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Developing Digital Courseware for a Virtual Nano-Biotechnology Laboratory: A Design-based Research Approach

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ABSTRACT

This paper first reviews applications of multimedia in engineering education, especially in laboratory learning. It then illustrates a model and accreditation criteria adopted for developing a specific set of nanotechnology laboratory courseware and reports the design-based research approach used in designing and developing the e-learning material. According to findings of the present study, the courseware developed satisfies the "e-Learning Courseware Quality Checklist version 3.0" in most dimensions. This paper concludes by presenting the researchers' findings and problems encountered in this ongoing study, and it describes a future study plan that will include the student input regarding these laboratories. This study should contribute to the innovative use of technology in facilitating engineering laboratory learning and in instructional design practice and research.

Keywords

E-learning, e-Learning Courseware Quality Checklist, Instructional design, Virtual nano-biotechnology laboratory, Nanotechnology

Introduction

Nanotechnology, which is the science, engineering and technology conducted at the nanoscale (United States National Nanotechnology Initiative, 2000), is a cutting-edge technology with great potential, and it is widely applied in many fields with inter- and cross-disciplinary approaches (Guggisberg, Fornaro, Gyalog, & Burkhart, 2003). Since the invention of the scanning tunneling microscope (Binnig, Rohrer, Gerber, & Weibel, 1982) opened the era of nucleation tools and applications studies, applications and research on the nanometer scale have prospered. However, nanotechnology laboratories are often expensive and of limited usage, so teaching nano-science with such equipment is rarely possible in practice. Considering the needs of today's nanotechnology engineers to be well educated in all aspects of nanotechnology design and implementation, efforts have been made to facilitate the investigation with the scientific process, a core competency in engineering education usually demonstrated through laboratory skills and performance. The current rapid growth in research to explore sound pedagogical methods in teaching interdisciplinary subjects of nanotechnology aims to improve student learning of relevant laboratory skills (Adams, Rogers, & Leifer, 2004; Sullivan et al., 2008; Swiss Virtual Campus, 2000; Tahan et al., 2005; Yueh & Sheen, 2009).

Along with the development of information and communication technology (ICT), which includes audio/ video instruction, computer-assisted instruction, intelligent tutoring systems, internet/ web-based instruction, and current Web 2.0 technologies, a substantial body of research has focused on the search for effective applications of technology in support of teaching and learning in various fields. The use of multimedia resources allows an integrative presentation of messages. In recent practice in engineering education, multimedia resources have become essential in teaching complicated engineering concepts and in demonstrating skills more vividly (Fernandez et al., 2011; Walker, Stremler, & Brophy, 2008). As Mayer (2001) argued, multimedia, when used in support of learning, can help learners not only to recognize and retain the presented materials but also to construct a coherent mental representation of what they have learned.

The virtual laboratory has been widely applied in science and engineering education in different formats. Through the use of different tools and platforms, laboratory exercises and experiences can be conveyed by wide-area network bandwidth on the Internet and satellites that allow remote access (Forbus et al., 1999; Wyatt, Arduino, & Macari, 1999), and such experiments can be presented by two- or even three-dimension simulated virtual environments (Dalgarno, Bishop, Adlong, & Bedgood Jr., 2009; Hwang, 1996; Wolf, 2010). For example, some studies have designed web-based modules that simulate laboratory assignments, and students interact with these learning modules virtually (Koretsky, Amatore, Barnes, & Kimura, 2008; Watkins, Hall, Chandrashekhara, & Baker, 2004). Other studies have combined remote and local laboratories so that students can manipulate real laboratories devices by performing simulated activities with web interfaces (Ogot, Elliot, & Gulmac, 2003; Sivakumar, Robertson, Artimy, & Aslam, 2005; Spanis & Atti, 2005). Still others have advocated the importance of providing students with flexible access to information on the underlying concepts behind experiments and laboratory work, and intelligent tutoring systems have been developed to facilitate learning in the virtual laboratory environment (Yueh & Sheen, 2009).

With virtual laboratories being applied so widely in engineering education, the effectiveness of these practices has been the focus of many studies (Hurley & Lee, 2005; Koretsky, Amatore, Barnes & Kimura, 2008; Ogot, Elliot, & Gulmac, 2003; Sivakumar, Robertson, Artimy, & Aslam, 2005; Spanias & Atti, 2005). As Reilly (2008) noted, virtual laboratories, whether accessed locally or remotely, have the potential to provide greatly enhanced and more effective deep-learning experiences. Although such innovations look promising and enhance student learning, many educators and researchers have encountered problems with judging the quality of multimedia design and its effect on learning improvement. It is also our belief that multimedia virtual laboratories, which are particularly suitable for learning about nanotechnology, require a quality assurance framework for their design, with emphasis placed on student-centered learning experiences. Thus, this paper reports on one cycle of designed-based research (DBR) in which e-learning courseware for a nanotechnology virtual laboratory was developed and the e-Learning Courseware Quality Checklist version 3.0 (eLCQC 3.0) was used for quality assurance. The description of the emergence of a new virtual nano-bio engineering laboratory and the preliminary iterative analysis of the quality of its design could be interesting to the wider research community, and that information could be useful in setting up further studies and in the development of other courseware.

The eLCQC quality assurance framework

Quality assurance has been gaining attention from both educators, who adopt multimedia or e-learning approaches, and practitioners, who design and produce courseware for virtual laboratories. Pawlowski (2007) indicated that although many e-learning producers and users are aware of the importance of quality issues, they lack appropriate methods or tools for measuring the quality of their e-learning courseware. Institutions in several countries have begun efforts to promote e-learning quality. For example, the American Society of Training and Development (ASTD) has established an E-Learning Courseware Certification (ECC) program that employs a tool based on quality criteria and provides quality assurance services to organizations for their e-learning courseware accreditation (Sanders, 2001). The European Foundation for Quality in E-Learning (EFQUEL, 2007), having developed the UNIQUe certification system, issues an e-learning quality label for ICTs. FuturED, a non-governmental organization, has cooperated with the federal government in Canada to build an e-learning courseware and service quality assurance program, the Open eQuality Learning Standards (OeQLS), and the eQcheck certification, to protect e-learning consumers. Taiwan, similarly, has established the E-Learning Quality Certification Center (ELQCC) (Sung, Chang, & Yu, 2011).

The standards or criteria developed by those institutes, which all intend to promote the quality of e-learning, focus on different details of the features they check. More important is the fact that although they are used mostly for evaluating product quality, they could also be used as a framework for the design and development of e-learning materials or courseware. With this application in mind, this study adopted eLCQC 3.0 (Taiwan E-Learning Quality Certification Center, 2007) developed by the ELQCC in Taiwan as the quality assurance framework to scaffold the design and development of e-learning courseware for a nano-biotechnology laboratory. Although many quality frameworks are also available for examining e-learning courseware quality, the aspect of a specific context that learner experiences develop upon is considered the most important of all in the selection of the framework for quality assurance (Inglis, 2008). The eLCQC 3.0, which is designed for assessing the key quality factors of all aspects of e-learning courseware, was originally developed as part of a national project funded by the government of Taiwan. It consists of five dimensions (Table 1) that are intended to encompass the range of functions involved in supporting a good practice of digital courseware. In use, it is also intended to be contextualized to the setting of a courseware producer. Taking into account the value of the contributions of eLCQC 3.0 to assessment and improvement of e-courseware quality, it is recognized as a fit and adequate framework for this study. The original eLCQC was first issued in 2005, and the latest version, 3.0, was published in 2007. Built upon the perspectives of learner, instructor, courseware developer, and e-learning project manager, eLCQC 3.0 consists of five dimensions: content, navigation and tracking, instructional design, instructional media, and creativity. Each dimension consists of 3 to 6 standards, for a total of 19 standards. Additionally, except for those standards under the dimension of creativity, each standard has 2 to 3 criteria for the evaluation of e-learning courseware. Table 1 summarizes the specifications of eLCQC 3.0.

Table 1. Specification of eLCQC 3.0

Dimension	Standard	Description of Criteria
1. Content	1.1 Accuracy 1.2 Organization & Completeness	The e-learning courseware must provide accurate learning content with appropriate organization and concise presentation so that learners are able to achieve successful learning.
2. Navigation and Tracking	2.1 Navigation 2.2 Orientation & Help 2.3 Learning Tracking	The e-learning courseware must provide relevant mechanisms for guiding learners through the course smoothly so that learners can effectively control and monitor the pace and progress of their personal learning.
3. Instructional Design	3.1 Instructional Objectives 3.2 Instructional Methods 3.3 Practice & Formative Evaluation 3.4 Summative Evaluation 3.5 Facilitation Strategies 3.6 Congruence	The e-learning courseware must be consistent in the instructional design, thereby providing learners with concise learning goals, adequate presentation of instruction, and appropriate learning strategies. The learners can benefit from this design with improved understanding of the contents, good learning interactivity, and appropriate evaluation and feedback.
4. Instructional Media	4.1 Media Design & Use 4.2 Interface Design 4.3 Media Elements	Effective utilization of the instructional media, aesthetically pleasing interface design, and instructional media design and production are essential to the enhancement of learning and comprehension.
5. Creativity	5.1 Content 5.2 Navigation & Tracking 5.3 Instructional Design 5.4 Instructional Media 5.5 Other	To promote the “Creativity” of presentation in the e-learning courseware, creative examples should be highlighted, ranging from the instructional contents and learning guides to instructional design, instructional media, and other sections.

To determine the reliability of eLCQC 3.0, Sung, Chang and Yu (2011) analyzed its item difficulty, item discrimination, and generalizability. They confirmed that the eLCQC can effectively discriminate differences in quality in the courseware. As a result, eLCQC 3.0 was used in the present study, and it was coupled with DBR to refine the development process of the courseware of one unit of a virtual nano-biotechnology laboratory and to evaluate the effects of this effort in improving e-learning quality.

Design-based research

For research involving the development of teaching and learning innovations or the systematic design and study of instructional strategies and tools, design-based research (DBR) is commonly employed as a research method framework (Barab & Squire, 2004; Brown, 1992; Collins, 1992; Dede, 2004). DBR is an emerging paradigm for the study of learning in context, especially in technology-enhanced learning environments. The use of DBR enables educational researchers to grasp problems through its iterative development and emphasis on authentic contexts, and it allows a better understanding of the goals and implications of the research (Joseph, 2004). DBR methods focus on designing and exploring the whole range of designed innovations to optimize the design as much as possible. The Design-Based Research Collective (2003, p5) proposes that good DBR exhibits the following five characteristics:

> "(1) the central goals of designing learning environments and developing theories or "proto-theories" of learning are intertwined. (2) development and research take place through continuous cycles of design, enactment, analysis, and redesign (Collins, 1992). (3) research on designs must lead to sharable theories that help communicate relevant implications to practitioners and other educational designers. (4) research must account for how designs function in authentic settings. (5) the development of such accounts relies on methods that can document and connect processes of enactment to outcomes of interest. Therefore, DBR provides numerous opportunities for the exchange of expertise across disciplinary boundaries" (p. 5).

DBR, a pragmatic research approach, has gradually received extensive attention in various fields of engineering education, including the nanotechnology field (Middleton, Gorard, Taylor, & Bannan-Ritland, 2008). Since DBR aims to make sense of the complexity inherent in the authentic context, it is considered appropriate for research on applying knowledge to consequential problems and reflecting on that endeavor (Rick & Guzdial, 2006). In the present study, researchers, who were also instructional designers and content experts, applied DBR to the courseware development environment for setting up a virtual nano-biotechnology laboratory. In order to explore how a quality assurance framework, such as eLCQC, can be used in developing, enacting, and sustaining a better learner experience, DBR was used to inform and improve the development of e-learning courseware for nanotechnology learning.

Method

The context of the virtual nano-biotechnology laboratory

The unprecedented growth of online educational resources led Kilmeck, McLennan, Brophy, Adams and Lundstorm (2008) to affirm that in nanotechnology, as in other disciplines, the web is expanding our concept of classroom instruction, changing what is learned and how it is learned. This affects how students learn in class, and new types of nanotechnology learning activities and resources can help meet the educational needs of all groups of learners by improving their access to learning tools typically unavailable in the classroom. As part of an effort to enhance both laboratory and interdisciplinary learning, the "Nano-bio Technology Laboratory Corridor (NBTLC)" was established as the first group of laboratories to combine nano-manufacturing and biomedical science manufacturing processes in higher education in Taiwan (Sheen, 2007). The basic idea of NBTLC is a metaphor of open laboratories; it supports both independent laboratory work and integrated interdisciplinary learning laboratories. To further advance the idea and practice of NBTLC, a "Virtual Nano-bio Technology Laboratory Corridor (V-NBTLC)" was constructed as a supplemental learning space for the NBTLC. It represents a virtual portal to NBTLC with integrated multimedia design, and it offers digitized learning materials such as laboratory handbooks, conceptual lectures, instrument illustrations, step-by-step skill and procedure demonstrations, and some virtual and remote-controlled experiments of the four laboratories (Yueh & Sheen, 2009). Under the larger context of V-NBTLC, courseware on Atomic Force Microscopy (AFM) was developed in this study as a case that exemplifies the DBR approach of using eLCQC 3.0 to scaffold the design process and assure the quality of the learner experience in the virtual nano-biotechnology laboratory.

Designing the learner experience of AFM courseware

In order to facilitate the AFM courseware production process, the development team applied the "e-learning project development model" (Yueh, 2005), which includes the following phases: management and feedback, course analysis, material production, presentation and interaction, and learning and evaluation. The development team consisted of two expert groups, one group with the expertise in instructional design and the other group with expertise in the subject matter of nanotechnology. These two groups worked closely to confirm the purpose, structure, sequence and presentation of the courseware. Two researchers of the study were involved and responsible for coordination in each team, respectively. Figure 1 illustrates and emphasizes the actual tasks, process, and communication between the two groups.

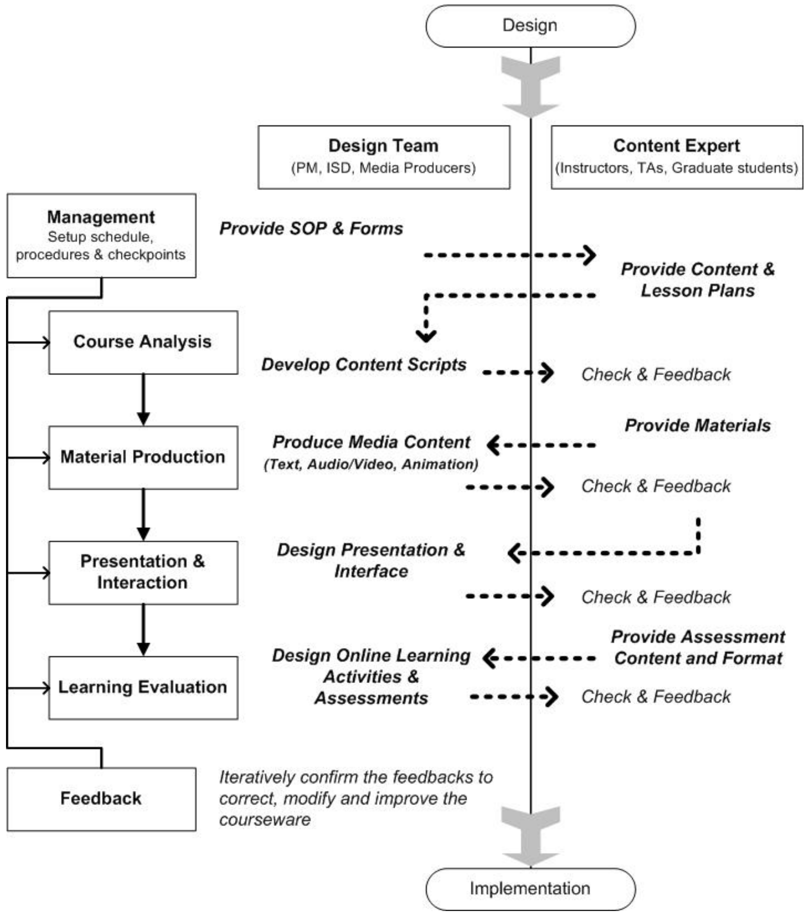

Figure 1. The e-learning project development model

Furthermore, researchers adopted eLCQC 3.0 to scaffold the design process and to evaluate the quality of AFM courseware mounted on V-NBTLC. DBR enables researchers to explore possibilities for novel learning and teaching environments; develop contextualized theories of learning and teaching; construct cumulative design knowledge; and increase the human capacity for innovation. Therefore, it was adopted as the research method framework for this study.

Throughout the process of courseware development, it is necessary to conduct progressive and iterative review and revision of the instructional design plan and output according to DBR (Design-Based Research Collective, 2003). To achieve this goal, researchers employed designer self-evaluations and content expert evaluations, as illustrated in Figure 2. In the course analysis phase, instructional designers first conducted a needs analysis by collecting information from subject-matter experts. Following the needs analysis was the first designer self-evaluation. Then the second designer self-evaluation and the first expert evaluation were performed, after which multimedia producers began the material production module of courseware development. When the courseware was officially implemented, two more designer self-evaluations and expert evaluations were performed before and during the presentation and interaction phases. In the learning and evaluation phases, one more expert evaluation and the learner/user evaluation were performed. Every action in the production of the AFM courseware, including analysis, design, development, implementation, and evaluation, passed through a review based on the eLCQC framework before the next step could begin. The three basic components of enactment, review, and revision formed a dynamic courseware developmental structure in this case.

This study reports the development and research of one of the cycles of the abovementioned dynamic structure. The researchers consisted of professional instructional designers and content experts of nanotechnology, who collaborated with a multimedia production team and a group of subject-matter experts through three phases of initial needs analysis, design, and development. The first two designer self-evaluations and first expert evaluation were conducted to serve as the progressive review and to collect comments, problems, and suggestions on refining the design plan in order to continue the design and development. Informal interviews were conducted, using eLCQC 3.0 as an analytical framework. The third designer self-evaluation and second expert evaluation integrated eLCQC 3.0 as a quality audit tool. While it was a review of the DBR process, the preliminary evaluation of the AFM courseware prototype was also considered. For data collection, the eLCQC 3.0 checklist was completed by five reviewers. The reviewers were instructional designers and experts on multimedia and content.

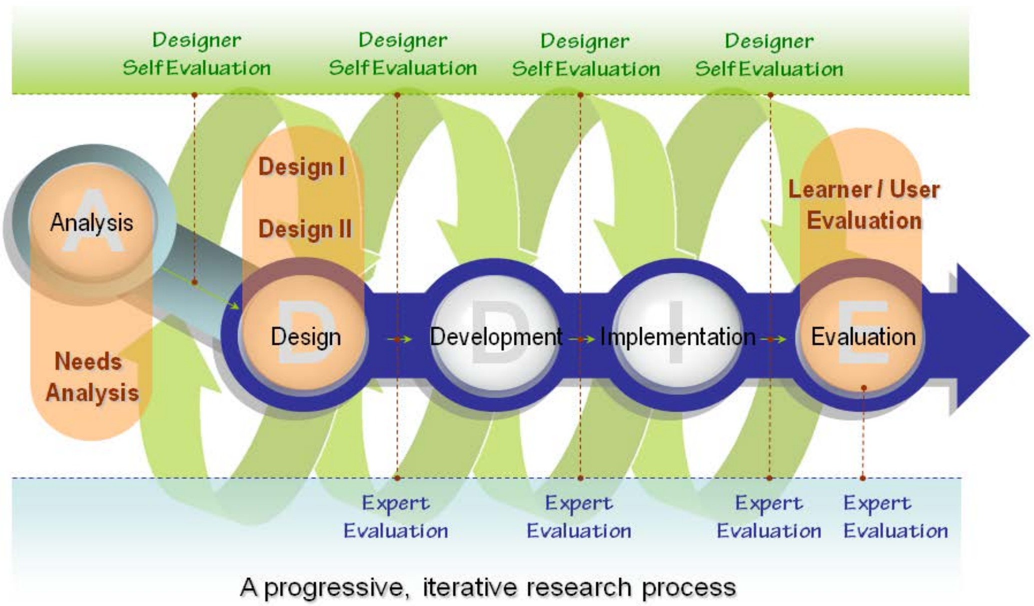

Figure 2. The DBR process of designing the learner experience of AFM courseware

Results

Production of the AFM laboratory courseware

The AFM courseware based on the framework of eLCQC 3.0 was first constructed from the needs identified from interviews with content experts. These included the instructional objectives of the course unit and purposes of developing this e-learning courseware. The target audience, instructional objectives, content to be covered thoroughly, in terms of broadness and depth of learning, and the content representation and organization strategies were thus defined and reviewed before the actual design stage began. Considering the smooth navigation functionality that e-learning must provide, the AFM courseware was carefully laid out with proper guidance, orientation, tracking, and interface designs (see Figure 3). To effectively deliver the learning contents to students at a distance, the e-learning courseware of AFM used diverse instructional methods with clear media presentation and multimedia design strategies (see Figure 4). To facilitate and ensure effective learning, the practices and the formative and summative evaluations were incorporated into the interactive and feedback designs (see Figure 5). Furthermore, the designers, working with content experts, carefully checked that instructional objectives, content design, and evaluations were consistent, and they also made sure the AFM courseware included creative design that would motivate students and lead to a successful learner experience in the virtual learning environment.

The courseware development process of collaborative scaffolding encouraged interactions among instructional designers, content experts, and the media production team; facilitated joint problem solving; led to richer construction or revision of instructional planning; and took into account different and emerging roles, joint goals, and actions. It also facilitated the fusion of multiple interpretations. Under the DBR process, the cycles of enactment (such as course or need analysis, learning design, and material production), review, and revision were conducted. The outcome at the end of each cycle was an explanatory framework based on eLCQC 3.0 that specified expectations as the focus of inquiry during the next cycle. The generic courseware architecture of AFM would also be re-used to produce a new prototype courseware for V-NBTLC.

Figure 3. User interface design

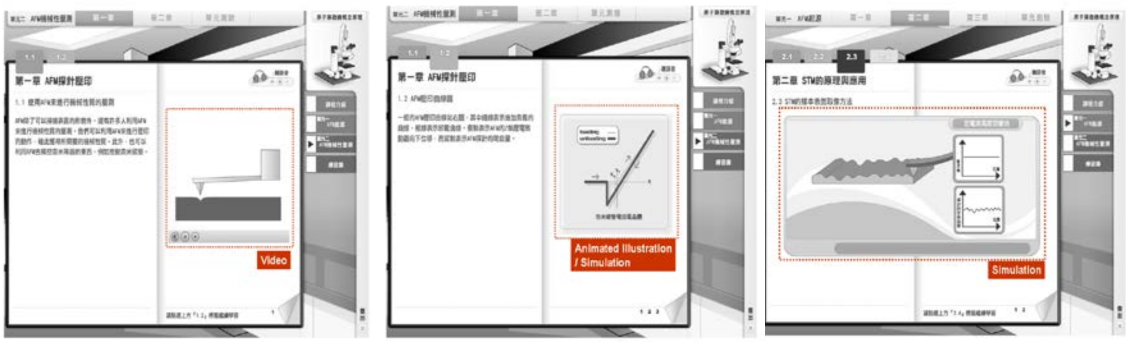

Figure 4. Media design (video, animation, interactive media)

Figure 5. Assessment and feedback design

Preliminary evaluation of the AFM laboratory courseware

At completion of the prototype of AFM courseware, researchers conducted a preliminary evaluation, similarly based on the eLCQC 3.0 framework, in the form of a survey of five reviewers consisting of instructional designers and experts on multimedia and content. The survey checklist, developed according to eLCQC 3.0, included five dimensions, with 19 standards specified. Under each standard, 2 to 3 criteria were also included. For each criterion under one standard, the reviewer was asked to award 0-3 points, depending how many criteria the AFM courseware met. For example, the highest possible score of the standard “1.1 accuracy” was 9, and the lowest was 0. The score range of each standard and the preliminary evaluation results are shown in Table 2. In general, these experts awarded this courseware middle to high evaluations (a total score of 73.25 out of 106). This implies that use of the eLCQC framework, applied along with the DBR approach, enabled the AFM courseware development team to construct a common quality assurance and inspection scheme to help achieve quality in learning design.

Table 2. Preliminary evaluation results of designer and expert review

Dimension	Standard	Score range	Average score	Total
I. Content	1.1: Accuracy	0-9	9.00	17.25
	1.2: Organization & Completeness	0-9	8.25	
II. Navigation and Tracking	2.1: Navigation	0-9	6.75	9.75
	2.2: Orientation & Help	0-6	3.00	
	2.3: Learning Tracking	0-6	0.00*	
III. Instructional Design	3.1: Instructional Objectives	0-6	6.00	32.75
	3.2: Instructional Methods	0-9	4.50	
	3.3: Practice and Formative Evaluation	0-9	6.75	
	3.4: Summative Evaluation	0-6	4.00	
	3.5: Facilitation Strategies	0-4	2.50	
	3.6: Congruence	0-9	9.00	
IV. Instructional Media	4.1: Media Design & Use	0-6	6.00	13.00
	4.2: Interface Design	0-4	3.50	
	4.3: Media Elements	0-4	3.50	
V. Creativity	5.1: Content	0-2	0.25	0.50
	5.2: Navigation & Tracking	0-2	0.00	
	5.3: Instructional Design	0-2	0.00	
	5.4: Instructional Media	0-2	0.25	
	5.5: Other	0-2	0.00	

Note. *The prototype did not include the tracking function that would be set up in the platform.

Discussion and conclusion

Findings and discussion

Despite the results indicating acceptable quality, not all of the reviewed dimensions and standards were of good quality. In particular, the creativity in instructional design was found to be the most insufficient. While the standards under the creativity dimension had no specific criteria, it seemed to the courseware development team that the guidance was comparatively limited. Thus, to accomplish creative learning design in all aspects, namely, content, navigation and media design, was quite challenging. In other words, it was necessary to provide substantial assistance embedded within a quality assurance framework to inspire the designers towards more creative design. One more issue should be raised in our preliminary evaluation. All of the input or feedback considered and analyzed in the present study were from the perspectives of designer practitioners or experts. If the aim is to develop more inclusive virtual learning of high quality, it is necessary to include more diverse voices, such as those of experienced senior students, laboratory assistants, or professional engineers in nanotechnology, at the beginning of courseware production. To achieve this attempt, the potential learners or experienced learners of previously developed courseware included in V-NBTLC will be identified and recruited to serve in the group of reviewers for quality checking. By doing so, a participatory approach of involving learners or content users in the quality assurance mechanism of courseware development can be promoted (Jung, 2011). In addition, reliable research data on the review and evaluation sessions of DBR have yet to be obtained. According to Hevner, March, Park and Ram (2004), five classes of evaluation methods are available for research consideration, including analytical, case study, experimental, field study, and simulation methods. To maintain the collaborative scaffolding of courseware development, using a mixed method to collect both qualitative and quantitative data under DBR may result in better outcomes.

Implications and conclusion

This study reports a new courseware development approach for the establishment of a virtual nano-biotechnology laboratory that considers the e-learning material quality assurance principles in combination with DBR. The overall results of this study should provide systematic, empirical evidence on the quality of AFM, the e-learning courseware evaluated. According to this study, the reflection of courseware development and the preliminary evaluation results provided by a group of experienced multimedia and e-learning specialists support that the courseware developed satisfied the standards of eLCQC in most dimensions. However, several suggestions to improve the design were made, such as providing more examples of creative learning design practices in either nanotechnology or other fields, considering the use of alternative pedagogies, adding more browsing or navigation guidelines, and providing a course map of the tutorial. As this is an ongoing study, researchers will continue the process of implementation and evaluation based on the same dynamic courseware developmental structure, which consists of enactment, review, and revision in compliance with DBR. In the future, the focus group method will be adopted for brainstorming and systematic review discussions. To be included in this focus group of quality assurance are content experts, instructional designers, multimedia producers, and courseware users or learners. In addition, feedback on the quality framework of eLCQC 3.0 will be collected and in turn will form an integral part of the process of validation of the framework. Additionally, researchers will further implement this V-NBTLC in a real educational context on a large scale, and student feedback will be collected to assure the quality of this courseware for future improvement as well. It is expected that through this DBR approach, this study will not only produce quality e-learning courseware but also provide more thorough understanding of design principles of, and theoretical claims about, using technology in facilitating learning in the engineering laboratory, as well as instructional design practice and research.

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