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The global perspectives of transitioning to e-learning in engineering education

Paul W. Magoha† & Andrew W. Otieno‡

Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya†
Northern Illinois University, DeKalb, United States of America‡

ABSTRACT: With the advent of modern information technology (IT), learning has entered into an era of change unparalleled in this generation. The issue is how this change will be directed and managed so that what does not work is shed, and opportunities seized to ensure that this critical infrastructure is sound. Worldwide, academics have come to the conclusion that traditional learning methods must give way to electronic learning (e-learning). However, in order to change a paradigm, there must be a change in the way that people believe, think and act. A change to e-learning in engineering education is a paradigm that has its associated challenges. Innovations are required so as to accomplish e-learning in engineering education. Developing e-learning tools that will take engineering education beyond traditional capabilities is a part of this challenge. In this article, the authors present a review of the global development of e-learning in engineering education. A framework to enhance e-learning in engineering education through online collaborative laboratory activities is also discussed. The authors conclude that e-learning should increase opportunities for everyone within and beyond national boundaries in the acquisition of engineering degrees.

INTRODUCTION

Twenty years ago, the Internet, as we know it today, did not exist and, as little as a decade ago, only a handful of people used personal computers at home, school or even work. Electronic learning (e-learning) is now a reality that has been made possible by very recent advances in technology; that same speed of technological change is set to continue over the next decade and beyond.

There is no doubt that the needs of engineering education today have changed. Traditional engineering education is a regimented approach and cannot be relied upon to fulfil the objectives of current global engineering education aimed at the masses living in different parts of the world. Currently, educational methods are changing with attempts being made to place the learner at the centre of the process. The development of e-learning and e-assessment services for learners, centres and employers is taking place throughout the world. Advances in technology have allowed for the expansion, focus and complementing of conventional methods of education with new products and services that add value to the learning and qualification market. All these aim at achieving a step-change in terms of support and flexibility.

Due to the nature of today's higher education learner as being one who seeks flexibility, and the continued developments in technology, the demand for e-learning services is steadily increasing. Enrolments, course offerings and the availability of distance education increased rapidly during the 1990s. In 2000 alone, 7.6% of undergraduate and 12.3% postgraduate students, totalling a little over one million, participated in distance learning in the USA [1]. Further, 20% of 2- and 4-year institutions also planned to start offering distance education courses between 1998 and 2001. These figures in the USA were projected to increase to about 2.2 million [2].

Despite the dramatic expansion in e-learning and distance education, e-learning in engineering education still faces a number of setbacks that prevent an equivalent expansion rate. For effective and complete learning in engineering, science and technology, education requires a mixture of theoretical and practical sessions. In order to understand how theoretical knowledge can apply to real world problems, practical exercises are essential [3][4].

While it is relatively easy to simulate experiments, performing practical experiments online has continued to be a challenge [3-7]. Coupled with this, engineering software is often very expensive and may not be easily affordable by the ordinary e-learner. Although low cost alternatives that utilise freeware have been successfully developed and tested, practical laboratories that support engineering education are still difficult to implement online [7].

The General Concept of E-Learning Education

E-learning, at its best, is learning that complements traditional methods and gives a more effective experience to the learner. Simply, e-learning is the use of technology to support the learning process. Fundamentally, it is about putting the learner first by placing resources at the learner's fingertips. The e-learner is able to dictate the pace and balance of learning activities in a way that suits him/her. E-learners can absorb and develop knowledge and skills in an environment that has been tailored to suit them – and at their own pace.

As opposed to online courses in their strictest sense, e-learning does not necessarily lead to a certification or degree programme but may be tailored, for example, to suit the needs of a specific company [8]. For example, the University of Michigan (UM) offers several courses on Six Sigma that students can take for credit towards their degree programmes at

the UM, but can also be taken by engineers and practitioners in industry, either for their own knowledge updates or for Six Sigma certification.

E-learning is much more than online courses. It is about outreach. It gives access to online information, networks with whom individuals can share learning problem solving and online tutors and mentors who can offer advice and guidance. The learning process should always drive the use of technology, not the other way around.

E-LEARNING STRATEGY IN ENGINEERING EDUCATION

Learning is not just an intellectual, brain-based activity; it is also a social interaction with people learning from each other. Learning is actually something we do every hour of the day. People like sharing information and ideas, supporting and helping each other; this can be done electronically too. So that is also very much a part of an e-learning strategy: offering learning communities or networks for selected groups of e-learners in selected subjects. By doing this, e-learners have dispelled the myth that they are loners.

E-learning brings together industry-leading tools that support learning. In every subject area, there is a set of community tools that allow users to come together in groups to share information. There are also discussion groups led by professional e-learning moderators who guide discussions and answer specific questions. By using basic network meeting tools, such as Web cams, online chat and *whiteboards*, students are able to carry out learning activities in the workplace, while also obtaining instant remote supervision and feedback from college-based tutors.

E-learning has been hailed as revolutionary, often because it is different. However, it is better to think about it as *transforming*, because like all successful revolutions, it changes lives.

ADVANTAGES AND DISADVANTAGES OF E-LEARNING IN ENGINEERING EDUCATION

Meeting Individual Needs

Many adult learners have a history of unrewarding educational experiences, which can often be attributed to a failure to establish an effective learning relationship. Some learners do not respond well to conventional methods of education delivery. For many, there was a lack of choice about when, where and what to learn, a lack of control over the pace of learning and a lack of individual communication or explanation. Those who have only ever learnt in a classroom situation may only have experienced learning anonymously, perhaps feeling invisible in a sea of faces. Many learners say they felt stupid at school if they had to ask for the same thing to be explained more than once. Others found lessons went too quickly or too slowly and their interest and concentration waned off as a result.

In contrast, supported e-learning has the potential to provide a very different and flexible learning environment that can adapt to individual needs. Online students are in charge of their own learning, responsible for the timetable and the school bell. They can choose what to learn, when to learn and how long to learn for, fitting their courses around their lives. Students do not have to struggle to keep up or wait for other members of the class, as the course can be taken at their own pace, repeating or spending more time on areas of difficulty. E-learning also suits some learners because it can provide instant feedback so there is no having to wait around for books to be marked or having to continue before problems are identified and dealt with.

Advantages of E-Learning in Engineering Education

E-learning offers unique pedagogical opportunities to enhance student learning: In the realm of e-education, there are clear benefits that can be derived from e-learning as follows:

- It promotes exploratory and interactive modes of inquiry.
- It supports and facilitates team-orientated collaborations and expands the ease of access to engineering education across institutional, geographical and cultural boundaries, among others.
- Class notes and materials are posted on the Internet and students can access the sites from anywhere in the world. This is quite unlike distance learning, where a student is given course materials and reads solely on his/her own until examination time.
- E-learning is interactive; the software permits the student to communicate, not only with the lecturer, but also with fellow classmates. It enriches and supplements the classroom experience by engaging the Web [9].
- E-learning has the ability to communicate consistently to learners by providing the same concepts and information – unlike classroom learning, where different instructors may not follow the same curriculum or teach different things within the curriculum [8].
- E-learning is cost effective in terms of learners per instructor. In addition, it saves classroom time and this is very significant for learners who are employed on a full-time basis.
- Students, instructors and evaluators can track learning outcomes more easily.

Disadvantages of E-Learning in Engineering Education

For all its potential in dealing with learners individually, online learning does have its own invisibility problems. The other side of online learning can seem far away and isolated. For the learner, the price of empowerment is the responsibility of wielding that power. As with all distance learning, e-learning relies on self-motivation. With no enforced discipline or deadlines, it is easy for the learner to be distracted and put off work for a distant tomorrow. With no human presence, it is also impossible for a learner with a problem to obtain help easily. Thus, personal interaction between the instructor and students is either absent or else very different from traditional face-to-face learning [10].

Other subtle disadvantages of e-learning include the ability to read text from the computer screen. Research has shown that linear text is often difficult for people to read from the computer [11]. Hence, learners often have to reformat the text and print it out for reading, necessitating the need for a printer.

The problems of invisibility, anonymity and isolation can be dealt with in several ways. Once more, the key solution is communication and there are several channels available to learners. The first is a national help line where learners can talk to someone trained to give them advice on their course. Many

e-learners are also assigned an online tutor who checks on their progress and can be contacted by e-mail with any queries or worries. Online message boards and chat rooms provide learners with the means to contact and talk to other people doing the same course, exchanging advice, ideas and encouragement. For those without access to computer at home or who require additional support there is a network of centres across countries. Surely, no engineering educator would argue against a legitimate teaching method that highly motivates students to learn their subject matter and promotes student interaction in the process. To witness students achieve an increased mastery of ideas, while also setting greater expectations for themselves, would be fulfilling educators' dreams. Table 1 summarises a comparison between e-learning and traditional learning.

Table 1: Summary: comparison of e-learning versus conventional engineering learning methods.

E-Learning	Traditional Engineering Learning Methods
Relies on learners' self-motivation	Lecturer plays a leading role in motivating and guiding learners
Assessment and examinations conducted at learners' pace	Assessment and examinations time does not depend on learners
Greater achievement in number of learners going through engineering courses	Learning restricted to those attending university or college
Innovative methods required to achieve practical assignments and experiments	Laboratories readily available for practical assignments and experiments
Duration of course normally decided by learners	Institution has calendars and set durations for courses

ONLINE ASSESSMENT OF ENGINEERING COURSES

The philosophy behind online testing is to provide a single technological infrastructure into which all qualifications eventually fit. There are other models, such as e-Quals, which allows taking multiple-choice examinations online. There is a need to pilot different forms of assessment, like simulation, drag-and drop, or short answers. There is also the need to develop new types of assessment to cater for different objectives and in various subjects.

In the USA, objective testing is the norm. They are leaders in psychometrics and, therefore, accustomed to devising sophisticated methods of checking underlying knowledge. With the traditional methods of education, the only way to achieve a qualification was to sit an examination, written on paper, with little or no control over when the examination was taken (or re-taken). Now with the e-learning, there is a possibility to offer online or network-based assessment that is truly on demand. Students can now register for an examination, walk into an approved centre, take the test and receive instant feedback on their performance. It is not just multiple-choice examinations that can be carried out in this way. Using advanced search and analysis software, it is even becoming possible to automatically mark freeform, essay style answers to a degree of accuracy equalling - or even exceeding – that of a human examiner. This offers the potential to make significant timesavings in the examination cycle.

Positive Aspects of Online Assessments

Creating online communities is essential in making each learner's experience positive. Someone who enjoys learning is likely to return for more. The effort is to forge effective relationships and get close to learners – reach the other side of the online connection – is the key to success, not only for the learning providers, but also for learners and a country's workforce as a whole. Gaining skills is important for both personal development, and essential for an individual to participate effectively in the workforce. It is also essential for the workforce to compete in the global economy. While one might start with the individual, the desired result sees one finishing with the wider community.

BEST PRACTICES FOR E-LEARNING IN ENGINEERING EDUCATION

E-learning has been extensively implemented in many institutions around the world. The challenge in implementing e-learning in engineering education still remains an issue for research. There are three key issues: available technology, learner issues and the role of instructors/course developers.

The most abundant technology for e-learning is the Internet. Although the Internet is readily available, most institutions, especially in developing countries, may not have enough bandwidth to access course materials. Course materials in engineering tend to contain a lot of graphics and simulations, and if virtual laboratories are to be included, real-time streaming video is also needed. More often, specialised software, such as *LabView*™ may be required to achieve this, as reported by various researchers who have made attempts to develop online e-learning materials for engineering education [12][13]. In addition, issues of standardisation and portability between software platforms continue to be a problem for the successful implementation of e-learning in engineering education [14]. To overcome these shortfalls, e-learning educators should address standardisation issues in software and hardware needed for e-learning. The use of open-software should be encouraged as much as possible. Recent work by the second author reported on the successful development of an Internet laboratory that was based partially on commercial software at the server and experimental system, and open software for the client access [7]. Collaborative efforts, an example of which is reported by researchers at Politehnica University of Bucharest and at Arizona State University, should also be encouraged as this will help reduce costs and allow for the sharing of skills and resources [15].

Case studies of successful developments of e-learning in engineering education provide examples of best practice. The underlying factors for successful e-learning in engineering education address issues such as portability, the use of standard software and hardware platforms, security, access, usability, and, more importantly, the ability to provide laboratory and/or simulation experience to learners. For instance, in the Finnish Virtual University Project, the successful implementation of an introductory programming course has been offered over the Web using a *WebCT* platform for high school students [15]. *WebCT* is a Web-based e-learning platform that is secure and requires only a browser [16]. Remote Web-based laboratories have been developed [3-7][12][13]; however the realisation of multiple physical experiments is yet to be achieved. In addition, the required hardware and software are also expensive. This is

evident from the fact that established e-learning consortiums, such as the Open University and the University of Phoenix, offer programmes in engineering that do not require extensive laboratory components and are mainly related to management [17][18]. To circumvent this, most researchers have resorted to a combination of some standard commercial software (for the server) and open software for the clients [7].

THE IMPACT OF E-LEARNING ON DISTANCE ENGINEERING EDUCATION

Some educators are not equipped with sufficient instructions to use educational technologies. Although this lack of instructions does not negate the power of technology to enhance learning, it does impede the pace at which technology is implemented on a larger scale. Once lecturers and professors realise the positive impact of technology on learning behaviour, they become advocates of educational technologies.

As with calculators and computer software in the 1980s, distance education has been making strides in the 1990s as a more advanced form of technology. Indeed, distance learning represents a network of technologies that can connect public school systems, colleges and universities, private industries, and governmental facilities – among others. As with most new forms of technology, it has so far been slow to impact on learning in public schools and university classrooms at a level to which it is capable. However, with the realisation of virtual laboratories and the continued development of simulations, e-learning in engineering education is set to impact upon the way engineering is taught today. It is expected that many people who have engineering related careers, but do not have degrees yet, will actively seek these e-learning channels towards obtaining college degrees. E-learning is also expected to increase collaboration between institutions of higher learning, thus fostering more knowledge distribution and research.

CHALLENGES OF E-LEARNING IN ENGINEERING EDUCATION

Software-based learning can offer realistic simulations of complex tasks, allowing learners to learn by doing. This is a well-proven technique and is used extensively with psychomotor skills training, for example, professional pilot training. What the learning and education world is realising is that software can also be used to realistically simulate a whole range of engineering experiments or activities. In the future, we are likely to see a growing sophistication in Web-delivered learning simulations.

Computer software has become an intricate component in every business, no matter how large or small the organisation or sector is. It has improved organisational efficiency and raised productivity as various kinds of tools are utilised to perform various functions. Furthermore, with emergence of the Internet, the use of software to conduct learning in engineering over computer networks has become fundamental to the performance of the global engineering education sector.

To avoid piracy, there will be a need for suitable software management within the global engineering education sector.

Despite the potential improvements to the learning experience that e-learning offers, there are still challenges that need to be faced. What will it take to meet these challenges? It will take creative thinking, effective partnerships, infrastructure and, as much as anything else, satisfying e-learners. Academics believe that the vehicle for that change is customer satisfaction. The much hailed multi-billion dollar market for e-learning vendors is failing to emerge, at least within the timescales initially predicted. Business is there, but customers are not biting yet in big enough numbers to fulfil the revenue predictions of key suppliers (or their investors). As a consequence of this and the general global stock market malaise, mergers, acquisitions and disposals are the name of the game. All of this makes it very difficult for educators to invest, because the company one signs the deal with may have disappeared by the time one starts to use the product.

Secondly, technology standards are not mature. Despite some good progress, there is still a long way to go before there is enough standardisation across content and Learning Management Systems (LMS) or Virtual Learning Environments (VLE). Organisations buying e-learning products need to know that, when they plug them into their VLEs, they will play first time and every time, and that they are modular and can be integrated into a wider curriculum. In assessment, there are several commercially available online examination systems, but little standardisation of items, databases and structures.

The third challenge is access. One of the key features of e-learning is that it can be a tool for levelling the playing field in terms of access to learning. Whether it is by reaching individual learners who are not able to travel to learning centres or colleges, or making learning to small manufacturing enterprises (SMEs) that cannot afford traditional or residential training, e-learning offers real potential. The reality is that the digital divide is very much still international and that, while access is growing, there is still a long way to go before organisations are able to reach some of the people who would benefit most.

Finally, e-learning is very expensive. Most e-learning takes place in large commercial organisations, where there is an overwhelming economy of scale to be gained. But for specialist skills, and for the further and higher education markets in particular, relatively small volumes and high content volatility mean that there are not necessarily compelling financial cases for moving to e-learning.

There are initiatives that help by aggregating content and offering it to a network of customers with similar need. However, any bespoke development is very costly. Add to that the cost of the necessary IT infrastructure, and it starts to look like an expensive option. For the time being though, it is probably best to choose e-learning because of the added functionality and flexibility it offers, and not as a route to saving costs.

Demand, particularly from SMEs and the corporate market, lies in flexible training solutions, not for online itself. Thus online learning must always start with the learner in mind and not the technology. This involves getting closer to learners, understanding their needs and making their learning experience positive. The key to reaching the other side of the online divide is involvement. Learning is not something that just happens to people, it is active rather than passive. It is essential to engage learners in a learning relationship, rather than in a learning transaction, which is essentially a one-way process. Vital in any relationship are the elements of choice, a degree of control and two-way communication. In order to meet these challenges, it will take creative thinking, effective partnerships and, as much

as anything else, standardisation. E-learning is itself a learning experience for e-learning providers.

STATUS OF E-LEARNING ENGINEERING EDUCATION IN DEVELOPING NATIONS

There are numerous e-learning programmes in developing countries. In Africa, for example, several distance-learning projects have been implemented successfully, the majority through collaboration with institutions in developed countries; a comprehensive list can be found from the African Distance Learning Association [19]. Concerted efforts through outside collaborations and partnerships with developing countries and a number of African universities have culminated in various distance learning degree programmes. The African Virtual University offers a range of degree programmes, most of them in collaboration with Australian institutions [20].

For developing nations, the realisation of e-learning, especially in engineering education, is yet to be thought of. There are several obstacles that developing countries have to overcome if e-learning is to be successfully implemented. The first and major obstacle is the lack of technological resources. While the Internet has been around for over 15 years, it is only in the last few years that most developed countries have had access or even networks on the Internet. While the Internet is dependent upon a reliable telecommunications system, most such networks in developing countries are either badly maintained or obsolete and often do not have the requisite bandwidth to support e-learning activities. In many developing countries, such networks belong to government agencies and are usually under-funded. A second obstacle is the lack of skilled personnel who are capable of implementing and maintaining an e-learning environment. According to ILO statistics, for instance, less than 1% of employed workers in Africa are professionals with an IT background [21]. All these factors, together with the lack of financial resources, have contributed to the slow growth in e-learning in engineering education in developing countries to date. While the progress is slow, a framework for sustained growth could be created through collaborative efforts, especially among institutions in developing countries and partnerships with institutions in developed nations.

POTENTIAL FOR E-LEARNING COLLABORATION IN ENGINEERING EDUCATION WITH DEVELOPING NATIONS

Engineering education relies heavily on capital-intensive laboratory equipment. Collaboration with developed countries would, therefore, be one path to enhance learning in engineering education for developing countries. As seen previously, several attempts have been made, but these are mainly in the social sciences. A collaborative laboratory component can bridge the gap between regular e-learning and e-learning in engineering. This can be achieved through an Internet laboratory.

Several Internet-based laboratories have already been developed and have been described elaborately by Heck et al [22]. Most of these laboratories are based on standard hardware systems, such as those provided by National Instruments (NI), and are commercially available. However they are costly and often require specialised training. The solution is to develop low cost systems that rely partially on expensive hardware at the server and open software at the client. Such a system has been developed and tested successfully by the authors [7][23]. The hardware of choice is NI's I/O cards. These are easily set up and configurable to use with any suitable input or output device. *LabVIEW* is used mainly to configure the I/O cards and develop the graphical user interfaces (GUIs) at the host computers. These GUIs are referred to by NI terminology as virtual instruments (VI). To complement access to an experimental facility or remote access by any other client, a low cost software would be utilised, especially if the client cannot afford NI products.

One useful software that has been successfully tested is *LabVNC*, an open source utility that utilises the open-source Virtual Network Computing (VNC) protocol to allow access to a VI. Therefore, the remote system or client requires only an Internet browser, since this software is free. A typical example of the *LabVNC* user interface is shown in Figure 1. The advantages of this technique are as follows: data can be collected from any location; algorithms can easily be incorporated for real time data processing; and it uses open

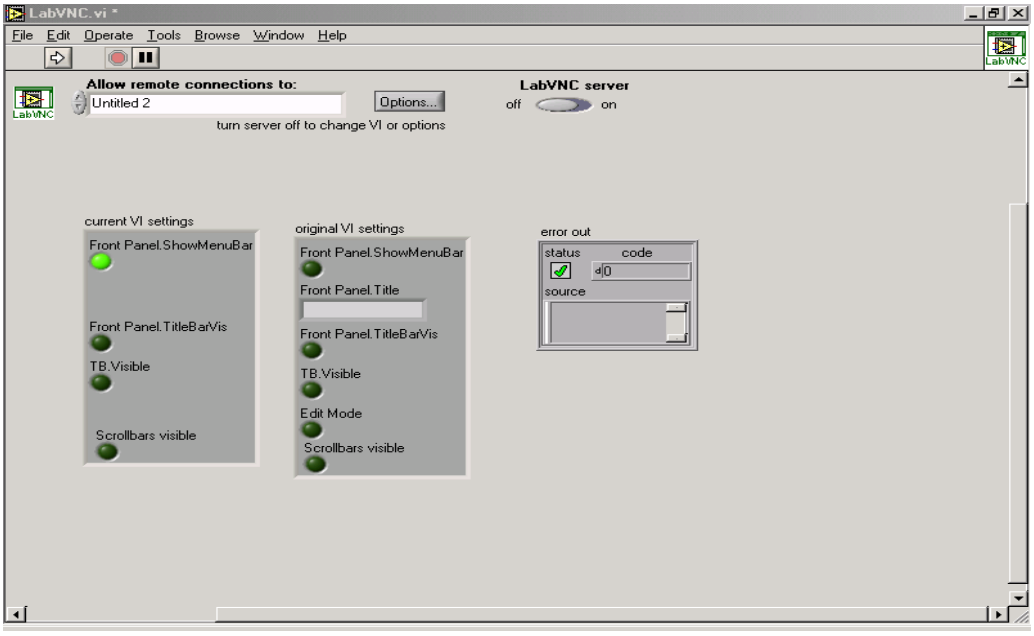

Figure 1: The *LabNVC* user interface as seen from a popup on a browser.

software that interfaces easily with *LabVIEW* VIs. Research is currently underway to incorporate video feedback so that the remote user can visualise the experiment as well. As such, it is envisaged that with such a technique in place, performing experiments in real time over the Internet will be achieved, thereby enhancing e-learning in engineering education.

CONCLUSIONS

Although the Internet has transformed the way in which learning can be delivered, the role of technology in learning must be carefully balanced and recognised as a means to an end and not an end in itself. It is not about what can be done or what is possible, it is about what aids the learning process. Behind the e-learning revolution is a consumer demand, and service providers must not make the mistake of thinking they are in computers rather than in education.

There is a need to extend access to learning engineering by continually adapting technology to respond sensitively to the differing needs of new and excluded learners. Transforming learning can change lives. In the end though, if supported, e-learning is indeed a revolution, a very conventional one. It is still all about social change, increasing opportunities for everyone, crossing modern boundaries and electronic lines.

Innovations are required to accomplish e-learning in engineering education. The innovations will make e-learning personal, providing an opportunity throughout life for the learner to take advantage of when he/she is ready, supporting him/her in terms of tutors, learning materials, careers advice, an opportunity to try out examinations and, eventually, to practice hands-on practical techniques through computer simulations when it is relevant to the qualification. It is about building confidence and building competences. The move of the engineering educational sector into e-learning will continue to inspire substantive research in all engineering disciplines to implement efficient learning methods. Meanwhile, there is a need to develop a portfolio of skill sets that will be updated as jobs or roles evolve.

For engineering educators, the accuracy, flexibility and performance will make e-learning systems the premier learning tool. E-learning providers will be truly on the cutting edge of technology by allowing clients (learners) the ultimate learning assessment and examinations in engineering education.

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