How does Problem Based Learning fit with Cognitive Load Theory?

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Abstract

This paper reports on an investigation with first year undergraduate Product Design and Management students within a School of Engineering. The students at the time of this investigation had studied fundamental engineering science and mathematics for one semester. The students were given an open ended, ill formed problem which involved designing a simple bridge to cross a river. They were given a talk on problem solving and given a rubric to follow, if they chose to do so. They were not given any formulae or procedures needed in order to resolve the problem.

In theory, they possessed the knowledge to ask the right questions in order to make assumptions but, in practice, it turned out they were unable to link their a priori knowledge to resolve this problem. They were able to solve simple beam problems when given closed questions. The results show they were unable to visualise a simple bridge as an augmented beam problem and ask pertinent questions and hence formulate appropriate assumptions in order to offer resolutions.

Introduction

The majority of learners come to university with predominantly procedural knowledge, they know how to apply a procedure to a set of variables and constants and obtain a result but with little understanding of what the result implies or means. They do not seem to possess the conceptual knowledge necessary to be able to make assumptions or an informed judgement as to how sensible their result is or indeed be able to interpret the outcome. This is not surprising since in the UK education system, schools are judged on their academic performance by a regime of league tables. The learners at level three of the NQF (National Qualifications Framework) are mainly assessed via formal examinations which predominantly assess knowledge and skills. In the consultation on the new A level regulatory requirements, OFQUAL (Office of Qualifications and Examinations Regulation) deemed assessment via coursework as unreliable (OFQUAL, 2013). One of the major challenges facing university engineering schools is to enhance this procedural knowledge into conceptual knowledge and to develop the skills required by a contemporary engineer. The vast majority, if not all, undergraduate engineering programmes feature a project, group or individual, as a final year module. In this restricted form of PBL (Problem Based Learning), learners are in some cases, given a teacher-selected problem which is based upon the learners’ a priori knowledge and skills (Heitman, 1996). Although this approach embraces the notion of problem solving learning, it represents a small fraction of the curriculum, is time restricted and contrived and cannot be accurately described as PBL. In order to fully develop the knowledge and skills required by a professional engineer, a more holistic and curriculum wide approach is necessary.

Problem Based Learning

For the purposes of this paper, PBL is defined as ‘Problem Based learning for professional action according to Savin-B (Savin-Baden, 2000)aden (2000, 2007). This model emphasises the important point that PBL is a combination of a learning methodology, knowledge construction and scientific approach (Kolmos, et al., 2009). It defines knowledge as ‘know-how’, learning is for the workplace, real life problems are used with the students solving these problems in order to undertake practical action. The facilitator acts as a
demonstrator of practical skills with assessment taking the form of assessing skills for the workplace and the necessary supporting knowledge.

In order for learners to be effective problem solvers they must be able to make sensible assumptions, be comfortable with the notion of resolutions and be prepared to adopt trial and improvement techniques. In addition to these skills the students must also be knowledgeable, confident and competent within the subject disciplines.

One fundamental question is how are knowledge and skills organised within the human cognitive system? One model suggested by Skemp (1986) and Sfard (1991) is the idea of schemata. A schema is defined to be how thought processes and the relationship between them are organised. For example, an arithmetic schema would involve a grammar (the rules) and a lexicon (the symbols) and how they interact.

Schemata construction is a process that starts from birth. They are constructed in order for us to acquire language, make sense of the world we live in and to survive. They provide a mechanism for working short term memory to have fast access to processes and knowledge stored in long term memory. This is an efficient way of accessing processes and knowledge since working short term memory can only deal with, approximately, seven items at a time. In terms of mathematics, schemata are created for arithmetic, fundamental algebra, solving simple equations etc. These schemata form the basis on which the learner interprets and makes sense of mathematical procedures. It is vital at this stage the fundamental aspects of mathematics are correctly learnt since it is extremely difficult to ‘unlearn’ a schema at a later stage (Skemp, 1986).

The knowledge and skills learners bring with them to university are at best incomplete and tend to be procedural in nature. The language used and the complexity of mathematics studied at level 3 NQF (National Qualifications Framework) is designed to be appropriate for that stage of the learners’ education. In order to move towards a more conceptual knowledge base, these schemata need to be enhanced to accommodate more precise language and definitions. They also need to be enhanced in order for students to begin to understand the basis from which the procedures they apply are formulated so they can apply them to novel situations.

The next stage in the learner’s journey towards competency and proficiency in problem solving is to bind the existing enhanced schemata with schemata from different domains. For example, vector calculus relies upon the calculus, knowledge of vectors, coordinate systems. The hierarchical nature of mathematics and the way it which it becomes more abstract, means that as the learner progresses, mathematics becomes more powerful but harder to learn. Therefore if the existing schemata are not resilient, the learners’ will demonstrate their inability to apply and interpret these higher order procedures but, in actual fact, the difficulty could lie with the knowledge and skills the learner is assumed to have from a previous stage.

To complete their journey, learners needs to be nurtured to look beyond their particular field and recognise the resolutions they require to solve problems, could exist in a different discipline. It is also important they have schemata in place to deal with open ended, ill formed problems. In addition to the technical schemata, engineering undergraduates also need to acquire skills in leadership, team working and industrial practice.

**Cognitive Load Theory**

CLT is premised on five principles: The information store principle, the borrowing and reorganising principle, the randomness as genesis principle, the narrow limits of change principle and the environment and linking principle (Sweller, 2010). The information store principle states that long term memory is central to human cognition. It is not only a repository of facts but also it is where, for example, problem
The construction and automation of schemata does not generate new information. It essentially allows communication and the combination of facts. In order to create new information, the problem solving and the randomness as genesis principle states the random generation of resolutions to a problem followed by tests of effectiveness is how this phenomenon occurs. The information held in long term memory can indicate potential resolutions, provided the learner has encountered similar problems before but in a totally novel situation, the learner has to adopt a ‘trial and improvement’ approach where a potential resolution is tried, tested for effectiveness and adopted if successful but discarded if not. This procedure of testing for effectiveness and how it fits with a learner’s existing schema also applies to the borrowing and reorganising principle. If the new information is deemed to be beneficial, existing schemata are updated and if deemed to be non-beneficial, discarded. In this sense, the contextualisation of information increases the probability the learner will see the ‘usefulness’ of the new information and consequently update their existing schemata.

A consequence of the randomness as genesis principle and the borrowing and reorganising principle is alterations to existing schemata must be incremental to avoid information overload. It is very easy to introduce a plethora of new ideas in a learning session which results in the learner’s cognitive system becoming overloaded and existing schemata being destroyed. Short-term working memory is capable of processing approximately seven items of information (Millar, 1956). To test the effectiveness of, say, four elements results in 24 possible permutations to test, but if ten items are presented, 3,628,800 permutations require testing, which is beyond the scope of short-term working memory capabilities (Sweller, 2010).

The environment organising and linking principle offers an explanation why experts can process large amounts of information. This principle suggests that, providing information is organised into schemata in long-term memory, experts are able to transfer asematically the necessary schema to solve a problem within their particular environment.

The Participants
The students who participated in this investigation were first year undergraduate product design and management students. A typical qualification profile was: A levels in Product Design, Humanities subjects and rarely Mathematics or Physics. Prior to the investigation the students had studied Mathematics and Engineering Science for one teaching period. These lessons covered such topics as resolutions of forces, beams, algebra and solving equations.

The Investigation.
The participants were given an open-ended, ill-formed problem which focussed on them designing a simple bridge to ford a river. The only information they were given concerned the width of the river and the height of its banks. They were also given a talk about using a problem solving rubric. They were not instructed on
any formulae they would need or how to go about resolving the problem. The participants were asked to work in pairs and the investigation ran for three sessions.

The Task
An outward bound company has set up a new campsite for young people in the Brecon Beacons National Park. There is a river running through the site which effectively separates the main camp site from the cook house. The river is 3m wide and the mean height of the river bank is 1m. During periods of heavy rain the river can overflow the banks. The management team have decided that they need to build a safe, simple bridge at minimal cost which would enable the young people to access the cook house all year round. Your task is to investigate and report back to the management team how you would resolve this issue. You will need to investigate resolutions which incorporate different designs and recommend a solution which is cost effective and fit for purpose.

Problem solving rubric

Exploring the problem:
1. What information is given by the problem?
2. What is the problem asking me?
3. Is there additional information I need to get started?

Resolving the problem
1. Have I resolved a similar problem before?
2. Do I know the mathematics to solve this problem?
3. What assumptions, if any, do I have to make?
4. Can the problem be broken down into smaller, more manageable problems?
5. Can the problem be looked at from a different perspective?

Reviewing my resolution
1. Is my resolution acceptable?
2. What have I learned from the resolution?
3. Could I use this resolution to resolve other problems?

Discussion of results
It was evident from the start of the investigation that the students found it extremely difficult to form assumptions. They had studied the loading of beams and Newton’s third law but seemed unable to apply this knowledge to the problem in front of them. They also seemed incapable of simplifying the problem to that of a ‘plank of wood joining the two banks’ even though the problem solving rubric asked the question, ‘have I resolved a similar problem before’. The students sketched bridges based on their conceptions of what a bridge should look like and seemed to have missed the affordance a bridge offers. After listening in on the group discussions, the investigator decided to intervene by initiating a class discussion on the nature of bridges which led to a discussion of the mathematics and engineering science required to offer an initial resolution.

In the second session many of the students had adopted, as a starting point, a wooden beam laid between the two banks. They proceeded to identify and signify the forces acting upon their bridge. Although they had correctly identified the forces they were unable to proceed since they had not considered factors which would influence the design and loading of their bridge. Once more a group discussion ensued which
considered assumptions on the loading model for the bridge ie. Should a point or distributed load be considered. This initial discussion led to considering the weight the bridge would have to support which meant having to make an assumption of the number of people who would use the bridge at any one time. The final factor discussed was the amount of flexion that was permissible of the platform to make walking comfortable and safe.

The final session of this investigation should have been where the students performed the necessary calculations in order to decide on the materials they would use and the dimensions of their bridge. Again, after listening in on the group discussions and in order for them to proceed, the investigator decided to initiate a class discussion. They were shown formulae needed to calculate the loading and flexion of their bridges. It was evident from their reaction that they could not interpret, what they perceived to be extremely complicated formulae. For example, they were shown the formula for a distributed load and had to be guided through its interpretation.

By the end of this final session, none of the groups had been able to offer a reasonable resolution.

Conclusions
Since its emergence at McMasters University (Woods, 1994), PBL (Problem Based Learning) has had mixed responses. Many advocate its benefits in terms of education, yet others report of little benefit to learners (Van Barneveld & Strobel, 2009). In fact, there is very little evidence in general for ‘constructivist’ based approaches, to support the notion of an increase in student knowledge (Kirscher, et al., 2006). If the principle aim for introducing PBL is to increase student knowledge, then Savin-Baden’s model 1: ‘Problem based learning for epistemological competence’ (2007) would be more appropriate, but if the aim is to equip students with the knowledge and skills required by many modern industries, then the model used in this investigation (Model II: Problem-based learning for professional action’) is appropriate with the caveat a way has to be found to provide the students with the necessary technical knowledge and skills to support their problem solving activities.

Although this was a small scale study and could possibly be more accurately described as problem solving learning using an open-ended, ill formed problem, the results do indicate a disconnect between theory and practice. Although the students, theoretically, had the a priori knowledge and skills, they were unable to form an overarching schema incorporating the technical knowledge and problem solving skills. All the way through the investigation, they were expecting to be given the mathematics and engineering science required to present a resolution. In terms of Cognitive Load Theory their behaviour can be characterised as having a number of disjoint schemata which have been learnt during lessons; evidenced by the fact they were able to solve typical closed, well formed problems. They did not possess the confidence to adopt a trial and improvement approach (randomness as genesis principle) and subsequently were at a loss as to how to even begin to offer a resolution. Although, in principle like many learning philosophies, Problem Based Learning does meet the needs of contemporary engineers, there needs to be a clear and well-articulated reason for introducing it into the curriculum and its implementation requires careful and detailed planning.
References


