Clinical Radiology (2006) 61, 640–648

REVIEW

Radiology education: a glimpse into the future

A.F. Scarsbrook*, R.N.J. Graham, R.W. Perriss

Department of Radiology, John Radcliffe Hospital, Headley Way, Headington, Oxford, UK

Received 6 April 2006; received in revised form 14 April 2006; accepted 20 April 2006

The digital revolution in radiology continues to advance rapidly. There are a number of interesting developments within radiology informatics which may have a significant impact on education and training of radiologists in the near future. These include extended functionality of handheld computers, web-based skill and knowledge assessment, standardization of radiological procedural training using simulated or virtual patients, worldwide videoconferencing via high-quality health networks such as Internet2 and global collaboration of radiological educational resources via comprehensive, multi-national databases such as the medical imaging resource centre initiative of the Radiological Society of North America. This article will explore the role of e-learning in radiology, highlight a number of useful web-based applications in this area, and explain how the current and future technological advances might best be incorporated into radiological training.

Introduction

At the time of writing the long-anticipated radiology integrated training initiative (R-ITI; http://www.riti.org.uk) encompassing an electronic validated case archive (VCA) and numerous computer-based study aids is about to be made available as a groundbreaking teaching resource for trainee radiologists in the UK (Fig. 1). At the same time, picture archiving and storage (PACS) systems are finally being installed into radiology departments across the country. Digital radiology is here to stay and teaching in radiology needs to adapt and embrace these rapidly developing technological advances.

For many years radiology education has revolved around interactive, film-based, small group teaching, didactic lectures and informal tutorials during reporting sessions. With the shift from hard to soft-copy reporting there has been a rapid increase in the use of digital images and computer-based presentations for teaching purposes. Alongside this, there is an emerging vogue for self-directed study using a variety of e-learning resources including CD-ROMs, departmental or web-based digital teaching file databases and educational websites.

A number of prospective observational studies have compared the use of electronic and traditional teaching methods in medical student education and these have shown that computed-aided learning is associated with greater improvements in class ranking and problem-solving ability.[1,2] Although there are many potential benefits from these new digital learning tools, trainee-centred, case-based teaching by experienced trainers remains a core part of the learning process. It is essential that future radiology educational resources are used in an innovative and creative way to avoid losing the interactive aspect of medical education.[3] Research has shown that despite the widespread availability of PACS and other technological advances within radiology departments in the USA, digital technology is frequently under used in radiology teaching.[4]

In previous articles in this series we have covered several important aspects of radiology informatics and discussed the role of a variety of e-learning tools for radiologists including

* Guarantor and correspondent: A.F. Scarsbrook, Department of Radiology, John Radcliffe Hospital, Headley Way, Headington, Oxford, OX3 9DU, UK. Tel.: +44 1865 220815; fax: +44 1865 220801.

E-mail address: andyscarsbrook1@aol.com (A.F. Scarsbrook).

0009-9260/$ - see front matter © 2006 The Royal College of Radiologists. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.crad.2006.04.005

Figure 1 Screenshot of the Royal College of Radiologists and Department of Health Radiology Integrated Training Initiative (R-ITI) website.

web-based educational resources and interactive teaching files.[5,6] This article will explore other exciting developments, including the increasing role of handheld computers in radiology education, assessment of radiological skills and knowledge using web-based interactive teaching files, radiology practical skill training using simulators and virtual patients, and finally, worldwide collaborative applications such as Internet2 and the Radiological Society of North America medical imaging resource center (MIRC), which may have major role in future radiology education.

Handheld computers in radiology

Since their introduction in the early 1990s, handheld computers or personal digital assistants (PDAs) have become increasingly popular for a variety of applications in medicine.[7] The current generation of PDAs are multi-functional and have many useful features including database, spreadsheet and word-processing applications, e-mail and web-browsing tools and digital media players. More information on the different types of handheld computer available and a comprehensive review of their expanding use in radiology is available elsewhere.[8]

The basic functions of PDAs are often very useful to radiologists and these generally include an address book, calendar/scheduler (with alarm reminder function), to-do list and a memo composer, which help organize and prioritize tasks. Data held on the handheld device should ideally be regularly synchronized with the user's desktop computer to ensure backup and maintenance of up-to-date information.

In addition to their basic functionality, there are several other useful features of PDAs for radiologists. First, handheld computers can be used as a flexible research data entry tool once a customized database has been set up on the PDA. This is simple to achieve using a standard spreadsheet or database application such as Microsoft Excel or Access. The data can subsequently be downloaded to a personal computer for archiving and data analysis. Similarly, handheld computers can easily be configured to allow trainees to collect essential radiological logbook data. For those interested in this option, two Scottish radiologists have developed a database based on the Royal College of Radiologists logbook that is free to download from http://www.burgul.com/logbook. This can be installed easily, the only downside being that an addition piece of software must be purchased in order for it to run, although this only costs a few pounds.

Another useful feature of handheld computers is the ability to store electronic books. The use of handheld digital books in radiology was first pioneered by Michael D'Alessandro and colleagues in the mid-1990s.[9] Since then, an increasing number of electronic textbooks and reference materials have become available commercially for radiologists to use on handheld computers. A wide variety of medical and radiological e-books are available for purchase and download from the internet and one of the more comprehensive websites is available at http://www.handheldmed.com (Fig. 2a). The main advantage of this type of electronic study aid is portability when compared with conventional textbooks. Rapid access from the palm of the hand is also an alluring feature. In addition to commercial available electronic textbooks, there are also a number of free educational resources that can be downloaded onto a PDA and may be of interest to radiology trainees. In particular, the University of Wisconsin have produced a PDA version of their Collaborative Hypertext of Radiology (CHORUS to go) website. This provides an extensive database of radiological differential diagnoses and can be downloaded from http://chorus.rad.mcw.edu/to-go/. An excellent website containing links to a wide variety of medically orientated, freely available, PDA software is available at http://www.pdaMD.com (Fig. 2b). Useful example software includes a free drug reference database called Epocrates (http://www.epocrates.com) and a statistics package called EBM Calculator developed by the Centre for Evidence-Based Medicine at the University of Toronto, which automatically calculates the relevant type of statistical analysis needed in different research studies. This software can be downloaded from http://www.cebm.utoronto.ca/palm/ebmcalc.

Figure 2 Screenshots of useful handheld computer websites for radiologists: (a) handheldmed.com; (b) pdaMD.com; (c) Avantgo; (d) Highwire Press.

Rapid access to medical literature is an essential part of most radiologists day-to-day work and free software can be installed onto a PDA to allow Medline© searches to be performed directly from handheld computers provided a wireless internet connection is available. The necessary software, called MD on tap, is available from http://archive.nlm.nih.gov/proj/mdot/mdot.php. In addition, a large number of medical journals are now available online and many allow free access to abstracts and full articles, which can be accessed via a PDA. Before this can be achieved, an application called Avantgo that allows capture and display of web documents on the handheld computer must be installed. This software is freely available from http://www.avantgo.com (Fig. 2c).

Both of the Radiological Society of North America (RSNA) journals, Radiology and RadioGraphics are compatible with this application and more information on how to configure your PDA is provided on the journal websites at http://radiology.rsnajnls.org/misc/pda.shtml and http://radiographics.rsnajnls.org/misc/pda.shtml. Another highly useful and freely available web-based resource is the comprehensive database of e-journals provided by the Stanford University libraries in California, called Highwire Press and available at http://highwire.stanford.edu (Fig. 2d). This website also provides complimentary software that is easily configured to allow the most recent table of contents and article abstracts from selected journals to be automatically downloaded whenever your PDA is connected to the internet or alternatively sent to your e-mail address. In addition, customized alerts can be set up for whenever new articles on a specific subject, e.g. positron emission tomography, are published. In either case the information is stored on your handheld computer for browsing at leisure.

Many new models of PDA have built-in wireless networking capabilities, which can facilitate remote access to departmental intranets and PACS databases.[8] Radiologists from the Beth Israel Deaconess Medical Center in Boston, Massachusetts have utilized this advanced functionality and designed a PDA-based platform for radiology information management and resident education.[10,11] This team developed a simple method of synchronizing web-based departmental and educational resources with handheld computers to provide a mobile alternative to traditional desktop computer-based intranet access. This application requires some background knowledge of computer networking and further details on the processes involved are available for interested parties.[10] Radiology trainees fortunate enough to work in this institution have access to a variety

of resources on their PDAs, including imaging protocols, contact details, resuscitation guidelines and on-call rotas, as well as digital reference books and educational radiology teaching cases.[10] Unsurprisingly the mobile system has proved very popular and surveys performed before and after introduction have shown a statistically significant increase in the number of trainees using PDAs for radiology educational purposes.[11]

Other innovative uses of PDAs in radiology have been described, including the extended role of handheld computers in controlling image and patient data display on high-resolution monitors,[12] and their use as projection devices for Microsoft PowerPoint presentations.[13] These applications illustrate the diverse role of PDAs in radiology teaching and education both at present and in the near future.

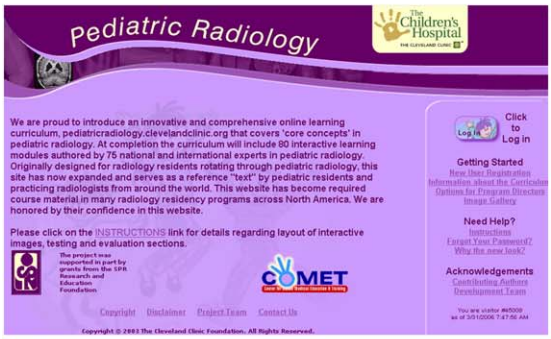
Web-based assessment of radiological skills and knowledge

One of the stated objectives of the R-ITI and VCA in the UK is to help trainees develop the skills required for assessing and interpreting radiological investigations.[14] It is claimed that radiologists will be able to use these resources to undertake self-assessments to test radiological ability and deduction skills once the system becomes available. Meanwhile, radiologists from the University of Erlangen-Nuremberg in Germany have developed a free, web-based radiological knowledge and skill assessment application which allows both intra and inter-subject comparison.[15] This resource attempts to simulate the routine work of a general radiologist using a continually updated database containing over a thousand cases. The application is able to measure the user's ability to recognize anatomical structures and pathological patterns in a variety of different imaging techniques and can analyse performance on a single session, over several sessions or comparatively with other users.[15] The difficulty level can be adapted to take account of prior knowledge and assessments are specifically designed to stimulate learning by linking to other related web-based resources. This project, entitled E-learning in Radiology or ELERA, is highly commendable for its novel interactive approach, compared with many other radiological educational resources and is recommended to trainees as a valuable learning resource. ELERA can be accessed on the web at http://www.elera.de/e/cgi-bin/cpt_newuser.asp (Fig. 3a).

The same group of radiologists have also developed an interactive web-based radiology training program, called COMPARE, available at http://www.evaluation.idr.med.uni-erlangen.de/Ecomparetitlepage.htm, which is designed for medical students and allows users to test and build their knowledge of radiological anatomy[16] (Fig. 3b). The project was designed by a group of students, guided by a radiologist, using an inexpensive and simple to use authoring system and without any specialist information technology input. This helps demonstrate that interactive

(a)

(b)



(c)

Figure 3 Screenshots of useful web-based radiological skill assessment resources: (a) ELERA; (b) COMPARE Radiology; (c) Pediatric Radiology Online Curriculum.

radiology training resources can (and should) be developed with relative ease.

Recently a collaborative group from the Netherlands and Germany have described a strategy for implementing a diagnostic radiology e-learning curriculum for medical students.[17] They developed an integrated learning management system consisting of online courses, a web-based forum for interactive communication and user evaluation using computer-based exams and questionnaires. The new curriculum was effective and increased the efficacy of teaching by reducing the course duration by 50%.[17]

Similarly, a group of paediatric radiologists from America have created a web-based curriculum for paediatric radiology education, which includes comprehensive interactive learning modules each consisting of a presentation, followed by a self-guided quiz, feedback on performance, and finally an evaluation form.[18] This learning tool is freely available on the internet at http://www.cchs.net/pediatricradiology (Fig. 3c). As with all of the web-based applications described above, the continued development of state-of-the-art, interactive and accessible learning packages that incorporate self-assessment and appraisal is vital to enhance future radiology education.

Radiology practical skill training using simulators and virtual patients

Certain radiological skills can be technically difficult to master and increasingly simulation-based training has been used both to maximize patient safety and ensure trainee competence. For example, ultrasonography can be a difficult technique to learn requiring a fine balance of both manual dexterity and visual interpretive ability. One team has evaluated the effectiveness of using a sonographic simulator to assess trainees before unsupervised performance of the technique.[19] The assessment consisted of 10 teaching cases performed on a sonographic simulator (Ultrasim, Med Sim, Fort Launderdale, Florida, USA, http://www.medsim.com/products/products.html) with three-dimensional data from real patients used to test interpretive skill and imaging work-up.[19] This allowed objective assessment and detection of any weaknesses that could be rectified before commencing on call.

More recently, a group of gynaecologists from Munich in Germany designed an ultrasound training system that utilized a software-based simulator allowing creation of a virtual model based on pre-recorded three dimensional datasets from real patients to standardize trans-vaginal sonographic teaching.[20] The technique was developed to overcome the limitations of conventional training, including the embarrassment factor for both patient and doctor, and was found to be comparable to conventional training.[20]

Medical simulators to improve interventional radiological training and provide objective competence testing are currently in development and these show great promise for the future.[21] There is evidence in the surgical literature that colonoscopic and laparoscopic skill training using simulators is directly transferable to real patients.[22,23] At present there is a lack of similar evidence on the validity of virtual endovascular training methods and a joint task force from the RSNA, the Cardiovascular and Interventional Radiological Society of Europe and the Society of Interventional Radiology has been established to develop standards for the use of simulators in this subspecialty area and to investigate the validity of these techniques.[21]

Worldwide collaborative radiology teaching applications

Many radiologists may be unaware of the potential educational uses of Internet2 and related worldwide research and educational networks such as the Medical Imaging Resource Center from the RSNA.

Internet2

Internet2 (http://www.internet2.edu) is a consortium of hundreds of academic institutions around the globe working alongside governmental and industrial partners to design cutting edge network applications capable of providing very high bandwidth connections between educational institutions (Fig. 4). These networks are capable of transmitting broadcast quality video-conferencing streams and are a viable alternative to conventional face-to-face lectures and tutorials. In order to ascertain the status and capability of your own departmental network a software package, called Internet2 Detective, can be freely downloaded from http://detective.internet2.edu. This tool can be used to verify whether or not your local network has an appropriate bandwidth and connectivity to support high quality web-based video conferencing.[24]

A number of collaborative medically orientated educational projects have been developed within

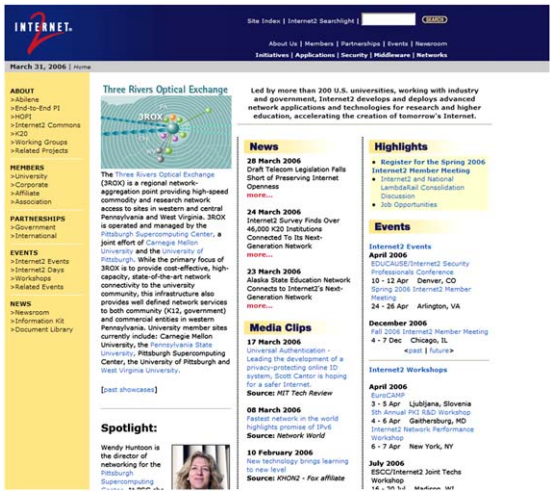


Figure 4 Screenshot of Internet2.edu website.

the Internet2 community allowing interaction between groups at geographically remote locations. Examples include a sophisticated digital anatomy teaching resource,[25] and medical student knowledge and skill testing using problem solving and management of simulated patients.[26] In addition medical education sessions have been successfully conducted by videoconferencing between training centres in Honolulu and Bangkok.[27]

These new academic partnerships are already improving medical education. Hopefully the technologic advances of Internet2 will gradually filter down to the common or garden Internet so that we may all benefit from the great opportunities this medium offers for interaction within the medical imaging community.

Medical Imaging Resource Center

The Medical Imaging Resource Center, or MIRC, is an initiative from the RSNA developed to facilitate sharing of the vast amount of information generated worldwide in radiology, for educational and research purposes[28] (Fig. 5a). The full potential of the project has yet to be realized and at present the software is subject to regular updates.

MIRC provides a simple method of identifying, indexing and retrieving images, teaching files and other radiology information from an increasing number of institutions. It also allows users to search multiple imaging libraries as if they were a single library. A powerful authoring tool is also provided which facilitates creation of radiology teaching files and other electronic documents in flexible formats with a common underlying structure. Finally, the project enables management and

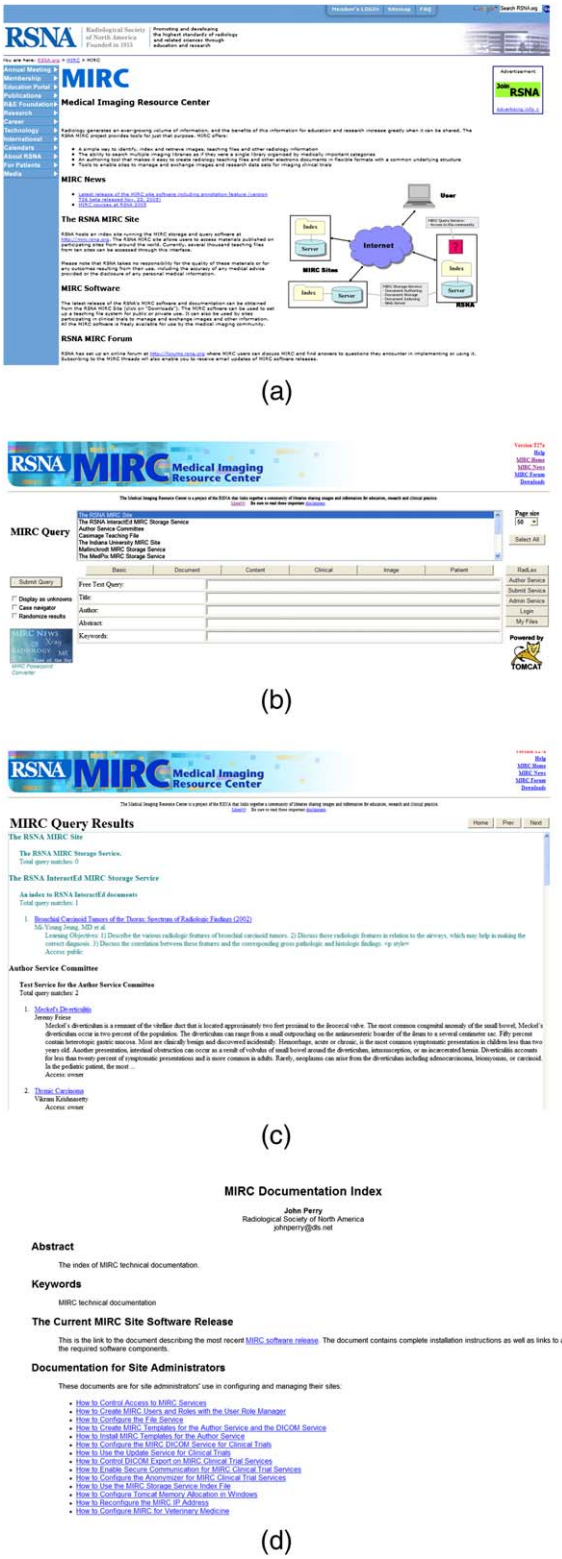


Figure 5 Screenshots demonstrating various aspects of the RSNA Medical Imaging Resource Center server: (a) MIRC homepage on RSNA website; (b) MIRC Query search engine; (c) example of query results; (d) MIRC documentation and download site.

exchange of images and research datasets for clinical trials in radiology.

RSNA hosts a MIRC query service, available at http://mirc.rsna.org (Fig. 5b) which provides a search engine allowing users to access educational resources from participating radiological institutions. At the time of going to press many thousands of teaching files from 15 diverse sites around the world are included in the network.

The MIRC query service is very flexible and allows advanced searching using six sub-categories. The first category, ''Basic'', allows input of a free text query as would be used in a conventional internet search engine such as Google™. The search can be restricted to words appearing in the title or abstract, to a specific author's name or can be done by keywords. The second option, ''Document'', allows searching for a specific document type, e.g. a teaching file. A particular radiological subspecialty can be specified in the category box to narrow the search. In addition, the search can be restricted to a certain difficulty level of teaching case (e.g. intermediate or advanced) or to cases that have been peer reviewed. The third category, ''Content'', enables the search to be confined to specific words within a particular section of a teaching file, e.g. a particular feature of the history or of the imaging findings could be selected. The fourth category, ''Clinical'', allows searching by anatomical location, pathology, organ system or radiological technique. Using the fifth category, ''Image'', the search can be restricted to specific types of image file format, e.g. DICOM files. The type of image compression and imaging technique used can also be specified. The final category, ''Patient'', allows searching by name, ID, medical record number, age, sex, or ethnicity. The ability to search for patient demographic data is particularly useful when using MIRC in clinical trials and research.

Users can conveniently use the ''Select All'' button to run a search of all repositories. Alternatively one or more can be selected in isolation by clicking on them directly. Finally, before submitting the query, the search can be restricted to only those cases that can be viewed as unknowns, by ticking the ''display as unknowns'' box. Search results are displayed in a list by institution of origin and a hyperlink to the particular case is provided (Fig. 5c). MIRC is a powerful resource for rapid access to a huge number of teaching files, and can be used to facilitate radiology teaching and learning.

MIRC software can also be used to set up a teaching file for public or personal use or can be used by sites participating in clinical trials to manage and exchange images and other information. The latest software release is freely available for download from http://mirc.rsna.org. The installation process is described on the website and is a reasonably complex process. Clicking on the ''Downloads'' hyperlink on the MIRC website opens the documentation index (Fig. 5d). Under the heading ''The Current MIRC Site Software Release'', clicking the ''MIRC software release'' hyperlink, opens the latest MIRC release installation instructions, which help guide users through this process with step-by-step instructions. Once installed onto a personal computer, the MIRC software should be used in combination with the Microsoft Internet Explorer web browser. In doing so, the software will appear identical to the MIRC server available via the RSNA website.

The authoring service can be used to create teaching files after first importing images into an image repository known as the ''file cabinet''. Images in the ''file cabinet'' can be added directly into any teaching file at a latter stage. It is relatively easy to create a basic teaching file containing both text and images which can be annotated. Any annotations can be set to only be displayed when they are selected allowing those using the teaching case to test themselves with an option to reveal the diagnosis and show the pertinent imaging features only once the users has had chance to interpret the case unaided.

Individuals and departments who already have an existing digital teaching file stored in a system of folders and subdirectories may wish to make this more interactive and searchable by using free software developed by a technologically gifted group of radiologists from Thomas Jefferson University in Boston, USA.[29] Their software, called MIRCdocbuilder, allows bulk conversion of teaching files into a MIRC compatible format. Further information on this useful application and the necessary software can be obtained from http://www.neuro.tju.edu/MIRCdocbuilder.

Other radiologists have described how to automatically generate teaching file cases directly from PACS using the MIRC DICOM service for clinical trials rather than using the authoring tool.[30] The major advantage of this is that data already present in the DICOM header can be automatically inserted into the teaching file with minimal user intervention. A detailed presentation and a downloadable template of this software is available at http://www.gentili.net/rsna2005web/InforadExhibit9506_files/frame.htm. The same team of radiologists have also developed utilities for converting PowerPoint documents and/or websites into MIRC compatible files which can then be shared over the MIRC server either within a departmental

intranet or the wider radiological community via the World-Wide Web. Further information on these applications and the necessary software downloads are available at http://www.gentili.net.

Recently an enterprising group of radiologists from Singapore have described a novel way of enhancing MIRC teaching cases with multimedia files containing audio and video clips which enhance the enjoyment and learning experience for users.[31]

Establishing a MIRC server on your own departmental network (or an individual computer) offers great potential as platform for collating teaching cases. In our experience the set-up process is somewhat complex and requires a reasonable degree of computer literacy or the help of a friendly network manager or local IT expert. In addition, as the software is still under development there are a few technical problems particularly when upgrading to newer versions of the software. Despite these minor reservations, the MIRC project is highly commendable and a great step forward in allowing worldwide collaboration of radiological data for use in education and research. Users can choose to keep the information solely for use on a personal computer or hopefully, to share with colleagues via a departmental intranet and the rest of the radiological world via the internet. RSNA has set up a MIRC online forum, which can be accessed at http://forums.rsna.org, and is run by John Perry — the lead MIRC software developer; this is a valuable source of answers if there are any queries regarding implementation or use of the software.

Conclusion

As a group, radiologists are in an ideal position to maximize the huge potential benefits to teaching and education of future trainees that the rapid technological advances in medical imaging and radiology informatics are providing. All too frequently this potential is not effectively realized and an understanding of the many areas in which digital radiology education can be used may help direct future efforts. At the same time, it is essential that the interactive element of traditional face-to-face teaching is not lost in the transition to electronic learning. Innovative solutions to this problem have been, and should continue to be, sought. In this article we have explored a variety of exciting areas that will play a major role in the future of radiology education. It is hoped that this article will go some way towards inspiring readers to experiment with the technology we have at our disposal to improve teaching in radiology.

References

1. Makeck M, Fischer MR, Kammer B, et al. Do computers teach better? A media comparison study for case-based teaching in radiology. *RadioGraphics* 2001;**21**:1025—32.
2. Healy DG, Fleming FJ, Gilhooley D, et al. Electronic learning can facilitate student performance in undergraduate surgical education: a prospective observational study. *BMC Med Educ* 2005;**5**:23.
3. Shaffer K. Radiology education in the digital era. *Radiology* 2005;**235**:359—60.
4. Durfee SM, Jain S, Shaffer K. Incorporating electronic media into medical student education: a survey of AMSER members on computer and web use in radiology courses. *Acad Radiol* 2003;**10**:205—10.
5. Scarsbrook AF, Graham RNJ, Perriss RW. The scope of educational resources for radiologists on the internet. *Clin Radiol* 2005;**60**:524—30.
6. Scarsbrook AF, Foley PT, Perriss RW, et al. Radiological digital teaching file development: an overview. *Clin Radiol* 2005;**60**:831—7.
7. Fischer S, Stewart TE, Mehta S, et al. Handheld computing in medicine. *J Am Med Inform Assoc* 2003;**10**:139—49.
8. Flanders AE, Wiggins RH, Gozum ME. Handheld computers in radiology. *RadioGraphics* 2003;**33**:1035—47.
9. D'Alessandro MP, Galvin JR, Santer DM, et al. Hand-held digital books in radiology. Convenient access to information. *AJR Am J Roentgenol* 1995;**164**:485—8.
10. Bursch JM, Barbaras L, Wei J, et al. A mobile solution: PDA-based platform for radiology information management. *AJR Am J Roentgenol* 2004;**183**:237—42.
11. Nishnino M, Busch K, Wei J, et al. Use of personal digital assistants in diagnostic radiology resident education. *Acad Radiol* 2004;**11**:1153—8.
12. Ratib O, McCoy JM, McGill DR, et al. Use of personal digital assistants for retrieval of medical images and data on high-resolution flat panel displays. *RadioGraphics* 2003;**23**:267—72.
13. Yam C-S. Projecting PowerPoint presentations with a PDA. *AJR Am J Roentgenol* 2005;**184**:1356—9.
14. Radiology-Integrated Training Initiative Website, Available at http://www.riti.org.uk (Accessed March 30th 2006).
15. Grunewald M, Heckemann RA, Wagner M, et al. ELERA: a WWW application for evaluating and developing radiologic skills and knowledge. *Acad Radiol* 2004;**11**:1381—8.
16. Grunewald M, Heckemann RA, Gebhard H, et al. COMPARE radiology: creating an interactive web-based training program for radiology with multimedia authoring software. *Acad Radiol* 2003;**10**:543—53.
17. Gotthardt M, Siegert MJ, Schneider S, et al. How to successfully implement e-learning for both students and teachers. *Acad Radiol* 2006;**13**:379—90.
18. Reid JR, Goske MJ, Hewson MG, et al. Creating an international comprehensive web-based curriculum in pediatric radiology. *AJR Am J Roentgenol* 2004;**182**:797—801.
19. Monsky WL, Levine D, Mehta TS, et al. Using a sonographic simulator to assess residents before overnight call. *AJR Am J Roentgenol* 2002;**178**:35—9.
20. Heer IM, Middendorf K, Müller-Egloff S, et al. Ultrasound training: the virtual patient. *Ultrasound Obstet Gynecol* 2004;**24**:440—4.
21. Gould DA, Reekers JA, Kessel DO, et al. Simulation devices in interventional radiology: validation pending. *J Vasc Interv Radiol* 2006;**17**:215—6.
22. Sedlack R, Kolars J. Computer simulator training enhances the competency of gastroenterology fellows at colonoscopy. *Am J Gastroenterol* 2004;**99**:33—7.

23. Seymour NE, Gallagher AG, Roman SA, et al. Virtual reality training improves operating room performance: results of a randomised, double blinded study. *Ann Surg* 2002;**236**: 458—63.
24. Solez K, Hales M, Katz SM. Electronic strategies for information and research. *Kidney Int* 2005;**68**:S89—94.
25. Dev P, Senger S. The visible human and digital anatomy learning initiative. *Stud Health Technol Inform* 2005;**111**:108—14.
26. Alverson DC, Saiki Jr SM, Jacobs J, et al. Distributed interactive virtual environments for collaborative experiential learning and training independent of distance over Internet2. *Stud Health Technol Inform* 2004;**98**:7—12.
27. Vincent DS, Berg BW, Hudson DA, et al. International medical education between Hawaii and Thailand over Internet 2. *J Telemed Telecare* 2003;**9**:S71—2.
28. Medical Imaging Resource Center. Available from: http://rsna.org/MIRC/index.cfm (Accessed April 1st 2006).
29. Flanders AE, Lackey J, Boonn W, et al. MIRC document builder — a simple utility to convert an existing digital teaching collection to MIRC format [Abstract]. *Radiological Society of North America Scientific Assembly and Annual Meeting Program*. Ill: Oak Brook; 2005. p. 868.
30. Gentili A, La Jolla CA, Chung CB, et al. Using the MIRC DICOM service for clinical trials to automatically create teaching file cases from PACS [Abstract]. *Radiological Society of North America Scientific Assembly and Annual Meeting Program*. Ill: Oak Brook; 2005. p. 867.
31. Yang GL, Aziz A, Narayanaswami B, et al. Multimedia extension of medical imaging resource center teaching files. *RadioGraphics* 2005;**25**:1699—708.