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Reusable and Sustainable Science and Engineering Education

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In a recent survey by "The Times Higher" (Ince 2007), MIT, which ranked first among the technological universities in 2007, was described as "probably the world's biggest single technology innovator of the postwar period." Perhaps a small part of the "secret" underlying this unique status is reveled in this two-issue series on MIT's educational reform. This is the second of two special issues, which present a diverse collection of studies that describe and discuss innovative approaches to science and technology teaching and learning at MIT.

In environmental studies, the term sustainability refers to the duration for which human ecological systems can be expected to be usefully productive without endangering the welfare of future generations. Reuse is another relevant term borrowed from environmental studies, which is also a common software engineering concept. In the latter domain, it relates to gains in productivity stemming from the use of ready-made components that have proved to be functional and productive, rather than developing them from scratch each time they are needed. These two terms, sustainability and reuse, assume a special meaning when applied to science and engineering education: They relate to education that can serve both our generation and the future ones throughout the world, in areas and countries that cannot afford high quality live professors and teachers. Indeed, this issue focuses mainly on off-campus technology-based projects that have emerged from MIT and spread to various places around the globe.

To set the stage for the papers in this special issue, I refer to the framework provided in the Design Principles Database (Kali 2006, in press), which synthesizes dozens of design-based research studies about technology-enhanced learning in science, using "Design Principles" as a main construct. The various educational endeavors presented in the papers of the current issue employ two important pedagogical design principles. The first is "Reuse student artifact for learning", (The Design Principles Database 2008a) advocates the use of artifacts developed by learners, as resources for further learning of their peers. Scardamalia and Berieter (1994) defined as first-order environments the collective products, in which the knowledge produced by learners reflects the sum of knowledge in individual minds. Conversely, in second-order environments, members of the community produce a collective product as they elaborate on each other's work. Reuse is a major source of constructing such second-order environments.

With respect to this principle, Ronen et al. (2006) have presented a reuse-based approach for creating and conducting structured collaborative activities, such as reaching an agreement, peer-product evaluation, contest, and creating a group product, and incorporating them in existing instructional settings. Learners' products from previous stages are reused to conduct complex, multi-stage, structured activities. Teachers can explore these examples, adopt them for personal use and adapt their structure and content to suit their needs. As Day and Foley (2006) noted, by using Web lectures to present lecture material before class, more in-class time can be spent engaging students with hands-on learning activities, so class time can be used for "more learning by doing, less learning by listening."

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A second relevant pedagogical design principle (Design Principles Database 2008b) is "Employ multiple social activity structures". This principle calls for combining group activities with individual and whole class activities. The contribution of the individual shapes the team knowledge-building process, and the team process further constructs the knowledge of the individual (Salomon 1993). Linn and Hsi (2000) found that working in small teams is often more efficient than working in big groups, as individuals felt more comfortable in one-on-one discussions. However, opportunities exist also in larger groups, as students need to justify their opinions more coherently to get them heard and to negotiate tasks more carefully than when working with one partner. Hence, multiple social formats also increase the likelihood that all the participants will find an effective format for their learning. These two principles, namely "Reuse student artifact for learning" and "Employ multiple social activity structures", strengthen each other and they hold not only for students but also for teachers at all academic levels.

Indeed, Levin-Peled et al. (2007) have employed these two design principles in an innovative way: They extended the concept of reuse of student-generated materials to reuse of instructors-generated materials, and they combined group activities with individual activities in three hybrid courses: an undergraduate course, a mixed-population one, and a graduate course. This way they created multiple social activity structures in which both students and professors are partners. MIT's Studio—1.00 project (Barak et al. 2007), centering on the shift from teacher-centered lectures to studio-based instruction, is another example of a successful implementation of the two design principles.

Several of the papers in this issue build on reusing pedagogical ideas, settings, and learning materials, as well as employing multiple social activity structures. Pundak and Rosner (2008, this issue) have reused the TEAL setting for teaching college physics, developed by Beichner et al. (2006) and researched by Dori et al. (2007).

Abelson (2008, this issue) describes the OpenCourseWare (OCW) project, which is expected to bring about improvement in education on a global scale through reusing carefully prepared learning materials over the Internet. As Stevenson (2002) noted, since the period of the enlightenment and the advent of modernity and scientific thought, knowledge has been viewed as something to be discovered, categorized and distributed. The industrial and scientific revolution resulted in a worldview that has retained the leadership of the Western world, making its accessibility to less advantaged societies and remote corners of the world a grand challenge. MIT's LINC—Learning International Networks Consortium (Park and Zellweger Moser 2008; Larson and Murray 2008, this issue) respond to this immense challenge. The former paper focuses on tertiary education in developing countries, looking at what developing countries are actually doing and what help they need beyond pedagogical issues. The authors have identified challenges in establishing technology-based learning environments in the area of pedagogies, finances, technological infrastructure, cultural change, organization, and management. They discuss how a consortium like LINC can best support these efforts. The latter paper (Larson and Murray 2008) analyzes case studies on distance learning in developing countries as an enabler for economic development and poverty reduction. They describe extensive site visits to Community Learning Centers (CLCs) in impoverished portions of China and Mexico, operated by leading universities in the respective country. Sustaining the educational efforts worldwide mandates that cross-transfer of knowledge via collaboration among educators and policy makers is constantly maintained and nurtured between developed and developing countries.

The work of Crawley et al. (2008, this issue), answers two central questions regarding improving engineering education: (1) What is the knowledge, set of skills, and attitudes that engineering students should acquire, and (2) How can we ensure that students learn these skills? They suggest answers within an innovative educational framework, the conceive-design-implement-operate (CDIO) initiative. Attaining the ambitious goals of CDIO requires massive collaboration between engineering educators worldwide. A basis for any engineering activity is a solid mathematical background. Miller and Upton (2008, this issue) describe the use of interactive graphical simulation—"mathlets" that have become an essential part of MIT's large, university-wide subject in differential equations.

Mcginnis (2003) has analyzed discourse and conversation by science and mathematics teaching faculty in reforming content courses for teacher candidates participating in a mathematics and science teacher preparation project. He noted that understanding the role of "collaboration" in teaching and learning is crucial. Indeed this is a major element that runs as a common thread throughout the entire collection of papers in the Issue. It is my hope that sustainable collaboration in education among teachers, students, and educators will be fostered and enhanced as a result of assimilating lessons and pedagogical approaches for higher education from these works.

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