# Chapter 21
# Virtual Experiments in University Education

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## ABSTRACT

*A university curriculum in natural and engineering sciences should provide students enough time and adequate facilities to design and carry out experiments and to analyze and interpret experimental results. However, laboratory facilities require considerable investments, and the experiments themselves can also be very expensive. Furthermore, in many universities, scheduling laboratory practice can be quite constrained. It is often difficult to realize learning scenarios in which experimentation is an integral component. Finally, alignment of actual laboratory classes and assessment is seldom satisfactory. This chapter discusses potential benefits of and limitations to virtual experiment environments or virtual laboratories in university education. In addition, we aim to identify feasible objectives for faculty-based projects on design, realization and use of virtual experiments in university education.*

## INTRODUCTION

Active learning and inquiry are generally promoted as important modes of learning (Bransford, Brown et al., 2003). In particular, there is a huge body of literature on inquiry and the 'nature of science' in secondary education (see for instance Bybee, 2002; Clough, 2002; Flick & Lederman, 2006; Jong, 2006; Linn, Davis et al., 2004; Linn, Lee et al., 2006; Lunetta, Hofstein et al., 2007; Reiser, Smith et al., 2001; Schwartz, Lederman et al., 2004; Slotta, 2004). Major elements of inquiry are scientifically-oriented questioning, prioritizing evidence, using evidence for explanations, connecting explanations to scientific knowledge, communication and justi-

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fication. Thus, inquiry is much more than 'hands-on' activity (Bybee, 2004; Clough, 2002). Bybee (2004) notes that in many educational discussions on inquiry in science classrooms the relationship between educational objectives and means and methods to achieve these objectives is confused. Several authors show that such confusion can also be found in much of the literature on general learning objectives of BSc/undergraduate laboratory classes in natural and engineering university curricula (Feisel & Rosa, 2005; Kirschner & Meester, 1988). Articulating goals into objectives and requirements for laboratory classes appears to be difficult. We largely attribute this to the gap between objectives that faculty wants to achieve and the actual feasibility of objectives given the practical constraints of traditional means and methods. Literature on desired learning objectives of laboratory practice in higher education is mostly in keeping with the characteristics of inquiry (see for instance Buntine, Read et al., 2007; Diederen, Gruppen et al., 2006; Domin, 1999a, 1999b; Johnstone & Al-Shuaili, 2001; Perreault, Litt et al., 2006). At the same time, specifically in university education, the components of inquiry are strongly orientated towards the curriculum's particular knowledge domain and particularly to knowledge of specific equipment, methods and materials (see for instance Ana R. Linde, 2006; Brown, 2006; Buntine, Read et al., 2007; Tânia M. F. Günther, 2003).

Laboratory classes in BSc/undergraduate curricula are often criticized. In particular, reviews suggest that these classes are often inefficient and isolated and incorporate the wrong tasks (Hawkes, 2004; Kirschner & Huisman, 1998; Kirschner & Meester, 1988). If students are not engaged in an integrated learning experience that incorporates all major components of inquiry, and if experimentation is detached from other scientific activities, students are unlikely to acquire an adequate image of the nature of science (see for instance Alberts, 2005). However, achieving integrated learning experiences in laboratory classes in BSc/undergraduate curricula poses big challenges for many universities. First, laboratories require considerable investments. Second, even when adequate laboratory facilities are available, limited laboratory capacity, limited instructor capacity and curricular constraints tend to create difficult scheduling problems. Additionally, experiments may require long lead-times, expensive materials and safety measures.

In many countries, laboratory facilities and subject matter expertise are scarce. For many prospective students in these countries, distance learning may be a good opportunity to receive higher education. However, the question remains: how can distance learning can go hand in hand with the need to enable and support students in developing experimental competencies?

Advances in information and communication technology (ICT) and wide spread awareness of computer games and sophisticated virtual reality environments for training, such as flight simulators, seem to promise at least partial solutions for these curricular problems. In addition, learning management facilities in most universities provide already direct access to digital learning materials. Most of these learning materials are presentational, but some of these materials enable students to carry out 'virtual experiments'.

Another relevant development of the last decade is the integration of ICT into many scientific disciplines. In fact, much of the experimental work in many natural and engineering sciences would now be impossible without ICT. Management and retrieval of a wide variety of data and data types is often an integral aspect of experimental work. In carrying out an experiment, the experimenter often controls experimental conditions by computer and the computer presents experimental results. In these experimental settings, the gap between a reality presented by a virtual experiment environment and a real experiment environment can be relatively small. For instance, a virtual control panel for a chemical reactor (Cartier, 2007) is not so different from a real control panel (see