Pedagogical Approaches to Diagnostic Imaging Education: A Narrative Review of the Literature

Kathleen L. Linaker DC, DACBR, PhD*

Dean, Center for Life and Health Sciences, Mohawk Valley Community College, Utica, NY

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Abstract

Objective: The purpose of this study was to examine literature on how radiology is taught and learned by both radiology residents and undergraduates in the health professions.

Methods: A review of the literature was performed using relevant key words. Articles were retrieved through December 2012 using PubMed, ScienceDirect, ERIC, Proquest, and ICL databases along with a manual review of references.

Results: Of the 4716 unique abstracts reviewed by the author, 91 were found to be relevant to the purpose of this study. The literature retrieved reported pedagogical approaches to teaching radiology including the following: problem solving, technology as teacher, independent learning tools, visiting lectureships, case based teaching, and conferences. There was some exploration of the relative effectiveness of educational formats. Suggestions for future research identify 7 areas of relative consistency.

Conclusion: Radiology is a clinical skill that requires integration science, clinical information, clinical experiences, and information recorded on diagnostic imaging studies. The research in this area focuses on problem solving, the use of algorithm/scripts, introducing uncertainty in clinical scenarios, incorporating technology in learning environments, active learning techniques, and methods of independent learning. Although the literature in this area is still in its infancy, the research examining the relative effectiveness of these various educational formats is often contradictory, suggesting that this is a complex area of study with numerous factors influencing student learning.

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Introduction

Until recently, only a handful of radiology educators have explored questions relating to how students learn

and how to teach effectively.^{1,2} It is not surprising then that there is little in the radiology education literature exploring these areas of study. This article examines the literature surrounding how radiology is taught and learned by both radiology residents and undergraduates in the health professions because they often share similar needs and use the same resources.³ The purpose of this narrative review is to examine the existing

* Dean, Mohawk Valley Community College, 1101 Sherman Dr, PH301D, Utica, NY 13501-5394. Tel.: +1 716 931 1952; fax: +1 315 792 5697.

E-mail address: katlinaker@gmail.com.

literature that explores how radiology is taught and learned by both radiology residents and undergraduates in the health professions.

Methods

A review of the literature was performed focusing on how radiology is taught and learned by radiology residents and undergraduates. Search engines that were searched through December 2012 included the following: PubMed, ScienceDirect, ERIC, Proquest, and ICL databases, along with manual review of references. The comprehensive sampling strategy used the terms *radiology OR diagnostic imaging AND education OR teaching OR resident OR medical student OR chiropractic student OR curriculum OR medical education OR medical school OR medical students OR medical curriculum OR chiropractic education, OR chiropractic school OR chiropractic students OR chiropractic curriculum*. Articles were limited to those in the English language and to humans.

Results

The resultant 4716 unique article abstracts and/or titles were reviewed by the author. All articles that appeared germane to the pedagogy of diagnostic imaging education were obtained and reviewed by the author, which led to the inclusion of 91 articles in this paper.

Discussion

Pedagogical Approach: Problem Solving

One pedagogical area of interest in medical education literature deals with students' ability to solve problems. Radiology is a clinical problem-solving skill that requires students to be able to integrate what they see on the film with their knowledge of anatomy, pathology, and clinical information. This ability, combined with the use of an adaptable radiographic search pattern, has been shown to correlate with successful interpretation of radiographs.⁴ The article "Problem-Solving Model in Radiology for Medical Students"⁵ suggests that the use of algorithms will improve students' ability to develop this skill set. The authors propose that

radiology, with its multitude of rapidly developing imaging techniques and associated escalating costs, demands that students become proficient medical decision makers. Nonclinical issues such as cost-effective use of imaging modalities, safety, and patient comfort incorporated into the clinical decision-making process have been discussed in the literature for some time.^{6–10} A senior-level course, using small groups with faculty guidance to develop investigative plans in imaging, allows the students to learn to develop algorithms designed for specific patients rather than memorizing generalized algorithms that may not be effective for individual patients.⁵ Teaching medical students through the use of algorithms, also known as *scripts*, is based in cognitive psychology and provides the students with prestored knowledge that can be applied quickly and easily in the clinical setting.^{11,12} The Medical College of Georgia compared a traditional observation instructional method to an interactive learning method that involved specific learning objectives and tasks that enabled students to be actively involved in radiology. The results showed that medical students, residents, and faculty preferred involving students in appropriate decision making and problem solving.¹³ Similarly, Erinjeri and Bhalla¹⁴ found that shifting radiology case-based instruction from a passive observational approach to an active learning delivery was beneficial. An interesting article published in 2005 illustrates the importance of clinical histories in the interpretation of radiographs: groups of students examining the same set of radiographs were given different patient histories. The authors posited that different histories will drive the algorithm or script appropriately.¹⁵ A 2012 dissertation found that students find the use of clinical cases to be helpful in learning to interpret radiographs¹⁶ and is consistent with both the adult learning theory and experiential learning theory.^{17,18}

When residents are asked to discuss an unknown case, they are expected to focus on 1 question: what is the abnormality? This question assumes 1 correct answer. Thus, radiology residents, and radiologists themselves, often have an underlying assumption that to be a good radiologist, one has to have the accurate diagnosis every time.¹⁹ Gunderman and Nyce¹⁹ argue that, although this is an important part of being a good radiologist, this need for accuracy can be problematic when no absolute right answer can be derived from a given set of images. Residents need to learn to be active investigators and incorporate clinical information into their evaluation of a case. The authors suggest that residents be encouraged to ask questions and that, when

residents or radiologists make errors, it be viewed as a learning opportunity rather than a sign of failure. In addition, they recommend that residents be presented with cases in which the diagnosis is not known, or at least not provided to the residents, to encourage them to evaluate their performance by criteria other than getting the right diagnosis. The “art of uncertainty” creates an opportunity for learning.²⁰

Technology as Teacher and Independent Learning Tools

Many articles examine the types of technology that can be used to assist in teaching radiology to both undergraduate medical students and residents. These articles began appearing around the early 1970s,²¹ and the technologies discussed range from the traditional textbook,²² videodisc,^{23,24} analogue film teaching files,²⁵ interactive games,²⁶ digital/picture archiving and communication systems and Digital Imaging and Communications in Medicine–based teaching files,^{27–32} computer instruction,³³ and handheld computers or personal digital assistants,^{34,35} to radiologic Web sites³⁶ such as Web-based tutorials,^{37–39} Web-based teaching files,^{40–43} Web-based radiology information sites,^{44,45} open-source, social network virtual learning environments,⁴⁶ blended learning,⁴⁷ and intranet-based assessment tools.⁴⁸

These advances in technology have allowed the student to be able to study radiology without the use of the traditional cut-film teaching files in medical/chiropractic schools and radiology residence programs.^{49,50} This has resulted in lower costs⁵¹ and smaller space requirements for the educators²³ and greater convenience to the student.^{29,30} In addition, this technology has allowed the practicing radiologist to continue to learn and keep up with the exponentially increasing body of knowledge that represents modern radiology.⁵² Interestingly, authors recognized the value of using computers to teach problem solving in medicine as early as the 1960s.⁵³

Using an audience response system creates a more interactive learning environment and appears to improve performance and student participation in an undergraduate anatomy/radiology class.^{16,54} Another study found that using a computer to monitor cases in case presentation conferences allows better control of conference content, allows generation of teaching files, and facilitates modification of case content to allow for a more even representation of the spectrum of disease found in the organ or organ system being studied.⁵⁵

A mainstay of radiology education is independent learning, or self-learning. This is achieved through the use of textbook reading, American College of Radiology and institutional teaching pathology files,⁵⁶ educational slides/tapes/videos, educational videodiscs,⁵⁷ and CD-ROM/DVD/Internet programs. In the early 1990s, residents purchased and read 5 textbooks per year, spending an average of 9 hours per week studying textbooks.⁵⁸ The improvement in technology and image quality,⁵⁹ along with the explosion in the use of the Internet in radiology education, has enabled educators to create interactive educational Web sites that allow them to expand the sphere of their talents and contributions to the radiology education world⁶⁰ to a previously unparalleled extent. The radiology education literature follows the evolution of various technology developments and the utilization of technology as tools for increasing the quantity and quality of this type of study.⁶¹ Both undergraduate medical students and residents use these materials, so it seems that it was inevitable that the question of whether both populations can learn as effectively with the same educational materials arises. In the instance of resident-prepared chest radiology teaching cases, it appears that the answer is yes—the same materials can be used to teach both undergraduates and residents.³

A few authors⁶² make an effort to point out that new technologies will assist in helping with both the dissemination of information and with the workforce shortages facing medical academia. However, they stress that technology cannot replace the insight, experience, and dedication of human educators. The authors argue that technology must be used to ignite a passion for learners to seek out knowledge for themselves and to work with teachers and each other to solve problems, rather than simply use technology to transmit information. In short, technology must help the teacher provide learner-centered education.⁶³

Using technology to enhance the education experience, rather than viewing it as a mechanical teaching method that removes common sense from the process, is many authors' goal. Jaffe and Lynch⁶⁴ point out that computers are especially useful in allowing learners to complete self-evaluations, thereby receiving objective feedback about their level of mastery of the materials. Furthermore, they note that computer-aided instruction supports different learning styles and allows the student to progress at his or her own pace. In addition, computers allow learners to complete self-assessments that provide immediate, nonjudgmental feedback.^{64,65}

Visiting Lectureship Programs

A common activity in the radiology education arena is a visiting lectureship program. This is designed to bring experts on site to train residents and house staff. Visiting lectureship programs are generally expensive and effort intensive. However, preliminary research suggests that it is an effective method of information transfer and that the level of retention of knowledge is independent of location and level of training.⁶⁶ This can sometimes be incorporated into a didactic conference. Every radiology residency program has a series of didactic conferences as part of its curriculum.⁶⁷

Case-Based Radiology Teaching and Conferences

One of the traditional and standard methods of teaching radiology is commonly known as the *hot seat*, whereby the instructor sits with the student and presents a case consisting of imaging on a particular patient. The instructor then attempts to extract observations, diagnoses, and information from the student while other students observe the interaction. Ideally, this is an effective and enjoyable method of education⁶⁸ reflective of Socratic inquiry. However, as pointed out by Chew⁶⁹ in his article discussing a means of improving on this method of instruction, it can easily become viewed by students as an inquisition rather than as a valuable opportunity to learn. Chew suggests allowing all students to preview cases for 45 seconds, write down their findings and thoughts about each case, and take turns discussing their responses under the direction of the instructor. He found that this modification of the traditional hot seat resulted in greater student participation and favorable feedback and was overwhelmingly preferred by the students over the traditional approach. However, there are radiologists who believe that the traditional approach of creating stress during these hot seat sessions is a sound pedagogical principle because it recreates the stress of clinical practice settings, such as the emergency department setting, and that the residents need to be able to make decisions under stressful conditions (KM Hibbert, University of Western Ontario, personal communication, January 22, 2012).

Another proposed variation of the traditional hot seat case presentation consists of pairing residents and giving them a set of cases to review for a set period of time. The cases are subsequently discussed, with one resident from each team partaking in the presentation.⁶⁷ The conference moderator then provides a

written handout outlining the findings and diagnoses for each case. This format was found to be a statistically significant improvement over the traditional approach.⁷⁰ In addition, because of the increased visibility of findings associated with digital hot seat presentations, students appear to prefer these to analog film-based or slide-based presentations.⁷¹

Requiring residents to autonomously review resident-prepared independent learning/teaching cases has also been shown to be an effective learning tool.⁷² The cases included a short clinical history, radiographs, computed tomographic scans, concise description of the radiological findings using correct terminology, a list of differential diagnoses, the proven diagnosis, a discussion of that diagnosis, 2 or 3 learning points, and between 1 and 3 references. Having radiology residents present cases to each other at chest radiology conferences is also an effective teaching method.⁶⁸ Resident-prepared conferences are an effective way to teach radiology residents imaging utilization guidelines. However, this method of instruction does not appear to improve residents' perception of their ability to provide diagnostic imaging consultation.⁷³ Interestingly, having undergraduate chiropractic students prepare and present radiology cases resulted in the majority of students reporting that it was a valuable learning tool, helping them in their roles as both presenters and observers.⁷⁴

Relative Effectiveness of Educational Formats

Few authors examine the relative effectiveness of educational formats in improving radiology residents' short- or long-term retention of factual knowledge. Smith et al⁷⁵ sought to do just that and compared the effectiveness of lecture vs case presentation formats for teaching residents radiology. Their study failed to show any difference between the 2 formats. Thompson et al⁷⁶ examined the effectiveness of a single didactic session on family practice residents' performance and found that there was a significant improvement in their ability to detect pneumonia on plain film radiographs.

Preliminary studies have not been able to detect long-term differences between the instructional effectiveness of multimedia textbooks, traditional lectures, and printed textbooks.^{77,78} Similar studies found no difference between lecture, printed texts, and digital content delivery on examination results for radiographic anatomy⁷⁹ or between linear and Web-style layout of computer tutorials for learning to interpret radiographs.⁸⁰ One intriguing study found that computer-based teaching with case studies improves students'

problem-solving ability in radiology as compared with paper-based case studies.⁸¹

Other authors, however, suggest that self-instructional seminars, combined with examinations, are more effective than the traditional tutorial methods and formal radiological training.⁸² According to their study, 10 seminar hours result in the same level of performance as 140 hours of elective courses. One study suggests that no difference exists in long-term knowledge retention between students who attend lectures and those who are absent.⁸³ Conversely, others have found that formal radiology teaching significantly improves student performance.⁸⁴ Another study suggests that long-term retention of radiographic anatomy into the fourth year of medical school is poor overall.⁸⁵ This article was followed by 2 additional studies that found that a preclinical course in radiology may result in facilitation of long-term retention of radiographic anatomy.^{86,87} A blended learning approach with integration of Web-based, small group modules with didactic instruction was found to be effective at Harvard Medical School,⁸⁸ and a similar case-based integrated teaching model that appears to be improving outcomes and increasing academic efficiency is being used at Taipei Medical University in Taiwan.⁸⁹ Subramaniam et al⁹⁰ address problem-based learning as a whole, pointing out its advantages and disadvantages in relation to radiology education, and provide a list of suggestions to improve this method of teaching radiology to medical students. One qualitative study investigated student perceptions of effective pedagogical approaches and found that students believe that using active learning activities, using anatomical models learning radiographic anatomy, incorporating radiographic search patterns and appropriate vocabulary into radiology instruction, and incorporating clinical information into cases improve their mastery of diagnostic imaging interpretation.¹⁶

Studies into the efficacy of using interactive software as a learning method show that it is effective and well received by both medical students and residents.^{51,64,91} Others have found that, although students learn more radiology with computer-assisted instruction videodiscs than with a textbook, they were more time intensive.⁹² Only 1 study appears to examine the traditional interactive tutorials compared with computer-assisted instruction. It was a prospective, randomized study that compared the 2 methods of instruction using the same instructor and teaching style for both groups. The study found that, although both methods are effective instructional formats, interactive tutorials are more successful than computer-assisted instruction in teaching factual radiology knowledge.⁹³

Application to Educational Practices

Although the literature regarding diagnostic imaging pedagogy is sparse and often contradictory, there are 7 areas of relative consistency discussed above that should be noted:

1. The literature suggests that teaching radiology as a problem-solving skill using a variety of methods that are grounded in cognitive psychology and learning theory shows promise in improving student learning outcomes.
2. Providing opportunities for students/residents to experience cases where there is no right answer appears to improve learning outcomes.
3. Providing active learning opportunities consistent with learning theory appears to improve both learning outcomes and student satisfaction.
4. Advances in technology are altering how radiology is taught and learned by students, residents, and practitioners seeking continuing education credits.
5. Technology allows for faster dissemination of information but also needs to be used in a manner which allows for learner-centered education.
6. Learner-friendly variations of the traditional hot seat case presentation improve both learning outcomes and student satisfaction.
7. Research into relative effectiveness of educational formats is badly needed.

Limitations

This study was limited to articles available in the English language and therefore is not comprehensive of all literature worldwide. The search did not include the gray literature or other potentially relevant sources. It is possible that the search terms did not identify all relevant articles.

Conclusions

This narrative review describes radiology as a clinical problem-solving skill that requires integration of basic sciences such as anatomy and pathology, clinical information, clinical experiences, and the information recorded on the diagnostic imaging study. As such, much of the research in this area has focused on problem solving, the use of algorithms or scripts, introducing uncertainty in clinical scenarios,

incorporating technology in the learning environments, other active learning techniques, and various methods of independent learning opportunities. Although the literature in this area is still in its infancy, the research examining the relative effectiveness of these various educational formats is often contradictory, suggesting that this is a complex area of study with numerous factors.

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References

- Calhoun JG, Vydareny KH, Ten Haken JD, Blane CE. Journal publications in radiology education. A review of the literature, 1966-1986. *Invest Radiol* 1988;23(1):62-7.
- Collins J, Kazerooni EA, Vydareny KH, Blane CE, Albanese MA, Prucha CE. Journal publications in radiologic education: a review of the literature, 1987-1997. *Acad Radiol* 2001;8(1):31-41.
- Collins J, Riebe JD, Albanese MA, et al. Medical students and radiology residents: can they learn as effectively with the same educational materials? *Acad Radiol* 1999;6(11):691-5.
- Peterson C. Factors associated with success or failure in radiological interpretation: diagnostic thinking approaches. *Med Educ* 1999;33(4):251-9 [<http://www.ncbi.nlm.nih.gov/pubmed/10336755>].
- Blane CE, Vydareny KH, Ten Haken JD, Calhoun JG. Problem-solving model in radiology for medical students. *JMIRO Australas Radiol* 1989;33(2):173-4.
- Clarke RM. Undergraduate education in the cost-effective use of laboratory and radiological investigations in clinical decision-making. *MEDU Med Educ* 1981;15(1):17-25.
- Cockshott WP. Radiology in the medical student's program. *Radiology* 1971;100(1):197-8.
- Cozens NJ. Are we taught how to use a radiology department as medical students? *Clin Radiol* 1987;38(2):137-9.
- Dussault RG, Lafortune M, Saint-Georges G, et al. Undergraduate radiology clerkship: the Universite de Montreal program. *J Can Assoc Radiol* 1983;34(2):133-5.
- Edeiken-Monroe BS, Jackson H, Harris JH. Diagnostic radiology. One week prelude to the clinical continuum. *Invest Radiol* 1988;23(12):945-9.
- Charlin B, Tardif J, Boshuizen HP. Scripts and medical diagnostic knowledge: theory and applications for clinical reasoning instruction and research. *Acad Med* 2000;75(2):182-90 [<http://www.ncbi.nlm.nih.gov/pubmed/10693854>].
- Murdoch Eaton D, Cotrell D. Structured teaching methods enhance skill acquisition but not problem-solving abilities: an evaluation of the "silent run through". *Med Educ* 1999;33(1):19-23.
- Locksmith JP, Mundy WM, Passmore GG. Student and faculty perceptions of interactive learning in the radiology clerkship. *Invest Radiol* 1992;27(10):875-9.
- Erinjeri JP, Bhalla S. Redefining radiology education for first-year medical students. *Acad Radiol* 2006;13(6):789-96.
- Chew FS, Ochoa ER, Relyea-Chew A. Spreadsheet application for radiology resident match rank list. *Acad Radiol* 2005;12(3):379-84. [<http://dx.doi.org/10.1016/j.acra.2004.12.018>].
- Linaker KL. Shades of grey: an exploration of the student learning experience in diagnostic imaging education (doctoral dissertation). Chicago: Loyola University of Chicago; 2012 [Available from: http://ecommons.luc.edu/cgi/viewcontent.cgi?article=1307&context=luc_diss].
- Knowles MS. *Andragogy in action*. Jossey-Bass Higher Education Series. San Francisco, CA: Jossey-Bass 1984.
- Kolb DA. *Experiential learning: experience as the source of learning and development*. Englewood Cliffs, NJ: Prentice-Hall; 1984.
- Gunderman RB, Nyce JM. The tyranny of accuracy in radiologic education. *Radiology* 2002;222(2):297-300 [discussion 301. <http://www.ncbi.nlm.nih.gov/pubmed/11818589>].
- Gunderman RB. Education and the art of uncertainty. *Radiology* 2005;237(3):801-2.
- Cockshott WP. Audio-visual systems in support of radiology education for medical students. *Clin Radiol* 1973;24(1):25-7.
- Chew FS, Stiles RS. Computer-assisted instruction with interactive videodisc versus textbook for teaching radiology. *Acad Radiol* 1994;1(4):326-31.
- Chew FS. Interactive videodisc for teaching radiology. *AJR Am J Roentgenol* 1994;162(4):987-91.
- Chew FS, Lanier L. Learning radiology from interactive videodiscs: bar-code book versus computer-assisted instruction. *Acad Radiol* 1995;2(11):1016-20.
- Amorosa JK, Geller NL, Horrigan WD, Saxanoff S. Integration of the diagnostic radiological health sciences learning laboratory films into a radiology elective for medical students. *Invest Radiol* 1985;20:543-5.
- Roubidoux MA, Chapman CM, Piontek ME. Development and evaluation of an interactive Web-based breast imaging game for medical students. *Acad Radiol* 2002;9(10):1169-78 [<http://www.ncbi.nlm.nih.gov/pubmed/12385511>].
- Afaq A. Filmless images for radiology teaching. *J R Soc Med* 2001;94(554-555).
- Burger R, Künzel KH, Brenner E. DICOM—a new approach in medical under- and postgraduate education. *Med Educ* 2001;35(11):1076-7 [<http://www.ncbi.nlm.nih.gov/pubmed/11715962>].
- Mullins ME, Mehta A, Patel H, McCloud TC, Novelline RA. Impact of PACS on the education of radiology residents. *Acad Radiol* 2001;8(1):67-73.
- Novelline RA, Scheiner JD, Mehta A, Mullins M. Preparing medical students for a filmless environment: instruction on the preparation of electronic case presentations from PACS. *Acad Radiol* 2001;8(3):266-8.
- Dugas M, Trumm C, Stabler A, et al. Case-oriented computer-based-training in radiology: concept, implementation and evaluation. *BMC Med Educ* 2001;1:5 [<http://www.biomedcentral.com/1472-6920/1/5>].
- Seshadri SB, Arenson RL. The impact of PACS on research and education. *Int J Biomed Comput* 1992;30(3-4):3-4.
- Aronberg DJ, Rodewald SS, Jost RG. Computer-assisted instruction in radiology. *Radiology* 1985;154:345-7.

34. Scarsbrook AF, Graham RNJ, Perriss RW. Radiology education: a glimpse into the future. *Clin Radiol* 2006;61(8):640–8 [<http://www.ncbi.nlm.nih.gov/pubmed/16843746>].
35. McKenney RR. The next level of distributed learning: the introduction of the personal digital assistant. *J Oncol Manag* 2004;13(2).
36. Kalb B, Gay SB. Internet resources for education in radiology. *Acad Radiol* 2003;10(Suppl 1):S81–6 [<http://www.ncbi.nlm.nih.gov/pubmed/12585450>].
37. Azevedo R. Expertise in radiology: accounting for the evidence and implications for instruction. Proceedings of the 1999 Annual Meeting of the American Educational Research Association, April 19–23, 1999, Montreal. Washington, DC: American Educational Research Association; 1999.
38. Azevedo R, Lajoie S, Desaulniers M, Fleischer D. RadTutor: the theoretical and empirical basis for the design of a mammography interpretation tutor. In: Boulay B, Mizoguchi R, editors. *Artificial intelligence in education: knowledge and media in learning systems*. Vol IOS Press; 1997. p. 386–93.
39. Sparacia G, Tartamella M, Finazzo M, et al. Server World-Wide Web on the Internet for the provision of clinical cases and digital radiologic images for training and continuing education in radiology. *Radiol Med* 1997;93(6):743–50.
40. Jakobovits R, Brinkley JF, Rosse C, Weinberger E. Enabling clinicians, researchers, and educators to build custom web-based biomedical information systems. *Proc AMIA Symp* 2001;279–283.
41. Wagner M, Heckemann RA, Nömayr A, Greess H, Bautz WA, Grunewald M. COMPARE/Radiology, an interactive Web-based radiology teaching program evaluation of user response. *Acad Radiol* 2005;12(6):752–60.
42. Weinberger E, Jakobovits R, Halsted M. MyPACS.net: a Web-based teaching file authoring tool. *AJR Am J Roentgenol* 2002;179(3):579–82.
43. Jakobovits R, Halsted M, Shanaman M, Weinberger E. Developing a teaching file authoring system using content management technology. *J Digit Imaging* 2003;16:67–8.
44. Johnson PT, Rowell MR, Fishman EK. Internet-based medical education: use of an “expert-corner” for disseminating radiologic information and determining users’ educational interests. *Acad Radiol* 2006;13(3):338–42, <http://dx.doi.org/10.1016/j.acra.2005.11.039>.
45. Streeter JL, Lu MT, Rybicki FJ. Informatics in radiology: RadiologyWiki.org: the free radiology resource that anyone can edit. *Radiographics* 2007;27(4).
46. Howlett DC, Connelly JP, Vincent T. Real-time, online teaching to enhance undergraduate learning. *Med Educ* 2009;43(11):1115–6.
47. Howlett D, Vincent T, Watson G, et al. Blending online techniques with traditional face to face teaching methods to deliver final year undergraduate radiology learning content. *Eur J Radiol* 2011;78(3):334–41, <http://dx.doi.org/10.1016/j.ejrad.2009.07.028>.
48. Davison BD, Tello R, Blickman JG. World wide web program for optimizing and assessing medical student performance during the radiology clerkship. *Acad Radiol* 2000;7(4):260–3.
49. Chew FS, Smirniotopoulos JG. Educational efficacy of computer-assisted instruction with interactive videodisc in radiology. *Invest Radiol* 1993;28(11):1052–8.
50. Roberts CC, Chew FS. Teaching radiology residents, and radiology residents as teachers. *Acad Radiol* 2003;10:s97–101.
51. Chew FS, Smirniotopoulos JG. Teaching skeletal radiology with use of computer-assisted instruction with interactive videodisc. *J Bone Joint Surg Am* 1995;77(7):1080–6.
52. Swett HA. The power of knowledge in radiologic education and decision making. *J Digit Imaging* 1991;4(4):199–201.
53. Swets JA, Feurzeig W. Computer-aided instruction. *Science* 1965;150(3696):572–6.
54. Alexander CJ, Crescini WM, Juskewitch JE, Lachman N, Pawlina W. Assessing the integration of audience response system technology in teaching of anatomical sciences. *Anat Sci Educ* 2009;2(4):160–6.
55. Creasy JL, Cuttino JT, Sokhandan M. Computerized data base of teaching conference cases. *Invest Radiol* 1988;23(11):866–8.
56. Tegtmeier CJ, Keats TE, Pullen EW, Langman J. The teaching of roentgen anatomy to medical students: a self-instructional approach. *J Med Educ* 1974;49(5):455–6.
57. Hennessey JG, Fishman EK, Ney DR. Digital video applications in radiologic education: theory, technique, and applications. *J Digit Imaging* 1994;7(2):85–90.
58. Slone RM, Tart RP. Radiology residents’ work hours and study habits. *Radiology* 1991;181(2):606–7.
59. Schellingerhout D, Chew FS, Mullins ME, Gonzalez RG. Projected digital radiologic images for teaching. *Acad Radiol* 2002;9(2):157–62, [http://dx.doi.org/10.1016/S1076-6332\(03\)80165-4](http://dx.doi.org/10.1016/S1076-6332(03)80165-4).
60. Frank MS, Dreyer K. Empowering radiologic education on the Internet: a new virtual website technology for hosting interactive educational content on the World Wide Web. *J Digit Imaging* 2001;14(2):113–6.
61. Gunderman RB, Kang YP, Fraley RE, Williamson KB. Instructional technology and radiologic education. *Radiology* 2001;221(1):1–4 [discussion 5. <http://www.ncbi.nlm.nih.gov/pubmed/11568312>].
62. Gunderman RB, Williamson KB, Fraley RE, Steele JL. The role of technology in radiology education 1. *Acad Radiol* 2004;11(4):476–9.
63. Gunderman RB, Williamson KB, Frank M, Heitkamp DE, Kipfer HD. Learner-centered education. *Radiology* 2003;227(1):15–7.
64. Jaffe CC, Lynch PJ. Computer-aided instruction for radiologic education. *Radiographics* 1993;13(4):931–7.
65. Jaffe CC, Lynch PJ. Computer-aided instruction in radiology: opportunities for more effective learning. *Am J Roentgenol* 1995;164:463–7.
66. Franken EA, Albanese MA, Kirks DR, Scatliff JH, Smith WL, Gjerde CL. The visiting lectureship in radiology: an evaluation. *AJR Am J Roentgenol* 1983;140(4):803–5.
67. Roberts CC, Chew FS. Teaching radiology residents, and radiology residents as teachers. *Acad Radiol* 2003;10(Suppl 1):S97–S101 [<http://www.ncbi.nlm.nih.gov/pubmed/20447842>].
68. Collins J, Miller SS, Albanese MA. Resident learning and knowledge retention from resident-prepared chest radiology conferences. *Acad Radiol* 1997;4(11):732–5.
69. Chew FS. The case-based radiology teaching conference for residents: beneficial effect of previewing cases and using answer sheets. *Acad Radiol* 2001;8(10):993–7, [http://dx.doi.org/10.1016/S1076-6332\(03\)80644-X](http://dx.doi.org/10.1016/S1076-6332(03)80644-X).
70. Collins J, Garofalo RS, Albanese MA. Resident conference at the viewbox: an experimental approach. *Acad Radiol* 1996;3(11):962–7.

71. Su TJ, Shaffer K. Reinventing the apprenticeship: the hot seat in the digital era. *Acad Radiol* 2004;11(11):1300–7.
72. Collins J, Blankenbaker DG, Albanese MA, et al. Chest radiology case exchange program: a paradigm for resident teaching and independent resident learning. *Acad Radiol* 1999;6(1):34–9.
73. Mainiero MB, Collins J, Primack SL. Effectiveness of resident-prepared conferences in teaching imaging utilization guidelines to radiology residents. *Acad Radiol* 1999;6(12):748–51.
74. Young K, Mestan M. The usefulness of radiology case presentations as a method of self-directed study. *J Chiropr Educ* 2003;17(44).
75. Smith WL, Berbaum K, Franken EA, Ell S. Comparison of lecture and case presentation formats for teaching radiology to residents. *Invest Radiol* 1986;21(3):285–6.
76. Thompson BH, Berbaum KS, George MJ, Ely JW. Identifying left lower lobe pneumonia at chest radiography: Performance of family practice residents before and after a didactic session. *Academic Radiology* 1998;5:324–8.
77. D'Alessandro DM, Kreiter CD, Erkonen WE, Winter RJ, Knapp HR. Longitudinal follow-up comparison of educational interventions: multimedia textbook, traditional lecture, and printed textbook. *Acad Radiol* 1997;4(11):719–23.
78. Erkonen WE, D'Alessandro MP, Galvin JR, Albanese MA, Michaelson VE. Longitudinal comparison of multimedia textbook instruction with a lecture in radiology education. *Acad Radiol* 1994;1(3):287–92.
79. Ketelsen D, Schrödl F, Knickenberg I, et al. Modes of information delivery in radiologic anatomy education: impact on student performance. *Acad Radiol* 2007;14(1):93–9, <http://dx.doi.org/10.1016/j.acra.2006.10.013>.
80. Pusic MV, LeBlanc VR, Miller SZ. Linear versus Web-style layout of computer tutorials for medical student learning of radiograph interpretation. *Acad Radiol* 2007;14(7):877–89.
81. Maleck M, Kammer B, Zeiler C, et al. Do computers teach better? A media comparison study for case-based teaching in radiology. *Radiographics* 2001;21(4).
82. Squire LF, Becker JA, Blotnick V, Becker JA. Self-instruction in radiology for medical students. *Radiology* 1972;105(3):681–4.
83. Chan WP. Assessment of medical students' knowledge retention in a diagnostic radiology course: lecture attendees versus absentees. *Ann Acad Med Singapore* 2009;38(3):237–9.
84. Dawes TJ, Vowler SL, Allen CM, Dixon AK. Training improves medical student performance in image interpretation. *Br J Radiol* 2004;77(921):775–6.
85. Feigin DS, Smirniotopoulos JG, Neher TJ. Retention of radiographic anatomy of the chest by 4th-year medical students. *Acad Radiol* 2002;9(1):82–8.
86. Feigin DS, Magid D, Smirniotopoulos JG, Carbognin SJ. Learning and retaining normal radiographic chest anatomy: does preclinical exposure improve student performance? *Acad Radiol* 2007;14(9):1137–42.
87. Magid D, Hudson DW, Feigin DS. Chest radiographic anatomy retention: the impact of preclinical groundwork on clinical recall in two schools. *Acad Radiol* 2009;16(11):1443–7.
88. Shaffer K, Small JE. Blended learning in medical education: use of an integrated approach with Web-based small group modules and didactic instruction for teaching radiologic anatomy. *Acad Radiol* 2004;11(9):1059–70, <http://dx.doi.org/10.1016/j.acra.2004.05.018>.
89. Chan WP, Hsu CY, Hong CY. Innovative “case-based integrated teaching” in an undergraduate medical curriculum: development and teachers' and students' responses. *Ann Acad Med Singapore* 2008;37(11):952–6.
90. Subramaniam RM, Scally P, Gibson R. Diagnostic radiology: problem-based learning and medical student radiology teaching. *Australas Radiol* 2004;48(3):335–8.
91. Alvarez A, Gold GE, Tobin B, Desser TS. Software tools for interactive instruction in radiologic anatomy. *Acad Radiol* 2006;13:512–7.
92. Chew FS, Stiles RS. Computer-assisted instruction with interactive videodisc versus textbook for teaching radiology. *Acad Radiol* 1994;1(4):326–31.
93. Lieberman G, Abramson R, Volkan K, Mcardle PJ. Tutor versus computer: a prospective comparison of interactive tutorial and computer-assisted instruction in radiology education. *Acad Radiol* 2002;9(1):40–9.