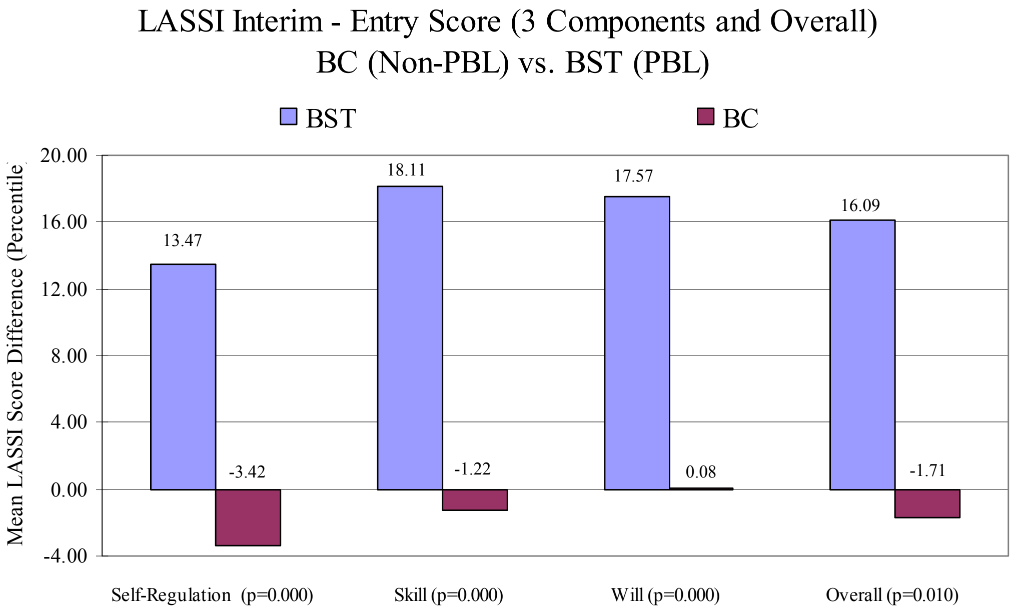

Figure 5. Mean difference LASSI scores (3 components and overall) of Group A (non-PBL) and Group B (PBL) students.

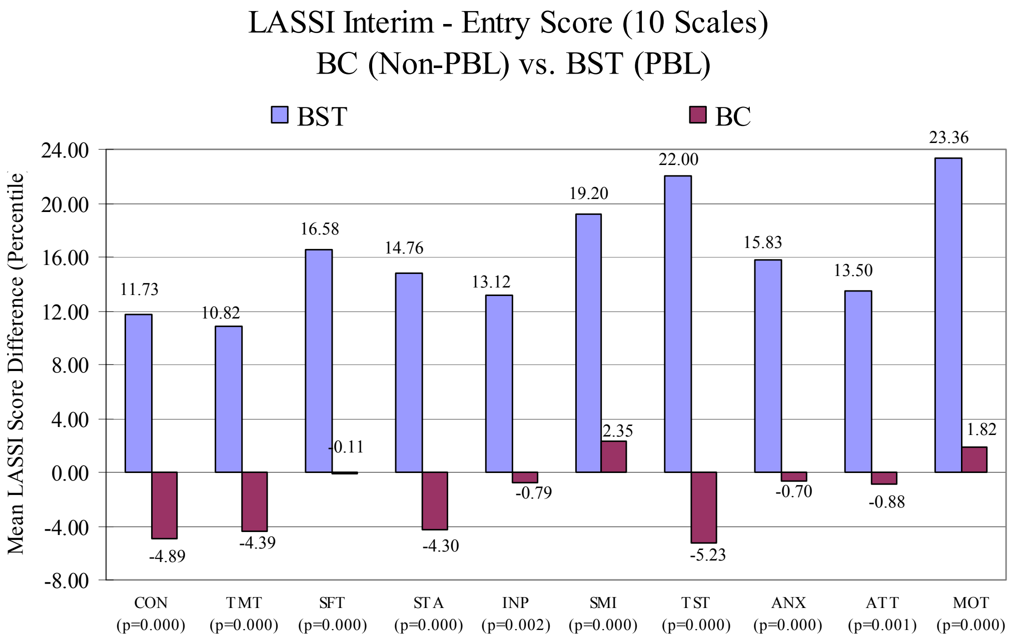

Figure 6. Mean difference LASSI scores (10 scales) of Group A (non-PBL) and Group B (PBL) students.

Table 3. Mean LASSI scores (10 scales, three components and overall) of Group A (non-PBL) and Group B (PBL) students evaluated at entry and interim, together with mean differences (Interim-Entry) and inferential statistics for group comparisons.

	Group	Entry			Interim			Difference (Interim - Entry)		
		Mean	SD	p-value	Mean	SD	p-value	Mean	SD	p-value
Self-Regulation	PBL	44.34	15.06	0.018	57.81	18.38	0.002	13.47	19.24	0.000
	Non-PBL	51.03	17.05		47.61	19.59		-3.42	16.91	
Concentration	PBL	44.55	18.91	0.032	56.27	22.52	0.032	11.73	23.01	0.000
	Non-PBL	52.50	22.94		47.61	23.41		-4.89	21.67	
Time Management	PBL	44.03	20.47	0.049	54.85	18.87	0.015	10.82	21.68	0.000
	Non-PBL	50.76	18.40		46.36	20.78		-4.39	22.42	
Self-Testing	PBL	38.52	20.64	0.095	55.09	25.21	0.023	16.58	26.39	0.000
	Non-PBL	44.95	23.30		44.85	25.76		-0.11	25.90	
Study Aids	PBL	50.27	23.72	0.181	65.03	22.69	0.002	14.76	28.52	0.000
	Non-PBL	55.92	24.51		51.62	26.25		-4.30	24.16	
Skill	PBL	39.37	16.61	0.029	57.48	21.09	0.001	18.11	18.84	0.000
	Non-PBL	46.05	18.17		44.83	20.23		-1.22	18.05	
Information Processing	PBL	43.15	22.59	0.199	56.27	24.09	0.047	13.12	23.48	0.002
	Non-PBL	48.44	24.39		47.65	25.39		-0.79	27.66	
Selecting Main Ideas	PBL	42.14	20.65	0.287	61.33	22.25	0.001	19.20	22.85	0.000
	Non-PBL	46.21	23.11		48.56	22.65		2.35	20.35	
Test Strategies	PBL	32.83	20.65	0.007	54.83	26.46	0.001	22.00	26.28	0.000
	Non-PBL	43.50	23.57		38.27	26.87		-5.23	24.64	
Will	PBL	27.27	11.39	0.002	44.83	19.84	0.007	17.57	18.75	0.000
	Non-PBL	35.15	16.49		35.23	20.71		0.08	19.46	
Anxiety	PBL	46.89	21.08	0.063	62.73	22.16	0.014	15.83	22.13	0.000
	Non-PBL	53.79	21.18		53.09	22.48		-0.70	24.09	
Attitude	PBL	12.08	9.47	0.006	25.58	24.14	0.175	13.50	23.00	0.001
	Non-PBL	20.73	23.10		19.85	24.15		-0.88	24.04	
Motivation	PBL	22.83	19.44	0.023	46.20	28.15	0.006	23.36	29.31	0.000
	Non-PBL	30.94	21.04		32.76	26.93		1.82	25.11	
Overall	PBL	37.73	11.64	0.003	53.82	18.02	0.001	16.09	17.05	0.000
	Non-PBL	44.77	15.17		43.06	17.94		-1.71	14.93	
CGPA	PBL	3.24	0.42	0.000	3.16	0.41	0.002	-0.09	0.25	0.010
	Non-PBL	2.86	0.57		2.90	0.51		0.04	0.30	

Discussion

In terms of replicating the earlier study by the authors [37], we once again hypothesised that, despite the differences in 'A' level entry scores, the students who followed the PBL curriculum (group B) would show greater improvement in their LASSI scores after the first 15 month period of undergraduate life. In common with the first study, the extent and significance of this difference surprised the researchers on this project because, whilst significant differences in scores on academic tests [38] and the LASSI [6] have been shown before, the former have usually been within the field of medicine and the latter immediately subsequent to 'learning to learn' type interventions. In this case, the events occurred naturally and we were able to take advantage of these conditions to conduct a natural experiment.

The 'will' component

The LASSI can be broken down into scores for three main components and ten items as identified above, and the second greatest difference observed from these results involves the 'will' component which has often proved the most resistant to change [39, 40, 41] with the PBL group improving 17 percentiles compared to a relatively static score for their non-PBL counterparts. The will component consists of three items from the questionnaire; motivation, attitude and anxiety. Anxiety is a reversed scale meaning that the higher the percentile scores the lower the anxiety levels. Only the PBL group showed improvement on this item suggesting a significantly greater reduction in anxiety levels than their non-PBL counterparts (Figures 4 and 6). The situation for the motivation scales is somewhat different in that the PBL group (B) showed a significant increase in their levels of motivation whereas group A showed no real progress in terms of motivation over the first fifteen months of undergraduate study. The operational definition of the motivation scale for the LASSI questionnaire suggests that it assesses students' diligence, self-discipline, and willingness to exert the effort necessary to successfully complete academic requirements. Therefore, students who score low on this scale need to accept more responsibility for their academic outcomes and learn how to set and use goals to help accomplish specific tasks. Clearly the use of a problem-based approach has facilitated the development of more confidence (less anxiety) and has substantially enhanced student levels of motivation. This is probably because knowing something about one's own thought processes and recognizing that it is possible to change one's thinking [11] are intrinsically motivating, giving the student a greater sense of control over, and satisfaction with what they produce [42]. The observed pattern for the attitude scale shows improvements in attitude for group B whereas group A results suggest a decrease over the same timescale. The attitude scale assesses students' attitudes and interest in university academic success, examining how facilitative or debilitating their approach to university and academia is for helping them to get their work done and be successful. Students who score low on this scale may not believe university is relevant or important to them and may need to develop a better understanding of how university and their academic performance relates to their future life goals. The improvement in scores for the problem-based group (B) might be partly the result of the use of real-world examples as problems to be considered. In other words, this improvement might be due to the phenomenon of situated cognition [43] where the more true to life the task is, the more meaningful the learning will be. The scaffolding provided by the teachers involved in a PBL approach should also leave students feeling supported by and more positive towards academic pursuits.

Therefore, the picture which emerges for the will component suggests that there are highly significant differences overall between the progress of the two groups over the first fifteen months of undergraduate life in relation to will and its three constituent items. This is broadly in line with the previous research conducted by the authors [37] and might be particularly important in terms of academic progress given that a number of researchers in this field [44, 45, 46] have identified this item as the most influential of all the LASSI items accounting in some studies for 21% of the predictive variance in academic scores. Motivation is also identified by Albaili [47] as the most powerful factor separating low-achieving students from their high-achieving peers but his results indicate similar significant relationships for two other LASSI items, Information Processing and Selecting Main Ideas. Motivation, levels of anxiety and attitude fall within a type of thinking which Hacker [13] calls 'Metacognitive experience' and describes an individual's current cognitive and affective state, distinguishing it from the other two categories of metacognition, metacognitive skill and knowledge. Broadly, it seems from these results that the notion that problem-based learning has positive impact upon motivation and confidence is strongly supported. The improvements for the PBL group for the attitude item, whilst significant, are comparatively less dramatic probably because attitudes are notoriously difficult and slow to change in comparison to the other items.

The 'skill' component

Only the PBL group showed self-perceived improvement in terms of the skill component scores over the fifteen month period of this study, and once again this improvement was highly significant. This was where the largest difference between the groups was found with the PBL group improving on average about 18 percentiles whereas the non-PBL group actually recorded a small and insignificant deterioration in their self-perceived abilities on this component. The largest difference between the two groups (27 percentiles) is evident on the testing strategies item, or the ability to prepare effectively for an examination and reason through a question when answering it. To some extent, this might be as a result of a more continuous approach to assessment taken in the PBL curriculum and the fact that students have more opportunities to engage in preparation for interim reports on the problems they have been set. The improvement in scores on this item, and the other two constituent items for this LASSI component, selecting main ideas and information processing, suggest considerable development of what Biggs [20] calls 'functioning' knowledge which allows students to integrate their academic knowledge base in ways which facilitate the acquisition and application of that knowledge to novel situations. The development of this functioning knowledge requires metacognitive activity because students must have reflected upon and perceived improvement in their strategies for these areas in order to bring about the magnitude of change demonstrated by their improved LASSI scores. Therefore, significant metacognitive development is evident in the PBL students, who have also clearly improved their ability to process ideas by mentally elaborating on them and organising them in meaningful ways (INP). The PBL curriculum by its very nature requires a different way of using knowledge to solve problems, and it is this functioning knowledge that involves the metacognitive processes in the way that Hmelo *et al.* [21] suggest. Problem-based activities place students in unfamiliar and challenging situations which demand that they not only think about the task or problem solution, but also the processes by which they might arrive at that solution. Consequently, their awareness of the processes of learning is likely to be heightened and this awareness can be regarded as a developing skill which is later transferable to other situations and problems. The structure of the 'seven-jump' approach [35] adopted by the problem-based curriculum is such that it clearly encourages students to acquire both cognitive and metacognitive skills, and metacognitive knowledge [13], crucially providing ample opportunities to integrate the two whilst working on realistic problems. The cognitive skills of information processing, selecting main ideas, and using testing strategies are continually analysed and reflected upon in steps 3 to 7 of the Vermunt [35] approach, until the student gains realisation and conscious control over the processes at a metacognitive level. The results for the skill component needs treating with some care, given the gender distribution within the matched groups because Downing *et al.* [48] found that males (n=44 in each group) tend to rate themselves significantly higher than their female counterparts in terms of their scores on the three items in this component. However, the gender matching of the groups, and the fact that the non-PBL group demonstrates no significant progress on this component, suggests that we can be confident that the improvement in scores for the PBL group is nonetheless dramatic.

The self-regulation component

This component of the LASSI is made up of four items which demonstrate student perception of their ability to focus their attention, develop schedules to manage their time, review their learning, and develop study aids to assist with problem solving. The PBL group also shows significant improvement overall and, when compared to their non-PBL counterparts, in all of these areas. Piaget [3] himself recognised that an environment rich with appropriate challenges was more important than trying to force the pace of change in order to help increase the pace of cognitive development. Therefore, it should not be surprising to find that metacognitive development also progresses as a result of challenges from the environment and, if these challenges are the result of finding solutions to a real world problem within a fixed timescale, this will involve the internalisation of new self-regulatory practices [1], and subsequent increases in metacognitive activity, as these are further developed and refined. In order to address the problems faced in adapting to a problem-based learning environment, and achieve significant improvements in self-regulation scores, students will need to bring to bear functioning, declarative, procedural and contextual knowledge [20] so that they can integrate the academic knowledge base, develop the professional skills required to solve the problem and learn to exercise control over the context in which they develop appropriate solutions.

Why then should self-regulatory metacognitive strategies such as concentration, time management, self-testing and the use of study aids evolve more effectively when undergraduates are engaged in problem-based learning? Vygotsky's [2] view was that in order to subject a function to intellectual and voluntary control, we must first possess that function. In other words, metacognition and self-reflection will develop first as a skill before it can be used as a series of consciously controlled strategies. The emphasis on problem-solving and associated social interaction as a pre-condition for the training of reflective skills is today shared by many approaches to instruction [49]. For example, the use of reciprocal or 'peer' teaching forces the teacher to use a whole series of metacognitive processes such as identifying what the learner already knows, deciding what is to be learned and how; monitoring understanding and evaluating the outcome in terms of increased understanding. This, in turn, encourages the teacher to reflect upon their own thinking processes. In terms of social constructivist theory, metacognitive processes begin as social processes and gradually become "internalised" [1]. The social context of working in a small group environment outside what might be termed your 'comfort zone' [50] will undoubtedly provide an action and discovery oriented learning environment, whilst the scope for peer interaction and social negotiation is also considerably widened. Socratic Dialogue is another method widely used in Europe which allows for in-depth understanding of various issues concerning everyday life. Through rigorous inquiry and consensus students start to unravel some of their basic assumptions and develop metacognitive skills and knowledge. This approach has long valued the problems presented by everyday life as a formidable teacher of self-reflection. Direct teaching of metacognitive skills through learning to learn courses can lead to increases in learning [51], but subsequent independent use of these strategies develops only gradually. Whilst there is a wealth of research in support of Scruggs [8, 33, 50], it is also essential that educators do not neglect the crucial role of the student's experience outside of the classroom in the development of metacognitive skills. Independent use of metacognitive strategies is a by-product of coping with the everyday new social contexts and cultures provided by well designed problem-based approaches to learning.

Conclusion

This paper set out to replicate an earlier smaller scale study by the authors which demonstrated that students engaged in problem-based learning showed significant improvements in metacognitive abilities during their first year as undergraduates. This study confirms, using a new and larger sample, that problem-based learning clearly does have a significant impact upon the development of metacognition after fifteen months of undergraduate study. Both the magnitude and statistical significance of the results provides further compelling evidence that the gains made by undergraduates engaged in learning through a problem-based curriculum are extremely unlikely to be a result of chance factors. According to Driscoll [50], there are three basic instructional principles on which cognitive theorists generally agree:

1. The learning environment should support the activity of the learner (i.e., an active, discovery-oriented environment).

2. The learner's interactions with peers are an important source of cognitive development (i.e., peer learning and social negotiation).
3. Instructional strategies that make learners aware of conflicts and inconsistencies in their thinking promote cognitive development (i.e., problem-solving and Socratic dialogue).

Everyday challenges emerging from the new social context associated with problem-based learning provide fertile environments for the development of metacognition. The highest 'meta-level' of cognition is usually not implicated when we receive an outside task and when the task solution is known. The meta-level tends to be consulted only when things go wrong or when a new problem is confronted. In other words, the challenging new social and academic context of working in the different culture of a problem-based learning environment increases the use of metacognition because the student cannot call upon routinised or 'automatic' cognition. Consequently, there is almost a requirement in these circumstances to have knowledge about and control over thinking processes [17].

In the past research into problem-based learning has tended to use academic assessment performance as a measure of success [38, 52] and of course this is a crucial factor for all undergraduates and their teachers. However, academic assessment is subject to all sorts of uncontrolled variability and subjectivity and the assessment tasks used to gauge success might vary considerably from one course and one semester to another. In contrast, the LASSI is a standardised and repeated measure which avoids many of these pitfalls and has the advantage of establishing a baseline from which individual and group metacognitive development can be measured. The use of a matched pairs design over a fifteen month period also ensures that any practice effects are not only limited but carefully controlled. Therefore, it seems that the LASSI has merit as a measure of the success of problem-based learning environments.

Whilst this research has demonstrated the potential value of both problem-based learning and the LASSI as a measure of metacognition, it is recognised that the nature of the design of the problem-based learning environment is critical to success. If insufficient attention is paid to providing the appropriate levels of scaffolding and support to students then they are unlikely to show the significant metacognitive development illustrated by this study. This is a theme confirmed by Downing [1], who points out that the extent of the success of any learning process is likely to be due to the same factors that have always been central to the provision of a quality learning experience. These factors include the energy, commitment and imagination of those responsible for providing the learning environment. Unfortunately, assessing these attributes is a far more difficult task.

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