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The discovery laboratory – A student-centred experiential learning practical: Part I – Overview

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ABSTRACT

Chemical Engineering's Discovery Laboratory at Imperial College London is a practical teaching programme designed specifically to support student-centred learning at an advanced level, bridging the gap between instructions driven lab experiments and fully open ended research. In the first part of this article we present an overview of this programme with particular attention given to the design of the pedagogical framework and the execution of teaching. The teaching goal is delivered by in-depth experiential learning, where students are assigned a specific subject area to conduct their own research within a set timeframe and boundary conditions that guarantee a successful learning outcome. Academic supervisors and teaching assistants play an important role in this process, where they provide students with continuing guidance throughout. The use of research or industrial grade equipment ensures the students' preparation for their final year research project as well as their post-graduation careers. In addition to summative assessments, students also receive formative feedback periodically from academic supervisors and teaching assistants. The Discovery Laboratory has received positive feedback from both teachers and students since its inauguration in 2011 and here we share some useful insights for the execution of such a practical teaching programme.

1. Introduction

Two decades ago, the shift from the traditional Instruction Paradigm to the Learning Paradigm was advocated in the higher education community (Barr and Tagg, 1995). Six dimensions of these paradigms were outlined clearly:

(1) mission and purpose;
(2) criteria for success;
(3) teaching/learning structures;
(4) learning theory;
(5) productivity/funding;
(6) nature of roles.

Since then, educators across the globe have answered the call for this paradigm shift through the adoption of various learner-centred approaches in higher education (Webber, 2012).

The importance of such a paradigm shift in teaching has also been recognised by various official bodies. For example, the European Association for Quality Assurance in Higher Education (ENQA) has published standards that emphasise the importance of student-centred learning, teaching and assessment in higher education by outlining specific standards on this issue (European Association for Quality Assurance in Higher Education (ENQA) et al., 2015). In essence, the Learning Paradigm aims to encourage students to be active learners by designing and executing their own educational activities accordingly.

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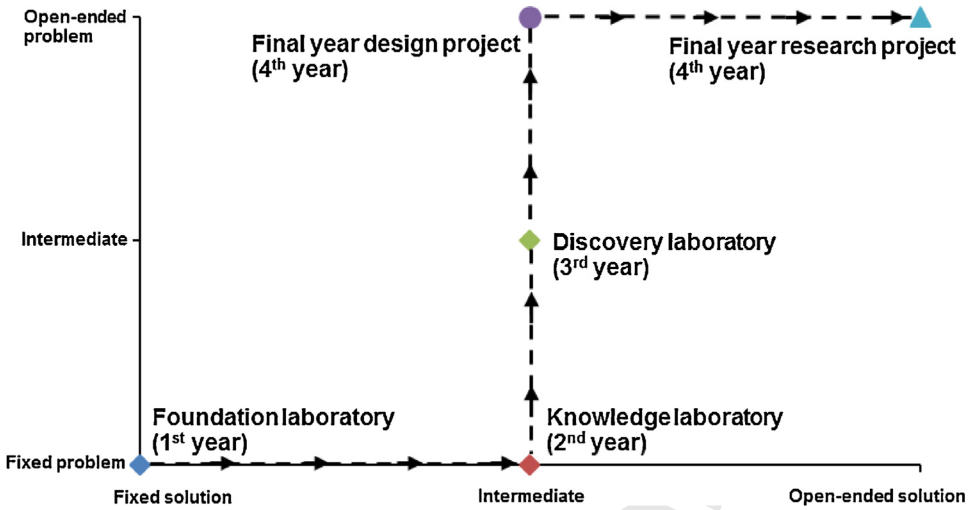

Fig. 1 – Problem-based learning opportunity for chemical engineering students.

In practical disciplines such as chemical engineering, this educational goal can be delivered by the problem-based learning (PBL) approach, which "empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem" (Savery, 2015). There is solid evidence to show that the PBL approach is effective in enhancing the learning of students in the engineering and medical disciplines (Tiwari et al., 2006; Walker and Leary, 2009; Yadav et al., 2011). In the context of chemical engineering education, several PBL modules have been designed and reported in the literature (Woods, 1996; Woods et al., 1997; Cline and Powers, 1997; Gossage et al., 2001). At McMaster University, the PBL module consisted of 120-hour workshops that helped students to develop 37 problem-solving skills and apply them to chemical engineering and daily life (Woods, 1996; Woods et al., 1997). At Carnegie Mellon University, the PBL module was laboratory-based and was designed around open-ended problems that were provided by local companies (Cline and Powers, 1997), whereas the PBL modules at Lamar University relied on computer-aided modelling and simulation (CAMS) (Gossage et al., 2001).

The chemical engineering department at Imperial College London invested £9 million in 2010–11 into the ChemEng Discovery Space, a set of facilities for undergraduates to explore different subjects in their curriculum. For instance, the new teaching laboratory has over 30 major pieces of industrial grade equipment to support various teaching activities, covering subjects ranging from particle engineering to membrane separation. Learning from the best practices of PBL modules in chemical engineering education (Woods, 1996; Woods et al., 1997; Cline and Powers, 1997; Gossage et al., 2001), the practical undergraduate curriculum in our department was designed by teaching staff with significant experience in industry, secondary and higher education with input from academic researchers. This ensures that the designed programme is academically and pedagogically stimulating as well as practically relevant. Receiving direct coaching from experts in a particular subject area, students can optimise their learning outcomes following their own individual interests.

2. Course context – module design with the end in mind

The hands-on learning opportunities offered in the department serve to prepare the students for their final year design and research projects, which challenge them with solving open-ended real-world problems (Fig. 1). Students undertake these practical learning opportunities in the undergraduate teaching laboratories in three different stages as they progress in their undergraduate studies: Foundation Laboratory, Knowledge Laboratory and Discovery Laboratory.

In the Foundation Laboratory, first-year undergraduate students are introduced to the laboratory environment, where they learn to perform experiments by following specific procedures precisely and safely, and to record and report data in a professional fashion. All foundation experiments present students with a *fixed problem* for which they have to determine a *fixed solution*. Lab hand-outs provide step-by-step instructions on how to execute a safety assessed experimental plan, what variables to measure at what time interval, and how to analyse the data as well as estimate experimental error. A combination of lab briefings, detailed hand-outs, and in session support by the module leader and graduate teaching assistants (GTAs) facilitates the development of hands-on competency. In the second year, students move up to the Knowledge Laboratory. All experiments in the Knowledge Laboratory introduce students to experimental objectives when investigating a *fixed problem*, which they can choose to solve through different experimental routes. Here, students are given *intermediate freedom* by designing their own experiments to solve the *fixed problem* with the equipment and material at hand. Activity risk evaluations of the proposed experimental plan before and supervision during execution ensure safe operation. Finally, in the Discovery Laboratory, third-year undergraduate students are given a set of equipment (e.g. a filter dryer) and a suggested investigational area (e.g. the filter drying of paracetamol) at the beginning, but they have the freedom to redefine the problem in consultation with an academic supervisor and investigate areas of their own interest. Hence, they are given *intermediate freedom* to define the problem as well as the appropriate approach to find a solution. The same safeguards as in the Knowledge Lab apply.

Although laboratory-based modules similar to the Foundation Laboratory and Knowledge Laboratory, as well as final year design and research projects are common features in chemical engineering degree programmes, students often need to overcome the intellectual gap between handling fixed and open-ended problems by themselves. The Discovery Laboratory was specifically designed to bridge this gap (Fig. 1): as students have more freedom in defining and solving the

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