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Abstract

This paper examines the history, utilization and assessment of educational technology and offers some guidelines for implementation. We review Puentedura's SAMR (Substitution, Augmentation, Modification, Redefinition) model of technology integration and its potential alignment with the more familiar Bloom's Revised Taxonomy of educational objectives. We discuss the current state of educational technology in the profession, particularly in the context of emerging technologies and how innovative educators can use technology to transform optometric education.

Key Words: *educational technology, SAMR model, optometric education, Bloom's Revised Taxonomy*

Introduction

We live and work in a world of constantly changing technology. As optometric educators we are part of an industry that interfaces with emerging technologies including digital mobile devices and computer-simulated reality. Within this context — and knowing that our students are accustomed to 24-7 access to anything and everything using their mobile devices — it is natural for educators with an interest in technology to find ways to utilize these resources to enhance student learning and engagement. As educators, we need to use information and communication technology in a manner that helps students acquire the professional skills necessary to succeed in a rapidly changing digital society.

As we implement new technologies in optometric education, we should keep in mind the following advice about integrating educational technology into teaching designed for K through 12 educators:[1]

- Educators usually do not develop technology (software or technology-based materials)
- Technically possible does not equal desirable, feasible or inevitable
- Older technologies can be useful
- Educators will always be more important than technology

Keeping this advice in mind, our goal as educators should be to align technology with curricular goals in a manner that is consistent with what we know about student learning. To this end, this paper examines the history, utilization and assessment of educational technology and offers some guidelines for the implementation of educational technology in optometric education.

A Brief History of Educational Technology

In order to promote student learning, successful educators often embrace innovative strategies that aim to be more efficient, engaging and collaborative than previously used methods. We can classify these methods as technological if they involve the application of scientific or other organized knowledge to enhance teaching, learning or assessment. These innovations can be further classified as either hard technologies (materials and physical inventions) or soft technologies (work processes or instructional templates applicable beyond a single case), both of which have the potential to improve student learning.[2] Thus, educational technology is defined as "the study and ethical practice of facilitating learning and improving performance by creating, using and managing appropriate technological processes and resources."[3]

The modern era of educational technology began in the late 19th and early 20th century with educators using projected visual images to supplement lectures. This initially expensive technology became more affordable and widely used with Thomas Edison's invention of incandescent lighting in the 1890s. This milestone was followed by the introduction of silent instructional film (early 1900s), radio (late 1920s), sound film (early 1930s) and television (1950s).[4] As the 20th century progressed, educators continually employed new technologies emerging from the radio, television and motion picture industries.[1] For example, the U.S. military developed training films for soldiers and the general public as preparation for their respective roles in the war effort. During peacetime, the U.S. military released these media innovations into the public domain, providing civilian educators with additional resources.[4]

In particular, the computer has been central to the evolution of educational technology. Just as the variety of technologies usable in education has increased, so too have the uses of computer-assisted instruction (CAI). Notably, the initial focus of CAI was drill-and-practice rather than the broader applications available today.[2] The earliest uses of computers in education involved mainframe computers whereby the machine quizzed the students on material presented by the teacher. Using punch cards as input, these computers were expensive and cumbersome to use. Since then, the use of integrated circuits led to the development of computers that are smaller and more accessible to teachers and students, representing the first milestone and major turning point in the use of computer technology in education.[2]

The use of computers in education increased dramatically with the commercialization of microcomputers in the late 1970s and early 1980s. Models manufactured by International Business Machines (Armonk, NY), Apple (Cupertino, CA) and RadioShack (Fort Worth, TX) entered the classroom. In 1982, Time magazine's tradition of "Man of the Year" was replaced by the personal computer as "Machine of the Year,"[1] illustrating the microcomputer's prominence in daily life.

Personal computers had a profound impact on the information environment of the 1980s, but their sway increased even more with the advent of the Internet in the 1990s. With the rapid increase in connections to the Internet as the decade progressed, the potential for sharing information at a distance increased and began influencing education in a significant way by lessening students' and teachers' reliance on physical resources in the classroom.[3] Thus, the introduction of the World Wide Web defined a second milestone in the history of computer technology in education.[1]

In 2005, the term Web 2.0 was coined as a way of characterizing the shift from the more static early web to an Internet that included interactive, user-centered web-based tools. Newly available tools included wikis, blogs, image and video sharing and podcasting. A new category of mobile devices was born in 2010, with the introduction of the Apple iPad, which allowed users to download books, videos and much more with a large, high-resolution touchscreen. The New Media Consortium, a not-for-profit organization that explores the impact of emerging technologies, declared tablet devices to be a completely new technology rather than simply a new kind of lightweight laptop computer.[5] The tablet, along with the wide adoption of the smartphone,[6] brought new resources to the classroom and clinical teaching environment. Today, innovative educators are using Web 2.0 tools and mobile devices to create engaging student-centered learning environments.[7,8]

Educational Technology in Higher Education

Higher education is in transition. With changes in the needs of the 21st century learners, educators are shifting from paper-based to technology-integrated classrooms. In parallel with these changes, the National Education Association developed a framework of skills for contemporary learning. Specifically, students today need more than the three Rs (reading, writing and arithmetic); they also need the four Cs (creativity, communication, collaboration and critical thinking).[9,10] Other authority figures have described the educational priority in higher education as "deep learning" defined as the "mastery of content that engages students in critical thinking, problem-solving, collaboration and self-directed learning."[11]

With the ability to electronically access textbooks, e-mail, learning management systems and the Internet, the nature of teaching and learning will forever be changed and transformed.[12] While it is intuitive to experiment with and adopt new technologies, especially for educators with a special interest and affinity for computer technology, it is important to focus on the application of educational tools rather than the actual educational tools that are available.[1] The implementation of educational technology must include careful consideration of how best to apply these tools and materials to existing curricular goals. Evaluation of any new educational tool or process can be challenging. The Substitution Augmentation Modification Redefinition (SAMR) model of technology integration in education offers one way to evaluate the implementation of educational technology.

The SAMR Model of Technology Integration

Popularized by Ruben Puentedura, the SAMR model has been adopted by educators involved in teaching students at levels from kindergarten through higher education. SAMR was created by Puentedura as a response to his experience at Harvard University as a graduate student.[13] The SAMR model is used to describe a hierarchy of integration of technology from Enhancement (substitution and augmentation) to Transformation (modification and redefinition). Puentedura's challenge for educators is to find ways to use technology that do not merely enhance learning but rather transform learning. This model has been used in universities for evaluation of the use of mobile devices for teaching[14] and other learning technologies.[15] It provides a framework to evaluate how computer technology potentially impacts teaching, learning and student engagement.

Substitution

At the first level of the SAMR model, technology is used as a simple substitution for a more traditional educational tool, activity or teaching method. At this stage there is no change in the process or results through the inclusion of technology. In substitution the benefits for students are modest; the new technology may provide a practical benefit such as lower cost or improved efficiency. An often-cited example is the use of a computer and word-processing software instead of paper and pen to complete a writing assignment. An elementary example that is ubiquitous within health education programs is the

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provision of digital course notes rather than paper copies. Other examples that have been utilized in optometric education include recorded lectures or podcasts (digital audio files) to replace traditional lectures.[16,17] Podcasts have been shown to be a popular supplement to conventional teaching in an optometric clinical environment. Perceived benefits include mobility and flexibility.[16] Substitution typically involves a switch from analog to digital technology that generates no functional change.[18]

Augmentation

At the augmentation level, use of technology leads to a functional improvement to the teaching, learning or process that provides a benefit to the student. Videos created to supplement and reinforce course material presented in a traditional lecture, rather than simply replacing the original lecture, exemplify augmentation. Similarly, social media has been used to provide students with additional course resources and access to the instructor outside the classroom. For example, Facebook (Menlo Park, Calif.) was chosen as a supplement to an optometric ophthalmic optics course because of the high proportion of students with an account. A separate Facebook page was created for the course. Students were notified when new materials (summaries, study guides, additional problem sets) were posted and given the opportunity to post comments and questions. The increased collaboration between instructors and students was attributed to students' high interest in social media and frequent access to this platform.[19] Secured testing administered on a student's personal electronic device is an example of augmentation (rather than substitution) if it provides additional benefits to the learning community such as the integration of multimedia into the examination, immediate student feedback of exam performance, or robust analytics for faculty and administrators. Computer assessment software (Examsoft, Delray Beach, Fla.) has been adopted by multiple schools and colleges of optometry, and portable electronic devices are increasingly being used in healthcare and education.[20,21]

One such institution surveyed student experiences with assessment and reported that most students preferred pencil and paper exams. However, the authors partially attributed this perspective to students' unfamiliarity with the software as compared to traditional testing methods. Additionally, they acknowledged that students may not initially recognize commonly reported benefits of computer-based assessments such as more specific feedback and faster scoring.[22]

Modification

A significant change in technology adoption in the classroom occurs at the modification level. The use of, and access to, technology facilitates the redesign of educational assignments and assessments. Modification allows students to analyze their work and their learning process through the lens of technology. An example of modification is the use of collaborative document editing to promote student team work and facilitate real-time communication. We recently observed such collaboration in a capstone course where optometry students analyzed optometric cases to further develop clinical diagnostic and management skills as well as integrate basic science with clinical problem-solving.[23] Google Docs (Google LLC, Mountain View, Calif.), a web-based document management application system, was employed to collaboratively create and edit documents online. A further example is the use of a note-taking app on a mobile device that allows annotation, audio recording, indexing and sorting. Such technology is useful in professional programs such as optometry where the lecture volume is high and time management skills are critical to success.

Redefinition

Redefinition, the final level of the SAMR model, allows significant changes and transformation to occur in the experiences of both students and educators. In Puentedura's conception, technology facilitates the "creation of new tasks, previously inconceivable."[24] The intent is to change traditional tasks and goals through the incorporation of technology in the classroom.

In contemporary illustrations of redefinition, the focus of instruction frequently shifts from the instructor to the student, and the collaboration between peers increases. Examples include student-generated media such as a blog or e-portfolio. Such media could be incorporated into case-based critical thinking exercises described above if it culminates into a student presentation. These resources lend themselves to problem-based learning exercises and case presentations that are common in the optometric curriculum. Alternatively, student e-portfolios can be monitored by faculty during the clinical rotation to ensure that educational objectives are being met, as reported recently by faculty overseeing an emergency medicine clerkship.[25]

Educators can also create new learning tasks, assignments and assessments using a digital platform to create a more immersive experience with virtual reality (VR) or augmented reality (AR).[17] Schools and colleges of optometry are currently using VR simulators for training diagnostic skills such as binocular indirect ophthalmoscopy. Virtual patient encounters and other VR/AR apps have been incorporated into health training programs and are potentially applicable to optometry.[26]

This final level of the SAMR model is difficult to describe because what is possible with technology is constantly being redefined.[27] The distinction between the levels evolves as the perception of what is “inconceivable” changes with the educator’s awareness of new technology and its implementation over time. The final level of SAMR might be viewed as a paradigm shift whereby education has been transformed using technology.

The SAMR Model and Bloom’s Taxonomy

As the foundation of many teaching philosophies, Bloom’s Taxonomy is familiar to many optometric educators.[28] Bloom’s Revised Taxonomy of educational objectives (Remember, Understand, Apply, Analyze, Evaluate, Create) expands upon the author’s original work and provides a framework for teaching, learning and assessment.[28] It provides direction for curriculum development in that it emphasizes higher-level thinking while acknowledging multiple dimensions of learning. The taxonomy has frequently been presented as a hierarchical framework, proceeding from simple to complex. Alternatively, the taxonomy has been displayed unranked, as illustrated by Alan Carrington’s padagogy wheel of mobile educational apps.[8] Coupling the SAMR model with Bloom’s, as originally recommended by Puentedura, may be useful for educators who are familiar with Bloom’s Revised Taxonomy but less experienced with implementing technology in the classroom **(Figure 1)**.

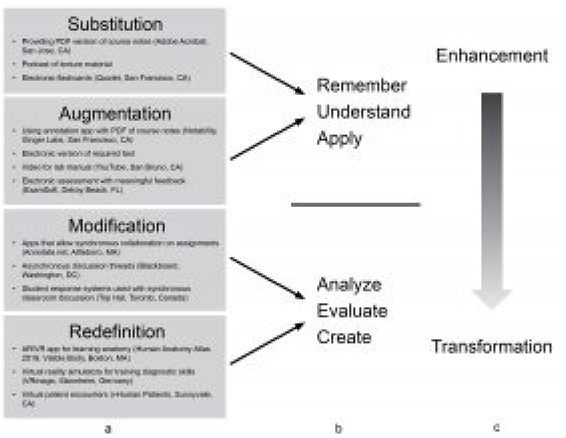

Figure 1. Click to enlarge Puentedura’s SAMR model of technology integration (a) aligned with Bloom’s Revised Taxonomy of educational objectives (b) to illustrate moving from enhancement to transformation (c) in optometric education. For a more detailed illustration applied to mobile devices, see Carrington’s Padagogy wheel V4.0.

According to Puentedura, the goal of an educator is to construct a SAMR ladder that is coupled to Bloom’s Revised Taxonomy.[24] Substitution and Augmentation are coupled with Remember, Understand and Apply, resulting in what Puentedura terms *enhancement*. Modification and Redefinition are coupled with Analyze, Evaluate and Create, culminating in *transformation*. At the transformation stage, deeper learning occurs, consistent with Bloom’s Revised Taxonomy. Thus, the model facilitates the integration of technology with teaching and promotes learning at a higher level.

Applied to optometric education, electronic flashcards help the student *remember* while viewing lecture excerpts from a video-enhanced lab manual help the student *understand*. Electronic assessment with meaningful feedback potentially helps the student to *apply* the information learned in class to a problem set or case-based learning exercise. Student response system apps used with synchronous classroom discussion potentially support the student’s ability to *analyze* in problem-based learning. Asynchronous discussion boards promote student collaboration and the opportunity to *evaluate*. Synthesizing data using a collaborative online white board provides the opportunity to *create*.

Criticism of the SAMR Model

While the SAMR model has been embraced and adopted by many educators, it is not without criticism. It has been noted that, despite its increasing popularity among educators, critical evaluation in peer-reviewed literature is lacking.[13,18] Further criticisms of the SAMR model include the absence of context, rigid structure, and a concern about product over process. We include these criticisms to inform educators of potential pitfalls and to help them apply the SAMR model in a thoughtful manner.

In the field of education, context refers to the characteristics of the learning environment. Specific criticisms of the SAMR model’s absence of context refer to lack of recognition for technology infrastructure and resources, community buy-in and support, and instructor knowledge and support for using technology. Access to the technology does not necessarily lead to its widespread use.[18]

The rigid structure of the SAMR model also concerns some educators who worry that by categorizing technology integration into one of four categories the model dismisses the complexity of teaching with technology. Critics are concerned that there is an emphasis on moving along a hierarchical continuum and this minimizes the important focus of

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using technology in ways to change pedagogy or classroom practices that enhance learning.[18]

Finally, the concern is that with the SAMR model, products remain the focus as one attempts to move to higher levels from enhancement to transformation.[18] Critics warn that educators should not get caught up in the act of adding technology that does not enhance the course or lesson, especially if the instructor has not done his or her due diligence in planning and testing the technology.[29] There are occasions when simply using substitution can achieve an educational objective.

Future of Educational Technology

According to the New Media Consortium Horizon Report, the key trends accelerating technology adoption in higher education are: advancing cultures of innovation, deeper learning approaches, growing focus on measuring learning, redesigning learning spaces, blended learning designs, and collaborative learning.[30] The mention of deeper learning approaches and collaborative learning is consistent with the integration of Bloom's and SAMR discussed previously. Educators are increasingly interested in tools that will allow them to assess student learning. This trend manifests in optometry's recent adoption of computerized assessment and associated analytical tools. Universities are also beginning to redesign learning spaces (the physical environment) to accommodate strategies that incorporate digital strategies and more active learning. These changes are occurring as more educators are accepting the role of online learning and demonstrating increased support for blended learning that combines online learning with traditional classroom methods. Collaborative learning, which involves students or educators working together on group activities based on the idea that learning is a social construct, is also becoming more accepted in higher education.

What tools will be used to support these changes in the use of technology in higher education? Some potential technologies include: AR, VR, artificial intelligence (AI), adaptive learning, Internet of Things, next generation learning management systems, and natural interfaces.[30,31] VR replaces the real world with a simulation while AR provides a real-world environment with digital information overlaying the participant's view. VR can bring the outside world into the classroom, while AR can provide additional information as a student moves through the real world. AI is being used to create intelligent machines that resemble humans in the way they function. Some potential uses of AI in higher education include personalized learning, curriculum evaluation and use of intelligent tutoring systems.[31] AI algorithms are utilized in adaptive learning technologies, which can adjust course content based on ability and skill attainment. Utilizing machine learning, adaptive learning technology adapts to the student in real time.[30]

The Internet of Things is a term used to describe devices connected to the Internet and each other, enabling them to exchange data. We are surrounded by these devices in the form of smart watches, smart TVs, smart thermostats and other networked appliances. Applied to the education sector, this technology enables textbook enhancements, student assessment, individualization of content delivery and group collaboration. In the optometric environment, this could be reflected by further augmenting class assignments or assessments with audio and video using networking devices.

Learning management systems (LMS) are software applications that are used to deliver online course content and monitor student participation. Current LMS place more emphasis on the administration of learning than the learning itself. The next generation LMS will support personalization and play a larger role in formative learning assessment.[30] Natural user interfaces are most commonly found in tablet and mobile devices that respond to taps, swipes and other touching for user input. iBooks with interactive optometric content and clinical resources are currently available.[32,33] Technology is in development that will allow more interaction with smooth glass surfaces, such as a tablet's display, that will create the feel of a textured surface. This will allow more user sophisticated interaction with applications such as electronic textbooks including direct manipulation of three-dimensional images.[19]

Awareness of the history of educational technology is only useful if we apply what has been learned from the past to decisions about the future. As educators we need to be cognizant of the relationship between pedagogy, technology and student learning. The field of educational communications and technology has a history characterized by adopting changes in technology as they become available. From visual, to audio-visual, and then to computer and web-based instruction, educators have been attracted by the opportunity to enrich the learning experience through involvement of the senses.[1] It is an exciting time to be involved in optometric education, especially for educators interested in finding ways to adopt and implement new technologies.

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