Contents lists available at ScienceDirect

Education for Chemical Engineers

journal homepage: www.elsevier.com/locate/ece

Teaching process simulation using video-enhanced and discovery/inquiry-based learning: Methodology and analysis within a theoretical framework for skill acquisition

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ARTICLE INFO

Article history:
Received 7 October 2015
Accepted 10 August 2016
Available online 15 September 2016

Keywords:
Process simulation
Skill acquisition
Active learning
Inquiry-based learning
Technology-enhanced learning
Qualitative research

ABSTRACT

Process simulation has become an essential tool for chemical engineers in education and industry. Various studies examining the teaching and learning of process simulation are available, although no clear theoretical frameworks for process simulation pedagogy currently exist. The work presented here describes a methodology for teaching process simulation that utilises video-enhanced and exploratory-based learning. The teaching approach is evaluated for a cohort of first year students, with the evaluation drawing on tutor observations, online survey responses and interviews with students. These data sources are used to explore the student experience and reveal that students engaged positively with the learning process. They also show that students benefitted from and valued the learning approaches used. Furthermore, interview responses were interrogated in detail using a thematic analysis, which revealed several key themes. The learning process is observed to occur in distinct phases, with each phase being underpinned by different learning modalities. An 'early' phase of learning is identified, which is supported by expository learning, whereas a 'late' phase of learning, also identified, is supported by a combination of discovery- and inquiry-based learning. A possible 'future' phase of learning is also described, where it is anticipated students could develop their process simulation skills further. These phases of learning are noted and observed to be linked with various stages of skill acquisition and cognition. The learning process is also supported by a range of factors, including student meta-cognition, motivation and knowledge development but hindered by a number of potential obstacles. Overall, the findings, supported by student quotations, provide a rich picture of how students can progress through successive levels of skill development in process simulation, forming a proposed learning model for process simulation pedagogy.

1. Introduction

Process simulation has become a ubiquitous and indispensable tool in chemical engineering (Stephanopoulos and Reklaitis, 2011). As such, the importance of process simulation and related computing skills for employability of chemical engineering graduates is widely reported (Grant and Dickson, 2006; Lewin et al., 2002; Ng and Chong, 2013; Tyson, 2013). In line with this, the essential role of process simulation in chemical engineering education has also been acknowledged (Dahm et al., 2002; Ng and Chong, 2013; Silverstein, 2004). Whilst the literature review by Dahm et al. (2002) concludes that process simulation is an important part of the chemical engineering curriculum, they suggest that it is sometimes

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http://dx.doi.org/10.1016/j.ece.2016.08.003

underused in university programmes. They also point out that process simulation should not be taught to the exclusion of other industrially relevant software tools. One potential barrier highlighted for holding back coherent teaching of process simulation is the unwillingness of faculty members to learn how to use new and complicated pieces of software. The overriding theme that emerges is that process simulation should not just be introduced and used for process design in the final year of degree programmes but rather that it should be introduced from year one and expanded into the wider curriculum. Overall, it would appear that integrated and scaffolded approaches might be effective in achieving this goal.

Various practitioner case studies for teaching process simulation have been reported in the literature (Dahm, 2002; Komulainen et al., 2012; Lewin et al., 2006; Ng and Chong, 2013; Silverstein, 2004; Wankat, 2002), but no clear theoretical frameworks or evaluation strategies have emerged for process simulation pedagogy. Ng and Chong (2013) provide a narrative account for the set up and implementation of process simulation teaching across the curriculum and at all levels of the degree programme. Whilst the teaching model is linked to educational theory, there is no evaluation of its effectiveness and the learner perspective is not represented. Lewin et al. (2006) also describe an integrated approach to the set up and delivery of process simulation teaching and include quantitative data on the student perspective, providing some useful insights. Lakshmanan et al. (2012) also advocate a curriculum based approach to teaching process simulation. In addition, they suggest that a multimedia approach can enhance student learning. This appears to be based on the work of Lewin et al. (2002), who indicate that multimedia delivery of teaching allows students to take a self-paced approach to developing mastery of process simulation. Online learning resources to support such an approach include tutorials with step-by-step instructions, screenshots, audio podcasts, screencasts and animations (Seider et al., 2010).

Whilst engineering education research is an active area (Aung et al., 2004; Borrego and Bernhard, 2011; Jesiek et al., 2010; Jesiek et al., 2009; Smith, 1991), the evaluation element of this work is a potential area of weakness, since it is sometimes absent or when included it often focuses on quantitative data or is simply based on subjective "feelings" as to the value of a particular teaching approach (Dutson et al., 1997). Although the use of quantitative analysis is very effective for showing what is happening, it does not elucidate how and why something is happening (Denzin and Lincoln, 2011). In order to achieve this, a qualitative research approach is required. Understanding why a particular phenomenon is occurring can be extremely powerful, especially in education research investigations and dissemination. Such understanding can influence teacher and student approaches to thinking, learning and skill development, by facilitating meta-cognitive development and by encouraging reflective practice (Case and Gunstone, 2002; Mann et al., 2009; Ramey-Gassert et al., 1996; Schraw et al., 2006).

Generalised theoretical frameworks exist for the acquisition and development of new skills, with potential relevance and possible implications for teaching process simulation. Whilst skill acquisition has been extensively studied from a cognitive science perspective (Johnson et al., 2006; Salvucci, 2013; Scott and Bansal, 2013; Speelman and Kirsner, 2005; VanLehn, 1996), a qualitative understanding of skill acquisition is more pertinent to the present work. For example, the Dreyfus and Dreyfus five stage model of skill acquisition was originally introduced in 1980 to understand skill development of aircraft pilots but has since been further developed (Dreyfus et al., 1986; Dreyfus, 2004; Dreyfus and Dreyfus, 1980). It has also been reapplied and reimagined for other fields, including nursing and software development (Benner, 2001; Hunt, 2008). The model suggests that someone can develop new skills by passing through five stages of development, from having no prior experience as a 'novice' through to becoming an 'expert' via the 'advanced beginner', 'competent' and 'proficient' stages of development. A conceptual understanding of how someone might think at the various stages of development has important implications for how they should be guided and instructed. For example, there are several important and informative distinctions between novices and experts. Notably, novices rely on rules whilst experts rely on experience and sophisticated pattern matching. Novices see a problem as a collection of equally relevant parts whilst experts see problems as a complete and unique whole where only certain elements are important. Complementary to this model is the idea that skills can be developed through 'deliberate practice' (Ericsson, 2008). This involves working on a well-defined task. The task needs to be appropriately difficult (challenging but doable). The learning environment needs to be informative, providing feedback that can be acted upon. The learning environment also needs to provide opportunities for repetition. This allows skills and expertise to be reinforced and for any actions, corrected by feedback, to be retried and tested. Such qualitative models can aid an instructor by providing insights into the thought processes and difficulties experienced by students, allowing the teaching experience to be designed and augmented to meet learner needs.

The present work examines the teaching of steady-state process simulation to first year chemical engineering students using screencast videos and exploratory-based learning. The aim of the work is to examine how student learning happens during this teaching and to situate observations made in the context of existing pedagogic theory. The teaching and learning process is evaluated using tutor observations, online survey responses, student interviews and a qualitative thematic analysis approach.

2. Methodology

2.1. *Teaching methodology*

Process simulation was taught by the author to 36 chemical engineering students on a module taught within the first year of BEng Chemical Engineering and BSc Chemical Engineering and Chemistry pathways. This process simulation training constituted one fifth of a 10 ECTS credit chemical engineering design module. Contact time was split across six sessions for 2 h per fortnight in a PC lab during the second half of the year. The software used was SIMSCI PRO/II 9.2 (Schneider Electric, formerly Invensys), steady-state process simulator. The learning was supported via twenty four instructional videos, watched by the students during the class time and hosted by the university's closed access video streaming website: https://unitube.hud.ac.uk.[1] The videos demonstrate how to build and run a simulation and how to use various features of the software. These were made by capturing an audio

[1] These videos are now freely available at www.youtube.com/c/ChemEngTutor.