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Supporting student learning of chemical reaction engineering using a socially scaffolded virtual laboratory concept

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ABSTRACT

This paper presents an example of open-ended problem solving in the field of chemical reaction engineering using the virtual laboratory (VL) concept. The study was structured as an educational design experiment, which used the VL concept in teaching chemical reaction engineering in the Chemical Engineering degree programme at the Lappeenranta University of Technology (LUT).

The artificial reaction system used in the VL assignment consisted of a small set of coupled reactions in a homogeneous medium. The groups communicated with the 'staff' of the VL via Moodle's discussion forum feature. The students gave written instructions about how and under what conditions their experiments should be performed. The experiments were conducted by the teacher, who ran the simulations using the parameters the students provided.

The VL concept proved to be an efficient method for supporting the students' ability to execute the various subtasks in reactor design in a professional manner. Students had to explicate their understanding of the task, and they could use their cognitive capacity on problem solving rather than the more technical or practical skills of data acquisition. For the teacher, the method provided an opportunity to scaffold the various student groups at different levels. It also helped to distinguish between groups using concept-based approaches and equation-based approaches and to guide the latter toward the approach used by the former. Q3

1. Introduction

In professional programmes, including chemical engineering, learning goals often specify that students must be able to use the knowledge acquired in practical contexts. This is emphasized for example in EFCE recommendations for the first cycle ("bachelor") programme outcomes (EFCE, 2010). Educating students for this type of professional activity requires building not only the appropriate base of technical knowledge but also professional skill (Glassey et al., 2013). Technical knowledge consists largely of declarative knowledge, but professional skill—the know-how to perform the task in a professional manner—is mainly functioning knowledge.

The situative learning theory emphasizes the importance of social and material context of learning, where learning emerges from active doing and participation in meaningful practices (Johri and Olds 2011). This is especially important in learning functioning knowledge. Yet, the learning goals related to functioning knowledge are often addressed with teaching and learning activities more suitable to declarative knowledge. For example, students may be taught to apply their knowledge by means of the teacher explaining and demonstrating application of that knowledge, without the students participating in the application process at all (Biggs and Tang, 2007, 136). Fortunately, students usually get to also practice problem solving. However, in chemical engineering classes,

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Nomenclature

E_a	Activation energy, kJ mol^{-1}
k	Reaction rate constant, s^{-1}
T	Temperature, K
T_{ref}	Reference temperature, K
$\Delta_r H$	Reaction enthalpy, kJ mol^{-1}
ρC_p	Volume-based heat capacity of the reaction mixture, kJ L^{-1} K^{-1}

the problems that students solve are typically what is called ‘closed problems’: those that have unique correct solutions (Savage, 1990, 148). Although this undoubtedly helps students learn to solve similar problems, it excludes from the learning process many features central to professional level problem solving. Most of the time, professional level problems are open-ended and have various constraints and conflicting goals and, thus, many possible outcomes. Such problems consist of several phases and require judgement and various types of decision-making. The objectives of the problem-solving may be known, but the problem itself usually begins to be ill defined, and the person solving it rarely has all the needed data and knowledge at hand.

The need to bridge the gap between instruction-driven exercises and the ability to solve fully open-ended problems has been noticed and addressed in chemical engineering education with respect to laboratory work (Chen et al., 2016), experimental design (Koretsky et al., 2008), difficult concepts (Bowen et al., 2015) and the entire curriculum (Glassey et al., 2013). Glassey et al. (2013) noted that although the traditional way of delivering a curriculum can enable students to understand the theory and derivations of the subject at hand, implementing the principles in real-life situations often remains difficult to achieve. The main means for closing this gap have been enquiry-based assignments (Chen et al., 2016; Glassey et al., 2013) with instructional scaffolding built into the learning tools (Bowen et al., 2015) or social scaffolding built into the supervision process (Chen et al., 2016), or both (Koretsky et al., 2008).

Learning functioning knowledge by solving open-ended problems transforms not only the role of the students but also that of the teacher. According to Mascolo (2009), ‘[t]he intellectual products of any given discipline are not natural objects whose properties can be explored and identified through unmediated experience’. This implies that a teacher has an important role and responsibility in orienting the students so that they are able to grasp the knowledge, values and conventions of the problem area at hand. For example, the support needed can be given in the form of social scaffolding, which comes in many forms and at many levels. The idea of social scaffolding is to adjust the help for each student to his/her current abilities. This means not supporting students with respect to the things they can do, but rather concentrating on the things that are just beyond their independent abilities. Mascolo suggested the following levels of scaffolding, with Level 1 providing the least support (intended for the most advanced learners) and the degree of support growing as the level number increases.

1. **Encourage/prompt:** Teacher provides encouragement, prompts, reminders or praise without specific direction or instruction.
2. **Sequential direction-and-independent-action:** Teacher explains concepts or models target operations, and the student performs the task afterward without further assistance during execution.
3. **Asymmetrical assistance:** Teacher breaks down a task, performs part of it or otherwise provides support so that the student can complete the rest of the task.
4. **Distancing:** Teacher creates cognitive demands, motivating constructive action in a particular direction, including by requesting an evaluation, inference or comparison or by asking open-ended questions.
5. **Direction:** Teacher provides explicit, specific directions about how to perform an action or a procedure or explains to-be-acquired meanings, such as in a lecture.
6. **Concurrent direction for student action:** Teacher provides direction and guidance while the student is in the process of performing a given task, and the student adjusts his/her actions concurrently to the guidance.
7. **Concurrent physical guidance for student action:** Teacher uses hand-over-hand guidance, physical contact or highly directive gestures to direct a student’s attention or actions.

Posing open-ended engineering problems to students seems to be a viable solution to teaching students professional problem-solving skills (see e.g. Diefes-Dux et al., 2004; Savage, 1990). The suitability of the problem and the organisation of the learning environment naturally depend on the discipline, learning objectives, circumstances and many other things. In this article, we present an example of open-ended problem solving in the field of chemical reaction engineering using the virtual-laboratory (VL) concept. We also analyse the learning and teaching processes during a VL group assignment in order to understand if and how the VL advanced student learning and achievement of intended learning outcomes. Finally, we identify some strengths and points in need of further development with respect to this teaching method.

2. Methods

2.1. *Aims, roles and research framework*

The aims of the research exercise were (1) to use the VL method to teach chemical reaction engineering in the Chemical Engineering degree programme at the Lappeenranta University of Technology (LUT), (2) to analyse the learning and teaching processes to identify ways in which the method differs from more conventional teaching and (3) to identify the method’s strengths and areas needing development to improve its use in future. The orientation of the research was both pragmatic and theoretical, and the methodological framework can be described as an educational-design experiment (see e.g. Cobb et al., 2003).

The design of the research process evolved step-by-step. In 2015, when the course was executed and the first aim realised, the idea of analysing the process occurred, so certain data were stored. However, the aims and methods for the analysis had not yet been decided upon. Up to this point, the process had involved only one of the authors, Prof Sainio, who had taught the course. However, when the course was complete and the data became available, Prof Sainio contacted the other author, Dr Naukkarinen, who suggested the scheme for analysing the data and mainly conducted that analysis. The conclusions were derived and the discussion written by both

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