Learning beyond the discipline: encouraging students to cross disciplinary boundaries in PBL

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Abstract: *The study reported in this paper investigated the disciplinary and cross-disciplinary learning by students in problem-based learning (PBL). Fifty students in eight PBL teams in a first year undergraduate engineering course participated in this study. Data collection for the study involved ethnographic observations supplemented by individual and focus group interviews and analysis of student work samples. It was found that most of the first year electrical engineering students acquired disciplinary knowledge relevant to the particular tasks that they worked on for the team. However, it appeared that they either did not appreciate the connection of their task to the main problem or did not value linking their task with the tasks of other members in their team. We think the findings of this paper should inform the design of PBL courses, in particular the design of problems and assessment. If we want students to cross disciplinary boundaries, we need to incorporate strategies that require them to integrate knowledge across disciplinary boundaries while solving problems.*

1 Background

Problem-based learning is a learner-centred approach to learning and teaching which is mostly constructed around a series of problems selected by the teacher (Barrows & Tamblyn, 1980). PBL approaches situate learning in meaningful, experiential learning activities, in which students learn by solving problems and reflecting on their experiences (Barrows & Tamblyn, 1980; Hmelo-Silver, 2004). Essentially, PBL is designed to help students develop competencies that will serve them throughout their professional lives. It is often claimed in the PBL literature that PBL develops cross-disciplinary knowledge that helps professionals expand their scope of knowledge and skills beyond the confines of their own professional disciplines. However, in PBL literature, the conditions which foster students to effectively cross disciplinary boundaries are scarce (Streichert, et al., 2005). The research study reported in this paper investigates how well an engineering PBL setting encouraged students to cross disciplinary boundaries.

1.1 Disciplinary knowledge

The term discipline is used to describe types of knowledge, expertise, skills, people, projects, communities, problems, challenges, studies, inquiry, approaches and research areas that are strongly associated with areas of study (academic disciplines) or areas of practice (professional disciplines) (Chettiparamb, 2007). A discipline can also be seen as a lens through which a phenomenon is examined in that each discipline affords different viewpoints and approaches as well as the obvious differences in subject matter (Moss, Osborn, & Kaufman, 2008). One impetus for the emergence of disciplines is the natural tendency of human beings to classify and conceptualise their surroundings.

The notion of a discipline suggests boundaries around a body of knowledge. But these boundaries are, to a degree, arbitrary and often more important to the academics who identify with that discipline than to practitioners who must necessarily cross disciplinary boundaries as they deal with messy real life problems in the 'swamp' of practice (Schön, 1983). For this reason, the emphasis in problem-based learning (PBL) on practice and on 'real life' professional problems means that crossing boundaries between academic disciplines is a characteristic of PBL. Many terms are used to describe when disciplines merge or the boundaries of existing disciplines are crossed. The most common are multi-disciplinary, inter-disciplinary and trans-disciplinary, arranged in order of increasing integration of disciplines, but in practice these terms are often used interchangeably. In this paper, we have chosen to use the less specific term 'cross-disciplinary', for reasons that we now explain.

1.2 Disciplinarity and engineering

In the engineering literature, the term 'discipline' often refers to the different specialties of engineering, i.e. civil, electrical, mechanical, chemical etc. The term 'cross-disciplinary' therefore mostly refers to a situation where knowledge from two or more of these engineering specialties is applied to solving a problem, but the degree of integration of disciplines may vary. But it may also be used when not only different engineering disciplines are involved but also disciplines outside of engineering, e.g. social sciences when an appreciation of the socio-political context of the problem is required (Cross-disciplinary Engineering Research Committee, 1986).

In this paper, however, disciplinary knowledge is defined as the knowledge and skills that undergraduate students make use of from subject areas such as electrical engineering, other engineering disciplines, mathematics, physics, computer programming, environmental science and business management. It therefore focuses less on the specialties of engineering ('macro-disciplines') than on the disciplinary building blocks of an undergraduate engineering course ('micro-disciplines'). Cross-disciplinary knowledge is defined as the application of knowledge across disciplinary boundaries while working on a problem or project. It makes no claim to the integration of the disciplines used but signifies the use by students of two or more disciplines when working on a problem in a PBL setting.

2 The study

This study is part of a broader qualitative study of learners in a PBL setting at Victoria University (Krishnan, 2009). The part of the study reported here is an investigation of how well this PBL setting encouraged students to cross disciplinary boundaries, i.e. how well they used knowledge from different micro-disciplines in working on engineering problems as a team in PBL. Fifty students and their PBL supervisors participated in this study. Eight student teams were observed and interviewed over two semesters. Work samples of eight randomly-selected students, in the form of individual portfolios submitted for assessment, were also collected from their teachers after they had been formally assessed (Krishnan, Vale, & Gabb, 2006).

Biggs and Collis (1982) described how a the growth in complexity of a learner's performance can be classified using the Structure of Observed Learning Outcomes (SOLO) taxonomy. They argued that, as students learn, the outcomes of their learning display similar stages of increasing structural complexity. They described quantitative (how much?) and qualitative (how well?) stages of learning as the amount of detail in the student's response increases and as that detail becomes integrated into a structural pattern (Biggs & Tang, 2007). The hierarchy of stages can be represented as the verbs in learning outcomes, through pre-structural (misses point), uni-structural (identify, do simple procedure), multi-structural (enumerate, describe, list, combine, do algorithms), relational (compare/contrast, explain causes, analyse, relate, apply) and extended abstract (theorise, generalise, hypothesise, reflect) stages. While Biggs and Collis (1982) designed the SOLO taxonomy to guide the assessment of learning within a single discipline, we found it a useful framework to guide the classification of cross-disciplinary learning as well.

As the SOLO taxonomy describes a hierarchy, where partial construction of knowledge becomes the foundation on which further learning is built, it was used to theorise the dimensions of students' disciplinary and cross-disciplinary knowledge as the basis of analysis. Of the levels of learning shown in Table 1, the multi-structural and relational levels seem to have some correspondence with multi-disciplinary and cross-disciplinary learning respectively.

Disciplines	Knowledge	Dimensions	Levels
• Electrical engineering • Other engineering • Mathematics • Physics • Computer programming • Environmental science • Business management	• What did they learn? • How did they apply their knowledge in that discipline? • How did they apply their knowledge across disciplines to solve problems?	• Content • Skill • Process	• Pre-structural • Uni-structural • Multi-structural • Relational • Extended abstract

Table 1: Levels of disciplinary and cross-disciplinary knowledge

2.1 PBL at Victoria University

The PBL curriculum was introduced in the School of Electrical Engineering in Semester 1, 2006. At the time of its introduction PBL units of study made up 50% of the course load in first year. Students worked in teams of about five members on three short problems in Semester 1 and a semester-long project in Semester 2. While the students produced a team report, they were only assessed on an individual portfolio of evidence that they submitted at the end of each semester. In the course material provided to students, the learning outcomes of the PBL units included team-working skills, technical skills, the use of a systems approach and an understanding of the principles of sustainable design and development (Stojcevski, 2006).

2.2 Data collection and analysis

Data collected from observations and interviews were transcribed and a combined description of the randomly-selected individual students and their PBL teams was developed. This data along with the data collected from student portfolios were analysed using bottom-up and top-down manual and computer-aided coding methods. The focus of the analysis for the part of the study reported here was to identify evidence of disciplinary learning and cross-disciplinary learning, i.e. what students learnt in each discipline, how they applied their knowledge of that discipline while working on problems as a team and how they integrated their knowledge of different disciplines when working on problems. Using SOLO as a guide, we analysed the content knowledge, the skills and the processes that students used individually and as a team while working on the problems. The findings were then categorised according to the SOLO levels as shown in Table 1.

3 Findings

3.1 Pre-structural and uni-structural levels – disciplinary knowledge

Students who simply acquire bits of unconnected information and make no overall sense of that information accomplish a pre-structural knowledge level. A uni-structural knowledge level is accomplished by students when they make simple connections. At this level students still do not understand the significance of the information that they gather (Biggs and Collis 1982).

From the analysis of data from the present study, it appeared that some students demonstrated knowledge of just one discipline at pre-structural and uni-structural levels. Perhaps this is all they needed to achieve, as some teams split the problems into tasks each of which was related to a single discipline and distributed the tasks between members of their team.

Some of these students reported that they found it hard to understand the problem and to make sense of the expected learning outcomes in PBL. A few others complained that the PBL environment did not encourage them to develop strong disciplinary knowledge. This could be attributed to deficiencies in the individual's prior knowledge, their poor understanding of the connection between different disciplines in PBL problems or their poor understanding of the expected learning outcomes in PBL. There were also some freeloaders in PBL teams who displayed very little knowledge of electrical engineering, computer programming, mathematics, physics or circuit theory when they were asked to explain their contribution to problem-solving during informal interviews.

3.2 Multi-structural level – multi-disciplinary knowledge

Biggs and Collis (1982) suggested that at a multi-structural level, students make a number of low-level connections between the information that they gather. However, they miss the meta-connections between them. Students with a multi-structural level of electrical engineering knowledge were able to demonstrate knowledge in two or more disciplines, for example knowledge of circuit theory and computer programming. For some, it appeared that their motivation to achieve high grades influenced this outcome.

Here too the way the team addressed their problems influenced the cross-disciplinary learning of team members. These students often worked on a number of tasks relating to different discipline areas and thus acquired knowledge in more than one disciplinary area. However, this did not mean that they saw the interconnections between individual tasks and the overall problem and often simply presented a mosaic of the individual contributions when completing their team report.

The following quote is a student account of her team's approach to solving one of the problems. Individual students in this team demonstrated specialist knowledge in the area of their own tasks, but failed to share their knowledge.

> Claire: Rod is doing the instrument part of it, I am doing the research and Damien is doing the battery… There is no reward for going the long way because you don't really learn a lot more. There is no real application for what we are doing. Technical side of it is fine but, doing the research is not really upping your skills. If we are doing solar panel for six months then fine. I have done all this research. I am not going to remember… there is so little space for research.

Claire reported that the main skills her team had developed were soldering, understanding of circuit components, testing of circuits and the technical language for project presentation. In general the members of her team had developed knowledge at a uni-structural level related to using electrical engineering equipment.

3.3 Relational level – disciplinary and cross-disciplinary knowledge

Biggs and Collis (1982) suggested that student knowledge increases in level of complexity to the relational level as they appreciate the significance of parts of information in relation to the whole. Our analysis suggested that only five out of the fifty student participants in this study demonstrated learning at the relational level in at least one discipline.

Most portfolios reported the list of tasks that individual members had carried out, mostly confined to a single discipline in each case. Some students reported reflecting on their initial designs and enhancing their solutions by constantly reviewing the outcome. This sometimes required them to cross disciplinary boundaries, as the following extract illustrates:

> After much analysis and deliberation, we have deduced that the main affliction effecting the Plenty Rd/Bell St intersection is the banking of traffic along both sides of the Plenty Rd intersection, causing significant traffic congestion. From our observations, we have concluded that the west side of the intersection is primarily responsible for this build-up of traffic. This is due to the amount of traffic flowing from the prior intersection not having ample time to get through.
>
> The following is a breakdown of our observations. There are two groups of cars, the first being that of Plenty/Bell and the second being that of the previous intersection. This is a hypothetical situation on an average day with mean traffic density…

> Thus we propose that a timing modification be made to better suit the two intersections and also increase in the timing on the west side of the Plenty Rd/Bell St intersection. This should be approximately 10-15 secs, when there is a higher traffic density. Therefore we suggest that there is also some sort of counting mechanism spanning the two intersections involved…

The leader of another team consistently demonstrated relational level learning and also ensured that the learning of his team members crossed disciplinary boundaries. He ensured that all team members engaged in various tasks such as programming, designing electronic circuits from scratch and using Boolean algebra to analyse the behaviour of digital circuits. It appeared that most students in this team not only developed knowledge in the disciplines that were relevant to their individual tasks but also formed an adequate understanding of the relevant areas in the other disciplines involved. For this reason it was concluded that most team members achieved learning at the relational level that crossed disciplinary boundaries. The following extract illustrates this:

> Jeff: We met on Friday [unsupervised] which was good; I started to explain a circuit diagram and asked if they can share theirs if they have any. Yasar did not come to the meeting. Cathy and I had a couple of ideas. We then went to [specialist teacher] and said that we understand this, but can't get past this one. He [specialist teacher] put it all together and helped us to simplify the idea. So we now have one main counter, 3 bit. Each bit represents a phase. So there will be 6 phases.
>
> Cathy: It was supposed to be a collection of AND and OR gates. But then we decided to go a bit more in depth, you know complex.
>
> (Students soon started a discussion between themselves. Supervisor enters the PBL studio. Students acknowledged the supervisor and continued their discussion.)
>
> Jeff: You are right [said to Cathy], when one of the phases gets called, it will send a signal to the main counter. It happened in the PSPICE simulation. And then using different phases the light transition will change.
>
> Supervisor: What are these circuit diagrams, guys? Where did you get these from? Internet or books? (Supervisor asks about the circuit diagrams on the whiteboard)
>
> Jeff: Cathy and I made them on PSPICE simulator and it works.
>
> Cathy: We did not use the internet. I was sitting in a dark room for a very long time and used the knowledge from the digital lectures and the notes from [Teacher] after last lecture.
>
> Jeff: We got the idea of using a 256 bit counter instead of using a 4X4 counter. We figured that out from the K-map.

Although not all of the students in this team displayed relational learning in all disciplinary areas, they all appeared to understand the relevance of different disciplinary areas that they were asked to explore and its application to the problem. Much of this could be attributed to the team leader, who took responsibility for ensuring that individual learning was shared with the group.

4 Discussion and conclusion

There is little evidence that these students developed disciplinary knowledge at a relational level. There was even less evidence that individual students crossed disciplinary boundaries in working on problems in this PBL setting. Indeed, most of the students only acquired the knowledge that was relevant to a particular task that they picked, and this was typically uni-structural, or at best multi-structural, learning in a single discipline. Moreover, it appeared that they either did not fully appreciate the relationship between the learning involved in their task and the main problem or did not value the learning related to the tasks of other members in their team.

The extent to which the students crossed disciplinary boundaries in this engineering PBL setting was strongly influenced by how they engaged with the problems as individuals and as teams. Therefore teachers need to monitor and, if needs be, actively intervene in what occurs in unsupervised team meetings, as teams spend a significant amount of time learning unsupervised in most implementations of PBL in engineering, including the model reported in this study.

We found that only one team engaged in collaborative learning and appreciated the significance of sharing the learning of individuals both in solving the problem and in maximising learning by all team members. This also led to team members crossing disciplinary boundaries as their learning was not entirely task-focused. The challenge for PBL designers and practitioners is to realise this potential in all or most teams.

If we want our students to learn beyond the discipline then we need to encourage them to cross disciplinary boundaries. That is, we need to incorporate strategies that encourage students to value the integration of knowledge from different disciplines while they are solving problems. We first need to design problems that can only be satisfactorily solved when students put their knowledge of two or more disciplines to work. Secondly, because assessment drives most student learning, we also need to design assessment tasks and criteria that recognise and reward not only relational learning but also the integration of knowledge across disciplinary boundaries. The flip side of this is that assessment should not reward students who present a pastiche of evidence demonstrating low-level learning in a single discipline by several individuals as if it were the product of high-level collaborative learning that crosses disciplinary boundaries. As academics, we may ourselves be prisoners of our disciplines in many ways but that is not a good reason for encouraging the future practitioners who are our students to also become discipline-bound.

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