Improving Problem Solving and Encouraging Creativity in Engineering Undergraduates

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***Abstract* – Many researchers have written about the importance and complexities of developing problem solving skills and encouraging creativity in engineering students. This paper provides a brief summary of some of the previous work, and sets an agenda for a research project to revisit the area using learning objects to improve and encourage these skills. Some interesting initial findings and thoughts are presented which support previous work, and open the way for the next stages of the research project.**

Index Terms – Problem Solving, Creativity, Learning Styles, Learning Objects

INTRODUCTION

Probably one of the most, if not *the* most important skill an engineer must possess is that of problem solving. Another desirable, but not always developed or encouraged skill in engineering students is that of being able to think creatively.

The teaching of problem solving in engineering is highlighted in many texts, for example Wankat and Oreovicz [1] suggest that engineering education focuses heavily on problem solving skills, but that lecturers and professors concentrate on teaching content rather than showing the processes involved in problem solving. Houghton [2] proposes that problem solving is 'what engineers do'. He contends that problem-solving skills may be the most important thing we can teach our students.

It is possible to identify, from both anecdotal sources and more defined evidence that deficiencies continue to exist in the teaching of problem solving skills to engineering students [3] – [5].

The development of problem solving and creativity skills in the classroom can be enabled through Enquiry Based Learning (EBL) and Problem Based Learning (PBL), which although not new are currently popular research areas [6].

Studies based on cognitive theory and psychological type indicators suggest, however, that engineering students tend to differ in their learning styles and problem solving methods compared with students from other disciplines [7] – [9].

Enquiry Based Learning and Problem Based Learning are defined as a 'component method' under the umbrella of Instructional Design (also termed Learning Design) [10]. Instructional Design is also considered as one mechanism for the operationalisation of cognitive teaching and learning theories such as those addressing problem solving and creativity [11]. Interestingly, Instructional Design methods lend themselves to the application of Learning Objects – a relatively new and developing research area [12].

Whilst Learning Objects are generally employed as 'content chunks', learning theorists are pushing for their use in case-based problem solving scenarios. When learning is in the context of problem solving then Learning Objects change from info-capsules into semiotic tools to mediate and shape the learners actions. The 'tool' aspect of Learning Objects in their mediation of problem solving remains an area which is almost completely unexplored [11].

It follows that skills developed at undergraduate level, such as being able to effectively problem solve or devise creative solutions, can be usefully transferred to other situations. These skills can be applied to other learning situations, and are also desirable skills when entering the employment market. Research into how knowledge or skills developed in instructional environments can be transferred to working or daily life is currently topical [13].

This research will address how the development of problem solving skills and the application of creativity in undergraduate engineering education differ compared with other disciplines and domains. It will then attempt to improve these skills using a Learning Object simulation in which Learning Objects will be used as a mediation tool. The transfer of these skills to other situations including professional practice will also be considered.

COGNITIVE SCIENCE AND PROBLEM SOLVING

Cognitive science and cognitive learning theories play an important role in our understanding of the mechanism of problem solving and the application of creativity in humans.

Studies and experiments carried out by Piaget in the early 1900's show that our ability to solve problems, albeit simple ones, begins to develop as early as 2 years of age [14]. These actions develop and become internalised up to about the age of 12 years. Piaget terms this development *operational thinking*. His studies of schoolchildren also observed subjects such as mathematics and science which

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require accommodation of things such as symbolic notation alongside creative activities where these accommodations could be externalised in different forms and contexts [15]. He suggests the need to find expressive or creative situations which are linked to, and run parallel with, activities requiring accommodation (e.g. mathematics with pattern making, geography with model making etc.).

Bruner supports Piaget's theories and suggests that any subject can be taught in some honest form (meaning simplified but not incorrect) at any age, and that the curricula for this should be something of which society deems worthy. He terms this recursive approach to teaching and learning and the development of cognitive skills, such as problem solving, the spiral curriculum. Bruner was an early proponent of the use of cognitive theory as the preferred basis for formulating Instructional Design [16].

Bloom developed a taxonomy that is widely used to categorise types of educational objectives for the cognitive domain [17]. His work has become the common language for educators, and a standard for classifying educational objectives. The higher level cognitive skills of analysis, synthesis and evaluation are relevant to our ability to effectively solve problems. The effective development of these skills, however, requires mediation.

Both Gagne and Tennyson have incorporated cognitive theory in their models for the conceptualisation of Instructional Design [18] – [19]. Both provide taxonomies on learning and thinking processes, including problem solving. Cox further supports cognitive science to produce guidance on improving problem solving education in chemical engineering students through the analysis of different types of problem (e.g. well and ill structured) [20].

LEARNING STYLES AND PSYCHOLOGICAL TYPES

The area of psychological types and their effects on a student's ability to learn and the teaching styles employed is not a new area, and has many supporters and critics.

Research undertaken during the late 70's to mid 80's by McCaulley, Godleski and Stice [7] – [9], plus others, showed that psychological types have implications for both the learning styles of students and consequently effectiveness of the teaching styles employed.

Much work already exists on the use of psychological type indicators, particularly those of Myers-Briggs based on Jung's work and Honey and Mumford, and their relevance to everyday activities. There are many other indicators in existence, which have recently been critically appraised in terms of their educational value by Coffield [21].

McCaulley [7] links this work on type indicators in its general sense to the implications for teaching engineering students. This is further developed to critical thinking and problem solving abilities by Stice [9], although not to engineering students in particular. A recent article by Fleming and Baume [22] revisits learning styles in general through an on-line self assessment process called VARK.

Supporters and critics of learning styles alike argue that they should be used with caution in order to avoid the potential of stereotyping students with a particular type, and that type may change with situation and time. They do, however, seem to have potential use in developing self awareness, which is of particular use to this research [23].

It follows that if cognitive science (including learning styles and psychological types) can be applied, adapted or developed to our understanding of problem solving or creativity in engineering students, then it may be possible to operationalise this through Instructional Design and hence through the application of Learning Objects. This hypothesis forms a basis for this research.

TEACHING PROBLEM SOLVING

It is argued by many commentators that the emphasis on problem solving in engineering is seen as the product of the problem solving exercise, rather than the process by which the solution or solutions are determined [24]. It is also argued that engineering educators tend to focus on teaching content rather than method [1].

The teaching of problem solving offers challenges in the areas of strategy and method. It is often debated whether the teaching of problem solving strategy should be integrated into subject modules, taught alongside these modules, or even taught separately. There are a host of different strategies for problem solving, which have been reviewed in detail by Woods [25]. Woods' own method, which is similar to that of Polya [26] but with one additional step (step 2), considers problem solving as a five stage process:

1. Define the problem
2. Think about it
3. Plan
4. Carry out the plan
5. Look back

Teaching process in the classroom can be achieved in a number of ways. One method is Thinking Aloud Pairs Problem Solving (TAPPS), where there is a problem solver and a listener. There are many other techniques, which cannot be explored in this short paper.

ENCOURAGING CREATIVITY

Excellence in engineering problem solving is synonymous with skill at convergent production; since engineering education normally involves only problems with a single correct answer. However, this is not particularly true of engineering practice in general.

So, can creativity be taught in the classroom? Felder [27] proposes that creativity is an ability that we must exercise and augment in our students through a suitable environment and using effective exercises. These exercises should encourage creative thinking by having divergent (multiple) solutions, or potentially no solution at all. He also advocates the use of open-ended questions, where students have to define what they need to solve the problem, and the use of brainstorming where students are encouraged to think of as many ways to achieve a specific task.

The development of problem solving skills, and the encouragement of creativity in the classroom shows a clear link with the philosophies of Problem Based and Enquiry Based Learning (PBL/EBL).

PROBLEM BASED LEARNING AND INSTRUCTIONAL DESIGN

One mechanism for developing problem solving skills in the classroom is the use of Problem Based Learning (PBL) exercises. These are described as a 'component method' under the umbrella of Instructional Design.

In PBL the handling of a problem drives the whole learning of the student [28] – [30]. The curriculum is structured as a series of problems as opposed to a systematic presentation of subject content. An extension of this is EBL which, although incorporating elements of PBL also covers a broader spectrum of approaches including small-scale investigations and project work.

It is acknowledged, however, that while problem based learning can be used to develop problem solving skills, other interventions are required to make this effective [31]. In order to be effective, students should have some problem solving skills before entering a PBL programme, and PBL offers the opportunity to develop and refine these skills but with some intervention or mediation. Felder, proposes that PBL exercises can also be used to develop creativity [32].

Instructional Design and Learning Design Theories are design-orientated, and can be considered as one approach to the operationalisation of cognitive education and strategies. They are concerned with providing guidelines for which instructional methods and models to use in which situation or context [10], [18], [19], [33] - [34]. The methods are probabilistic – meaning that they might not always produce the desired results. Values play an important part, and this relates to both the goals which the theories pursue and the methods to achieve the goals. Reigeluth [10] argues that this is a "New Paradigm" moving from the Industrial Age of standardisation, compliance and conformity to the "Information Age" of customisation, initiative and diversity.

From an educational perspective models or simulations developed as part of Instructional Design or Learning Design (such as those that utilise Enquiry/Problem Based Learning exercises) lend themselves to the application of Learning Objects [34] – [35].

LEARNING OBJECTS

Learning Objects, and in particular their reusability, is a relatively new concept in teaching and learning, and application and research in this area is growing rapidly [12].

We must begin with a basic understating of the concept of Learning Objects. One working definition is:

> Learning Objects are defined [here] as any entity, digital or non-digital which can be used, re-used or referenced during technology supported learning. Examples of Learning Objects include multimedia content, instructional content, learning objectives, instructional software and software tools, and persons, organisations or events referenced during technology supported learning [36].

Two metaphors presented by Wiley [37] liken Learning Objects in a simplistic model to pieces of Lego and in a more developed model as an Atom.

Other concepts relating to Learning Objects such as granularity, interoperability, design, rights and ownership and metadata (as a means of cataloguing and sequencing) are discussed at www.reusablelearning.org. Many of these issues are considered by an emerging set of international standards [32], [38] – [39].

Despite their promise of offering rapid course development and customised curricula, the uptake of Learning Objects until recently has been slow. Hartnett [40] speculates that the idea of using Reusable Learning Objects (i.e. Learning Objects that can be used and reused in different contexts) is a myth perpetuated by the software developers of Learning Management Systems. He goes on to say that a box of Lego without anyone to put them together sensibly is practically useless. Likewise, a system that can automatically put these together and sequence them needs to be extremely sophisticated.

Current subject-based applications and research of Learning Objects in the UK seem limited to areas such as sociology, geography, computer science, health and healthcare, statistics, and some general key skills [41] – [42].

Whilst Learning Objects are generally employed as 'content chunks', learning theorists are pushing for their use in case-based problem solving scenarios, such as those developed for EBL/PBL.

It is this aspect of Learning Objects in the context of mediating problem solving and developing creativity in undergraduate engineering students that forms the originality of this research.

THE RESEARCH PROJECT

In summary, the overall aims of this research project are to improve problem solving skills and to develop and encourage creativity in first year undergraduate engineering students. The objectives are:

1. A critical appraisal of how problem solving and creativity in engineering differs from other disciplines, supported by:
    - An evaluation of how problem solving skills are currently taught and developed at first year undergraduate level.
    - An evaluation of how, if at all, creativity is developed and encouraged in these students.
    - An investigation of how professional engineers differ in their approach to problem solving and application of creativity as compared to novice students.
    - An investigation of how professional engineers believe that teaching of problem solving and developing creativity at undergraduate level can be improved.

2. A critical appraisal of how problem solving and creativity in engineering aligns with cognitive science, learning styles and instructional design theories.

3. A critical evaluation of the application of Learning Objects as mediation tools in the development of a simulation to support problem solving and the development of creativity in undergraduate engineering students. This is to be achieved through action research [43] – [44].

4. A critical evaluation of the potential for transfer of problem solving and creativity skills developed in engineering undergraduates to other situations (such as employment), informed by discussion with practicing professional engineers.

EARLY FINDINGS

At the time of writing, the following aspects of this research project have been undertaken:

1. A pilot study of psychological types across faculties at The University of Northampton.
2. A wide scale web-based questionnaire to all UK Higher Education establishments that offer engineering to determine views on the teaching of problem solving and creativity.
3. A series of taped and transcribed interviews with practicing professional engineers to determine views on problem solving skills and creativity in the professional workplace.

1. Psychological Types

Figure 1 shows a summary of results of a survey of first year undergraduates from various subject disciplines. These are engineering, computing, product design and fine art. Each mark in the table indicates the type preferences for an individual student.

The psychological indicator test used was a modified Myers-Briggs (Jung) test developed by Pelley [45].

The interaction of two, three or four type preferences are known as *type dynamics*, and when dealing with a four-preference combination this is called a *type*. In total, there are 16 unique types, and many more two or three letter combinations. It is not possible within this paper to provide a detailed interpretation of each type, and many descriptions exist on the Internet.

Interestingly, and without full or detailed analysis here, the results tend to show engineering students as type TJ (Thinking/Judging) and fine art students as FP (Feeling/Perceiving). Product design students tend to fall somewhere between the two, while computing students are similar to engineering students apart from showing more introversion. This supports and confirms the earlier work of McCaulley, Godleski and Stice [7] – [9].

What must be noted, however, is that these findings are a snapshot in time and place, and may not necessarily reflect a students 'type' under different circumstances.

	ES	**EN**	**IN**	**IS**
TJ	XXXXXX +	XXX ++ *	XX +	XXXX +++++ %
TP	XXX ++ **** %	X ++ * %	+ **	++
FP	X %%	XX + %%%%%	XXX %	
FJ	++ %	** %%%%	%%%	X

X	Engineering		**E**xtravert	**I**ntrovert
+	Computing		**S**ensing	i**N**tuition
*	Product Design		**T**hinking	**F**eeling
%	Fine Art		**J**udging	**P**erceiving

FIGURE 1
SUMMARY OF PSYCHOLOGICAL TYPES ACROSS FACULTIES

This area will be further developed as part of the research project, with a cross-institutional initiative to include students from other science and engineering based disciplines.

2. UK Higher Education Institution Questionnaire

Early findings from an on-line survey (return rate 20%) of staff in engineering departments at UK Higher Education establishments regarding the teaching of problem solving and creativity shows:

- That all thought that problem solving and creativity were important attributes for engineering undergraduates.
- That there was a 50%/50% split on whether problem solving should be simply allowed to developed, or taught and developed.
- That there was a 50%/50% split on whether problem solving should be integrated into subject modules, or integrated and taught separately.
- That there was a 50%/50% split on whether creativity should be integrated into subject modules, or integrated and taught separately.
- That almost all had heard of learning objects.
- That almost all thought that learning objects might me useful for course development.
- That almost all thought that learning objects might be useful for skills development, such as problem solving.

3. Interviews with professional engineers

Following six semi-structured interviews with professional engineers, the following common themes regarding problem solving and creativity were evident:

- That problem solving involved a systematic process, and that experience was only part of this process.
- That being confident and willing to take risks was an essential element.
- That discussing others (i.e. informal discussion, brainstorming and teamwork) often aided the problem solving and creativity process.
- That having time to pause and reflect was essential.
- That reflecting on past experience was useful.
- That most did not identify with being creative, but believed that this was a somewhat inbuilt attribute that could be developed and encouraged.

CONCLUSION

It is clearly evident that the ability to solve problems is an essential attribute for an engineer, and one that should be developed, by whatever means, to the full potential in engineering undergraduates.

Whilst it is difficult to qualify if it is even possible to teach creativity, it is certainly a quality that should be encouraged in engineering undergraduates through the use of suitable classroom exercises and self reflection and awareness.

This research project will continue to explore these issues with engineering undergraduates through their involvement in an action research study, and to ascertain the potential of using learning objects to achieve this.

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