INTRODUCTION

Traditionally, learning has been a process wherein students are instructed by teachers, commonly in a classroom and/or laboratory setting. A series of advanced cyberinfrastructure developments occurring over the last decade or so and continuing at present exhibit strong potential for enabling a dramatic shift in the general educational paradigm where in the future the interactions between learners and educational resources as well as between groups of learners will increasingly be carried out online, computing resources will become ubiquitous and include access to networks of smart sensors and devices, and the pervasiveness of wireless communication tools will facilitate flexible on-demand learning taking place at anytime and anywhere (e.g. in classrooms, laboratories, laboratories, etc.).
libraries, workplaces, dormitories, homes, etc.). Educational resources will comprise not only digitized content (i.e. text, still graphs and photos, animations, voice and video clips, etc.) and delivery tools (i.e. content management systems such as Blackboard\(^1\)) but also a vast variety of online laboratory resources (i.e. remote experiments, virtual experiments, game-based virtual laboratory environments).

As an example for the seamless integration of various dispersed online resources into a comprehensive learning experience, imagine the following scenario in a typical undergraduate engineering class on statics or strength of materials. The syllabus might for example include a discussion of the classical modeling of a boom crane as a slender cantilever beam. First, a set of corresponding lecture slides can be downloaded (e.g. Massachusetts Institute of Technology’s OpenCourseWare, Livermore, 2006) and studied. The concepts of the elastic deflection curve of a slender beam under static loads and stress concentrations occurring around stress raisers (e.g. holes, changes in cross section, etc.) could then be reinforced using a remote laboratory exercise\(^2\) involving cantilever beams with/without hole. Next, the remote experiment could be complemented by a series of virtual experiments\(^3\) using a simulation module (implemented for instance using Virtual Reality Modeling Language\(^4\)). This would enable an exploration-based learning mode since many of the parameters that are fixed in physical experiments (beam material and geometry, location and dimension of the hole) can easily be changed in simulations. Finally, the local stress and strain distributions around the hole could be explored in more detail numerically using commercial finite element software (e.g. ANSYS\(^5\)) with a corresponding input file generated automatically by the simulation module.

By providing uniform networked access to such diverse online laboratory resources in combination with synchronous (e.g. Windows Vista Meeting Space\(^6\), Skype\(^7\), etc.) and asynchronous (e.g. e-mail, discussion boards, blogs, etc.) communication tools, students and instructors alike will be enabled to search for educational content, to flexibly combine geographically dispersed learning modules and to communicate and collaborate with others, thus leading to a fundamental change in the relationship between learners, instructors and knowledge.

Laboratory experiments are widely considered to be a crucial component of engineering and science curricula by all stakeholders in the higher education process. On the one hand, new ways of sharing educational content have been developed and implemented (e.g. National Science Digital Library\(^8\), Connexions\(^9\), Massachusetts Institute of Technology’s OpenCourseWare\(^10\), etc.) and numerous localized projects have generated a variety of resources for conducting online experiments (i.e. remote, virtual and game-based experiments). On the other hand, efficient mechanisms for discovering and widely sharing them are still sorely lacking.

This chapter highlights the role that online laboratory tools are likely to play in traditional on-site engineering and science programs as well as in the online educational offerings that are quickly gaining traction in many fields and are destined to reach a more dominant position within the spectrum of educational courses of study.

**BACKGROUND ON ONLINE LABORATORIES**

**History and Review**

With the advent of the Internet, online student laboratory facilities have become feasible and are increasingly gaining popularity. The underlying fundamental promise of such Internet-based laboratory approaches lies in the students’ ability to connect to the laboratory experiment of interest at anytime from anywhere, thus sharing the existing limited resources in a more efficient manner.
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