Effect of Simulation-Based Learning Strategies on Undergraduate Radiologic Science Students

Michael Kortbawi, MS, R.T.(N)(CT), CNMT
Albert Heuer, PhD, RRT, RPFT, FAARC
Janet Reid-Hector, EdD, RD
Mina Ghajar, MLS

Simulation-based learning (SBL) is a pedagogical strategy that aims to enhance education outcomes for students by replicating real experiences to develop clinical skills in a risk-free learning environment.[1-3] In addition, simulation has been perceived as a student-centric and positive teaching tool by students.[4-8] Examples of simulation techniques in health care education include role-playing,[9,10] simulated patients,[9] scenario-based questions,[11] manikin simulators,[10,12,13] virtual reality simulators,[10,14,15] and advanced computer applications.[4,10,16-18] The degree to which a simulation exercise replicates a real event and the value provided to the stakeholder can be categorized by their fidelity. Although all simulations aim to support conceptual learning, high-fidelity simulations best represent realistic environments whereas low-fidelity simulations tend to be less realistic and often have few or no technological features.[19]

Like other allied health professions, medical imaging and radiation therapy can benefit from SBL because of relatively high error rates related to physician ordering, interpretation, and image acquisition.[20] Although clinical practice guidelines attempt to reduce such issues, errors related to patient identification, wrong site, wrong procedure, patient positioning, and improper technique persist in clinical imaging.[21] Aligning with the need to prevent negative technical outcomes and to incorporate patient safety goals into undergraduate allied health education,[22] SBL environments provide resources for students to develop clinical skill sets aimed at reducing imaging errors, enhance operational efficiency, and improve patient safety. In addition, incorporating simulation strategies into didactic instruction has been shown to improve students' abilities to explain, prepare, and perform prescribed procedures,[11,23] helping students gain confidence in a clinical setting. In conjunction with traditional undergraduate radiologic sciences curricula, the integration of SBL strategies might assist in developing clinically competent and confident entry-level technologists[5] in a controlled and risk-free environment.[24]

Exploring the various uses of simulation in radiologic sciences education provides value to educators, students, and clinical education sites by identifying which adjunct strategies are better or worse suited to prepare students. In addition to assisting students in developing clinical competencies required to reduce diagnostic imaging errors, patients' quality of care, safety, accessibility, and overall imaging experience might be improved.

The literature includes randomized controlled trials, experimental studies, and qualitative research that aim to understand the efficacy of simulation as a pedagogy in health care education. This collection of work examined undergraduate, postgraduate, and professional development programs and originated from countries throughout the world. However, no published systematic reviews focused on the effect of SBL strategies on undergraduate radiologic science students' clinical competency and confidence. This gap in literature is the motivation and focus of this literature review. The population, intervention, comparison, objective, and time (PICOT) elements were defined to identify the reported use of SBL strategies in undergraduate radiologic science education throughout the world and their effect on student confidence and clinical competency between 2011 and 2021:

- population – undergraduate radiologic science students in the disciplines and specialties of radiography, computed tomography (CT), magnetic resonance imaging, nuclear medicine, mammography, sonography, or radiation therapy
- intervention – the use of an SBL strategy in clinical education
- comparison – clinical education involving patients using conventional medical imaging equipment when available
- objective – to examine the use of SBL strategies and their effect on students' clinical competency and confidence
- time – literature published between 2011 and 2021

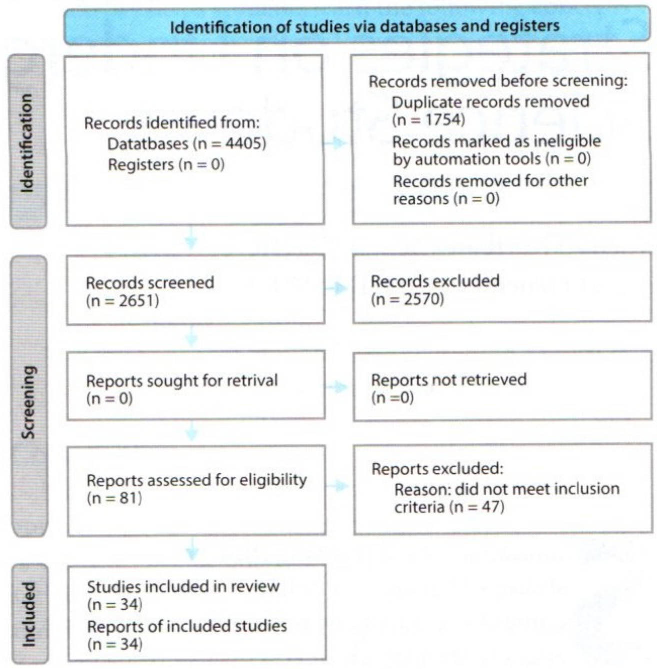

Figure. *Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 flow diagram. Image courtesy of the authors.*

Literature Search Strategy and Eligibility Criteria

A search of 8 synthesized databases (PubMed, Educational Resources Information Center [ERIC], Ovid Medline, Cumulative Index to Nursing and Allied Health Literature [CINAHL], Scopus, Cochrane Library, Web of Science, and Google Scholar) resulted in 4405 possible sources. Duplicate removal resulted in 2651 articles for screening. The **Figure** presents the progression from the initial body of literature to the final 34 articles in the framework of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 flow diagram.[25] The medical subject heading search terms were *simulation, undergraduate education, education, radiologic science, radiography, xray, x-ray, computed tomography, CT, magnetic resonance imaging, MRI, nuclear medicine, nuclear cardiology, positron emission tomography, PET, PET/CT, mammography, sonography, ultrasound, radiation therapy,* and *radiation simulation.*

Publications were limited to full-text peer-reviewed articles written in or translated into English between 2011 and 2021 worldwide and included randomized controlled trials, randomized parallel-group trials, quasi experimental, qualitative, controlled, crossover, action research, and mixed-methods experimental designs. Participants in SBL studies know whether they are receiving the simulation intervention; therefore, blinding was not a requirement for literature inclusion. Screening criteria required the study population to include undergraduate students in at least 1 discipline of radiologic science education and contain instructor-administered competency assessment or qualitative student feedback on their change in confidence level before and after intervention. Assessment of the 2651 articles for study inclusion was performed independently by 2 team members. Included studies were assessed for bias via the revised Cochrane risk-of-bias tool for randomized trials[26] or the Risk Of Bias In Non-Randomised Studies – of Interventions (ROBINS-I) assessment tool.[27] Discrepancies in study inclusion and exclusion were resolved with a consensus agreement.

Analysis of Selected Literature

Thirty-four articles were selected for inclusion to exemplify the effect of a simulation strategy on student clinical competency and confidence levels. All included studies were found to exhibit some level of bias relating to lack of subject and assessor blinding by study design.

Types of Simulation and Utilization Trends

Role-play was the most prevalent simulation method (n = 16), which was an expected finding because it can be implemented in some capacity throughout all disciplines and specialties in radiologic science education. The use of role-play ranged from low-fidelity scenarios involving workshops[28,29] or students acting as patients[15] to high-fidelity operating theaters.[30,31] On the higher end of the fidelity spectrum, virtual reality simulators and virtual environments provided students with a unique immersive opportunity by offering a 3-D experience of a conceptual model designed to improve knowledge and gain clinical experience without risk to patients.[32]

Findings from the literature identified the reporting of simulation strategies in undergraduate radiologic sciences education among 12 countries, including Australia, Canada, China, Ireland, New Zealand, Norway, Portugal, Singapore, Sweden, United Arab Emirates, United Kingdom, and United States. When considering simulation content by origin, Australia reported the most frequent publication of simulation efforts in CT, radiation therapy, radiography, and sonography, with a total of 15 studies. The second most active country in reporting simulation strategies was the United Kingdom with 7 studies in the fields of radiation therapy, radiography, and sonography. Regardless of country of origin, the field of radiography yielded the most reporting (n = 17) followed by radiation therapy (n = 10) and CT (n = 4).

Simulation's Effect on Student Clinical Performance or Perceived Confidence

Most studies that reported the effect of simulation on clinical competency were focused on radiography (n = 7), radiation therapy (n = 4), and CT (n = 2), with role-play and virtual reality simulators exhibiting the most use. Improvements in the clinical performance domain were measured by observer assessment or competency testing, whereas change in confidence was self-reported by students. Although an increase in student confidence is of potential value to the student, the weight of this observation is subjective and therefore less reliable. In addition, confidence does not always equate to knowledge or competency.

When considering the range of studies evaluating the effect of simulation on student confidence, radiation therapy (n = 6) exhibited the highest frequency followed by radiography (n = 2) and CT (n = 2), with role-play (n = 5) and Virtual Environment Radiotherapy Training (VERT [Vertual]) system (n = 4) as the most used strategies.

Role-play and virtual reality simulators produced a range of effects on student clinical competence, with the most improvement in a radiography application.[12,23,33-35] Conversely, CT[17] and radiation therapy virtual reality simulators[36,37] efforts reported equivalent assessment scores between simulation and control (conventional clinical education) groups. Other findings included improved student attitudes toward a specific patient population when exploring role-play in radiography[28,29] and students identifying VERT simulation as an effective method of enhancing their technical radiation therapy skill sets.[38]

Perceived confidence in various aspects of performance, such as communication, collaboration skills, patient care, and technical competency, were reported as improved with VERT,[37,38] role-play,[11,35,39] and a medium-fidelity operator's console.[4] Conversely, similar improvements in confidence between simulated and nonsimulated techniques were reported with VERT,[40,41] virtual reality CT simulation,[14] and role-play.[36]

Themes Among Simulation Strategies

Role-play, virtual reality, and a medium-fidelity simulator garnered positive feedback on students' ability to explain, prepare for, and perform studies.[11] Improvements in technical skills, communication skills,[23] knowledge,[6,30] and understanding of theoretical or clinical concepts[42] also were related to these SBL strategies. In addition to student engagement[15] and recognition of teaching value,[4,33] simulation exercises were reported to benefit students by creating a safe, collaborative, and realistic learning environment that enhanced the efficacy of the education experience.[23,42]

Although previous use of computers would appear to be a logical influence on computer-based simulation exercises, Bridge et al found weak or no correlation between previous computer experience and enjoyment, ease of use, and understanding of the simulation experience.[42] Similar results were identified with previous exposure to gaming.[33]

Although Stowe et al[43] found no correlation with length of time in an education program and improvement in academic performance after virtual reality CT simulation, Gunn et al, Ketterer et al, and Bowman et al identified simulation-related improvements associated with early or preclinical student status.[14,36,44] Furthermore, student acknowledgment of perceived value of the simulation intervention was reported[14] in addition to improvement in clinical[44] and communication[36] skills in a preclinical setting. Conversely, a contrast of opinion was identified among students with previous clinical experience,[14,38] which highlights the effect and importance of early simulation interventions in a student population.

Negative Attributes of Simulation Experiences

Specific themes that degraded the user experience included software deficiencies,[15,45] technical challenges,[6,18] or lack of adequate guidance on simulation functionality.[17] Green and Appleyard reported that 4 out of 44 students experienced nausea and dizziness,[38] and Bridge et al reported headaches in 2 students,[33] exemplifying the possibility of physical adverse effects from virtual reality simulators. Although not negative, equivocal perceived value of conventional clinical exposure compared with simulation[36] and ambivalence regarding ease of use[42] were reported.

Simulation experiences were deemed more valuable when tutors or clinical professionals were available for immediate feedback.[17,23,45,46] Although virtual reality experiences provided value by depicting anatomy and theoretical concepts,[47] lack of feedback to the untrained student was reported as detrimental to the simulation experience.[6,48] Technical difficulties and the inability to experience hands-on scanning with actual patients[18] were noted as additional detriments.

Key Findings

Several interesting findings related to SBL were discovered in undergraduate radiologic science education. Some findings were more informational in nature, while others are potentially actionable by radiologic science educators to enhance their use of SBL and concomitant student learning outcomes.

An informational finding was the discovery of a wide disparity in SBL use by country. Many countries were not identified as SBL users; other countries reported SBL use that varied substantially and did not always correspond to economic attributes such as gross domestic product. For example, although Australia's gross domestic product is considerably less than many other developed countries, it had a comparatively greater published use of SBL in radiologic science education. This finding likely is related to the rapid expansion of simulation equipment and instruction through government investments such as Australia's Quality Framework for Simulation Programs in Australian Health Care Settings, also called the *QualSim Framework*.[49] These focused investments have created a large simulation community in Australia with an ever-increasing appetite for support to create and deliver the highest quality programs possible. Hence, although many countries with higher gross domestic products, such as the United States, Canada, and United Kingdom report heavy investments in health care SBL, the investments in Australia might produce more clinical and scholarly outcomes because they are better structured and have features that could be emulated by other countries.

As for findings that might be more relevant and potentially actionable by radiologic science educators, this project explored the effect that SBL can have on student learning outcomes. This review identified several studies that noted the positive effect SBL can have on clinical competency after intervention.[6,12,15,23,33-35,45,50-53] Some of the articles included in this review proposed that because of the ability to explore positioning and exposure techniques, radiographic simulation in high-fidelity phantom and virtual reality formats is particularly beneficial to clinical progression because of the ability to quickly repeat imaging and review outcomes. With these applications, students can repeat image exposure, making it possible to iteratively develop their clinical skill sets without harming patients. In addition, this type of simulation can intentionally exemplify pitfalls of poor imaging techniques without putting patients at risk.

On the lower end of the fidelity spectrum, role-play was identified as a valuable learning experience when considering the patient experience.[46,54] This was attributed to its ability to help students recognize aspects of their roles, interactions, and clinical challenges[31,53] through reflection.[48] Furthermore, lower-fidelity role-play simulations require fewer resources and are more readily available than are many other forms of simulation, potentially further explaining their relative popularity. No single simulation strategy was identified as addressing all aspects of clinical care. Therefore, a blend of low- and high-fidelity simulations should be considered by radiologic science educators and trainers as a holistic approach to developing clinical competencies ranging from interpersonal skills to technical performance.

Findings suggested potential benefits to undergraduate students, educators, and clinical education sites, though not to a specific form of simulation. Because of the range of SBL strategies, students were able to reduce the amount of education-related exposure to ionizing radiation,[12] mentally process complex scenarios in preparation for future clinical experience,[35,53] and improve their clinical competencies.[6-8,13,36,45,52,55] In addition, SBL strategies increased the number of experiences for developing image interpretation skills.[55] Clinical educators experienced a reduction in the amount of required tutoring or observation for students to achieve clinical competency[12] and were able to identify aspects of clinical care that required improvement.[4] Lastly, some clinical education sites had less need for patient-dependent instruction,[56] which reduced the demand on critical diagnostic imaging equipment needed for patient care.[17]

One factor radiologic science educators should consider is the timing for introducing SBL in the curriculum. Early or preclinical simulation exposure was shown to have a role in the transfer of proficiency-based skills[34,36,38,44] and confidence levels of students,[14,39] subsequently improving competency, reducing the teaching burden on clinical staff, and increasing patient safety.[44] However, although the value of VERT as a teaching tool has been well established,[57,58] Leong et al proposed the benefit of establishing a conceptual framework via a traditional treatment planning system followed by VERT exposure based on student and teacher feedback.[41] Therefore, radiologic science educators who choose to combine traditional education and simulation exercises in a preclinical setting should consider the order in which instruction methods are implemented to maximize the education and performance effect.

Introducing SBL strategies can provide compounding effects that bolster student performance outcomes, as was exhibited by the collateral reporting of improvements in clinical competency and confidence in the same studies.[18,35-38,41] The improvements in student confidence throughout a range of simulation fidelity provided value for students as a result of their improved communication and collaboration skills,[50,59] patient care skills,[46] and technical skills.[44] Instructor feedback,[39] exposure to new techniques or protocols,[4,37] and exposure to uncomfortable scenarios[11] were noted as contributing factors that improved student confidence. Therefore, educators should be mindful to consider these points to develop students' confidence and help avoid producing anxiety in students, which can affect their learning negatively.[60]

Likewise, when radiologic science educators are considering the implementation of a new simulation strategy, including a feedback mechanism that provides students with validation or direction for improvement is important. Outside of technical skill development, professional feedback can enhance nontechnical competencies of radiologic science students such as communication.[36,50] Failure to provide direction and feedback during a simulation can result in participants having a negative view of the experience, which might hinder skill development and foster a reluctance to actively participate in future sessions.[17,23,45,46]

Despite the usefulness in augmenting more traditional education strategies, disadvantages to simulation in radiologic science education were found. One drawback is that simulations can be resource intensive, making it difficult for some education programs to acquire, integrate, and use them in a meaningful way. To help address this concern, radiologic science education programs might elect to pursue grants or seek strategic partnerships with organizations (eg, hospital systems, other educational institutions) that possess such resources. Another potential drawback is that SBL could have the potential to induce false confidence and perceived capabilities that could slow or halt efforts to continue skill development.[61] Educators should be aware of this challenge and include cross-validation measures in their programs to verify clinical competence in other elements of the curriculum. Furthermore, undesirable attributes of the simulation experience such as a lack of feedback,[17,23,45,46] software deficiencies,[15,45] or technical challenges[6,18] might act as barriers to user acceptance and engagement and negatively affect student confidence.[14] Radiologic science educators should remain mindful of these pitfalls and adopt simulation-based exercises with robust feedback features that are intuitive and relatively free of technological shortcomings.[59]

A few radiologic science disciplines did not report use of simulation in undergraduate education. For example, no manuscripts for nuclear medicine or mammography were identified in this project. The implications of the lack of findings in these disciplines is not entirely clear but might be related to resource limitations, comparatively smaller undergraduate class sizes, or specialized education that is limited in an undergraduate setting. In addition, these disciplines might use simulations but do not perform such activities in the context of research or decline to convert the results of SBL exercises into published scholarly work.

Limitations

Most of the studies included in this review were quasi experimental designs that do not assign students to a control group. Although this design method exemplifies the effect of an intervention, it fails to compare simulation outcomes with those of traditional teaching methods. Another limitation involved some risk of bias in all included publications, which was again related to study designs. The predominant lack of blinding of students in all studies, though unavoidable, introduces opportunities for bias in reporting improvements in clinical skills and confidence. This lack of conformity illuminates the need for more blinded assessment in the form of randomized controlled trials; it also provided some of the motivation for this project and was a notable finding.

Lastly, a single study reported on the effect of simulation at later time points,[29] highlighting the need for future research exploring the effects of simulation exercises on sustained actual and perceived performance for an extended period.

Conclusion

For stakeholders connected with undergraduate radiologic science programs, there are potential values of and concerns with SBL. Although there was not uniform employment of simulation strategies among the disciplines and specialties in radiologic science education, themes related to user engagement, time of simulation introduction in the curriculum, efficacy compared with traditional teaching methods, and pitfalls of implementation did become apparent. The ability to experience and repeat a range of clinical scenarios provides opportunities for reflection and interventional guidance that can assist students in the transfer of theory to clinical skills. To get the most benefit from SBL strategies, current and prospective users should evaluate and use SBL with these points in mind. Stakeholders also should keep abreast of new developments as the body of literature matures further in this area to help ensure they reap maximum value from this dynamic and potentially effective education strategy.

Michael Kortbawi, MS, R.T.(N)(CT), CNMT, is chief technologist for the nuclear medicine division at University Hospital in Newark, New Jersey.

Albert Heuer, PhD, RRT, RPFT, FAARC, is professor for the Department of Interdisciplinary Studies in the School of Health Professions at Rutgers, The State University of New Jersey, in Newark.

Janet Reid-Hector, EdD, RD, is assistant professor and program director for the Department of Interdisciplinary Studies in the School of Health Professions at Rutgers, The State University of New Jersey.

Mina Ghajar, MLS, is education and research librarian for the Rutgers Biomedical and Health Sciences George F Smith Library in Newark.

References

1. Gaba DM. The future vision of simulation in health care. *Qual Saf Health Care.* 2004;13(Suppl 1)(suppl 1):i2-i10. doi:10.1136/qshc.2004.009878
2. Mayo PH, Hackney JE, Mueck JT, Ribaudo V, Schneider RF. Achieving house staff competence in emergency airway management: results of a teaching program using a computerized patient simulator. *Crit Care Med.* 2004;32(12):2422-2427. doi:10.1097/01.CCM.0000147768.42813.A2
3. Rosenthal ME, Adachi M, Ribaudo V, Mueck JT, Schneider RF, Mayo PH. Achieving housestaff competence in emergency airway management using scenario based simulation training: comparison of attending vs housestaff trainers. *Chest.* 2006; 129(6):1453-1458. doi:10.1378/chest.129.6.1453
4. Elshami W, Abuzaid M. Transforming magnetic resonance imaging education through simulation-based training. *J Med Imaging Radiat Sci.* 2017;48(2):151-158. doi:10.1016/j.jmir.2017.01.002
5. Gibbs V. An investigation into sonography student experiences of simulation teaching and learning in the acquisition of clinical skills. *Ultrasound.* 2014;22(3):173-178. doi:10.1177/1742271X14528491
6. O'Connor M, Stowe J, Potocnik J, Giannotti N, Murphy S, Rainford L. 3D virtual reality simulation in radiography education: the students' experience. *Radiography (Lond).* 2021;27(1):208-214. doi:10.1016/j.radi.2020.07.017
7. Pessin YJ, Tang-Simmons J. Sonography simulators: use and opportunities in CAAHEP-accredited programs. *J Diagn Med Sonogr.* 2018;34(6):435-444. doi:10.1177/8756479318799347
8. Qin Y, Huang Z, Yu J, et al. Practice-based learning using Smart Class: a competency-based model in undergraduate radiology education. *Acad Radiol.* 2022;29 (1):150-157. doi:10.1016/j.acra.2020.09.028
9. Aebersold M. Simulation-based learning: no longer a novelty in undergraduate education. *Online J Issues Nurs.* 2018;23(2):1. doi:10.3912/OJIN.Vol23No02PPT39
10. Heuer A, Bienstock J, Zhang Y. Simulation-based training within selected allied health professions: an evidence-based systematic review. *J Allied Health.* 2022;51(1):59-71.
11. Kloc L, Ballor C, Boldt K, Curry R. Using scenario-based simulation to address affective behaviors of sonography students. *J Diagn Med Sonogr.* 2019;35(2):113-124. doi:10.1177/8756479318819458
12. Ahlqvist JB, Nilsson TA, Hedman LR, et al. A randomized controlled trial on 2 simulation-based training methods in radiology: effects on radiologic technology student skill in assessing image quality. *Simul Healthc.* 2013;8(6):382-387. doi:10.1097/SIH.0b013e3182a60a48
13. Holmström A. Radiography students' learning of plain x-ray examinations in simulation laboratory exercises: an ethnographic research. *J Med Imaging Radiat Sci.* 2019;50(4):557-564. doi:10.1016/j.jmir.2019.07.005
14. Gunn T, Rowntree P, Starkey D, Nissen L. The use of virtual reality computed tomography simulation within a medical imaging and a radiation therapy undergraduate programme. *J Med Radiat Sci.* 2021;68(1):28-36. doi:10.1002/jmrs.436
15. Sapkaroski D, Mundy M, Dimmock MR. Virtual reality versus conventional clinical role-play for radiographic positioning training: a students' perception study. *Radiography (Lond).* 2020;26(1):57-62. doi:10.1016/j.radi.2019.08.001
16. Khan K, Pattison T, Sherwood M. Simulation in medical education. *Med Teach.* 2011;33(1):1-3. doi:10.3109/0142159X.2010.519412
17. Lee K, Baird M, Lewis S, McInerney J, Dimmock M. Computed tomography learning via high-fidelity simulation for undergraduate radiography students. *Radiography (Lond).* 2020;26(1):49-56. doi:10.1016/j.radi.2019.07.001
18. Liley T, Ryan E, Lee K, Dimmock M, Robinson J, Lewis SJ. Student perceptions of remote access simulated learning in computed tomography. *Interact Learn Environ.* 2020;28(7):865-875. doi:10.1080/10494820.2018.1546746
19. Munshi F, Lababidi H, Alyousef S. Low- versus high-fidelity simulations in teaching and assessing clinical skills. *J Taibah Univ Med Sci.* 2015;10(1):12-15. doi:10.1016/j.jtumed.2015.01.008
20. Itri JN, Tappouni RR, McEachern RO, Pesch AJ, Patel SH. Fundamentals of diagnostic error in imaging. *Radiographics.* 2018;38(6):1845-1865. doi:10.1148/rg.2018180021
21. Waite S, Scott JM, Legasto A, Kolla S, Gale B, Krupinski EA. Systemic error in radiology. *AJR Am J Roentgenol.* 2017;209(3): 629-639. doi:10.2214/AJR.16.17719
22. Vivekananda-Schmidt P, Sandars J. Developing and implementing a patient safety curriculum. *Clin Teach.* 2016;13(2):91-97. doi:10.1111/tct.12528
23. Kong A, Hodgson Y, Druva R. The role of simulation in developing clinical knowledge and increasing clinical confidence in first-year radiography students. *Health Prof Educ.* 2015;16:29. doi:10.11157/fohpe.v16i3.83
24. Linder LA, Pulsipher N. Implementation of simulated learning experiences for baccalaureate pediatric nursing students. *Clin Simul Nurs.* 2008;4(3):e41-e47. doi:10.1016/j.ecns.2008.09.002
25. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ.* 2021;372(71):n71. doi:10.1136/bmj.n71
26. Sterne JAC, Savović J, Page MJ, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ.* 2019;366:l4898. doi:10.1136/bmj.l4898
27. Sterne JA, Hernán MA, Reeves BC, et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. *BMJ.* 2016;355:i4919. doi:10.1136/bmj.i4919
28. Booth L, Kada S. Student radiographers' attitudes toward the older patient: an intervention study. *Radiography.* 2015;21(2): 160-164. doi:10.1016/j.radi.2014.09.010
29. Booth L, Kada S, Satinovic M, Phillips P, Miller PK. Student radiographers' attitudes towards the older patient - a lon-

gitudinal study. *Radiography (Lond).* 2017;23(3):229-234. doi:10.1016/j.radi.2017.03.014

30. Carramate LFND, Rodrigues A, Simões JL, et al. Simulation of image-guided intervention in medical imaging education. *J Med Imaging Radiat Sci.* 2020;51(2):235-240. doi:10.1016/j.jmir.2019.12.007
31. Naylor S, Foulkes D. Diagnostic radiographers working in the operating theatre: an action research project. *Radiography (Lond).* 2018;24(1):9-14. doi:10.1016/j.radi.2017.09.001
32. Dalgarno B, Lee MJW. What are the learning affordances of 3-D virtual environments? *Br J Educ Technol.* 2010;41(1):10-32. doi:10.1111/j.1467-8535.2009.01038.x
33. Bridge P, Gunn T, Kastanis L, et al. The development and evaluation of a medical imaging training immersive environment. *J Med Radiat Sci.* 2014;61(3):159-165. doi:10.1002/jmrs.60
34. Gunn T, Jones L, Bridge P, Rowntree P, Nissen L. The use of virtual reality simulation to improve technical skill in the undergraduate medical imaging student. *Interact Learn Environ.* 2018;26(5):613-620. doi:10.1080/10494820.2017.1374981
35. Shiner N, Howard ML. The use of simulation and moulage in undergraduate diagnostic radiography education: a burns scenario. *Radiography (Lond).* 2019;25(3):194-201. doi:10.1016/j.radi.2018.12.015
36. Ketterer SJ, Callender J, Warren M, et al. Simulated versus traditional therapeutic radiography placements: a randomised controlled trial. *Radiography (Lond).* 2020;26(2):140-146. doi:10.1016/j.radi.2019.10.005
37. Wijeysingha ES, Chin VY, Lian CP. Utilising virtual environments for radiation therapy teaching and learning. *J Med Imaging Radiat Sci.* 2021;52(4S):S83-S95. doi:10.1016/j.jmir.2021.07.001
38. Green D, Appleyard R. The influence of VERT characteristics on the development of skills in skin apposition techniques. *Radiography.* 2011;17(3):178-182. doi:10.1016/j.radi.2011.04.002
39. Kelly T, Surjan Y, Rinks M, Warren-Forward H. Effect of communication skills training on radiation therapy student's confidence and interactions during their first clinical placement. *Radiography (Lond).* 2021;27(1):59-66. doi:10.1016/j.radi.2020.05.015
40. Cheung EYW, Law MYY, Cheung F. The role of virtual environment for radiotherapy training (VERT) in medical dosimetry education. *J Cancer Educ.* 2021;36(2):271-277. doi:10.1007/s13187-019-01622-2
41. Leong A, Herst P, Kane P. VERT, a virtual clinical environment, enhances understanding of radiation therapy planning concepts. *J Med Radiat Sci.* 2018;65(2):97-105. doi:10.1002/jmrs.272
42. Bridge P, Trapp JV, Kastanis L, Pack D, Parker JC. A virtual environment for medical radiation collaborative learning. *Australas Phys Eng Sci Med.* 2015;38(2):369-374. doi:10.1007/s13246-015-0348-3
43. Stowe J, O Halloran C, Photopoulos G, et al. CTSim: changing teaching practice in radiography with simulation. *Radiography (Lond).* 2021;27(2):490-498. doi:10.1016/j.radi.2020.10.017
44. Bowman A, Reid D, Bobby Harreveld R, Lawson C. Evaluation of students' clinical performance post-simulation training. *Radiography (Lond).* 2021;27(2):404-413. doi:10.1016/j.radi.2020.10.002
45. Shanahan M. Student perspective on using a virtual radiography simulation. *Radiography.* 2016;22(3):217-222. doi:10.1016/j.radi.2016.02.004
46. Kelly T, Surjan Y, Rinks M, Beech J, Warren-Forward HM. Communication: preparing undergraduate radiation therapy students for initial clinical patient interactions. *Radiography (Lond).* 2019;25(4):320-326. doi:10.1016/j.radi.2019.02.012
47. Bridge P, Kirby MC, Callender JA. Evaluating VERT as a radiotherapy plan evaluation tool: comparison with treatment planning software. *J Radiother Pract.* 2020;19(3):210-214. doi:10.1017/S1460396919000797
48. Gibbs V. The role of ultrasound simulators in education: an investigation into sonography student experiences and clinical mentor perceptions. *Ultrasound.* 2015;23(4):204-211. doi:10.1177/1742271X15604665
49. Huysmans R. Quality framework for simulation programs in Australian health care settings. Published October 2014. Updated December 2015. Accessed September 7, 2022. https://simnet.org.au/QualSim_Framework_2016.pdf
50. Halkett GK, McKay J, Shaw T. Improving students' confidence levels in communicating with patients and introducing students to the importance of history taking. *Radiography.* 2011;17(1):55-60. doi:10.1016/j.radi.2010.02.006
51. Sapkaroski D, Baird M, McInerney J, Dimmock MR. The implementation of a haptic feedback virtual reality simulation clinic with dynamic patient interaction and communication for medical imaging students. *J Med Radiat Sci.* 2018;65(3):218-225. doi:10.1002/jmrs.288
52. Sapkaroski D, Baird M, Mundy M, Dimmock MR. Quantification of student radiographic patient positioning using an immersive virtual reality simulation. *Simul Healthc.* 2019;14(4):258-263. doi:10.1097/SIH.0000000000000380
53. Shiner N. Can simulation impact on first year diagnostic radiography students' emotional preparedness to encounter open wounds on their first clinical placement: a pilot study. *Radiography (Lond).* 2019;25(4):294-300. doi:10.1016/j.radi.2019.04.009
54. Palmaria C, Bolderston A, Cauti S, Fawcett S. Learning from cancer survivors as standardized patients: radiation therapy students' perspective. *J Med Imaging Radiat Sci.* 2020;51(4S):S78-S83. doi:10.1016/j.jmir.2020.09.011
55. Arya S, Mulla ZD, Kupesic Plavsic S. Role of pelvic ultrasound simulation. *Clin Teach.* 2018;15(6):457-461. doi:10.1111/tct.12714
56. Sheehan FH, Zierler RE. Simulation for competency assessment in vascular and cardiac ultrasound. *Vasc Med.* 2018;23(2):172-180. doi:10.1177/1358863X17751656
57. Bridge P, Appleyard RM, Ward JW, Philips R, Beavis AW. The development and evaluation of a virtual radiotherapy treatment

machine using an immersive visualisation environment. *Comput Educ.* 2007;49(2):481-494. doi:10.1016/j.compedu.2005.10.006

58. Phillips R, Ward JW, Page L, et al. Virtual reality training for radiotherapy becomes a reality. *Stud Health Technol Inform.* 2008;132:366-371.

59. Shuid AN, Yaman MN, Abd Kadir RA, et al. Effect of early clinical skills teaching on 3rd year medical students' learning: the student perspective. *J Taibah Univ Med Sci.* 2015;10(1):26-32. doi:10.1016/j.jtumed.2014.12.004

60. Melincavage SM. Student nurses' experiences of anxiety in the clinical setting. *Nurse Educ Today.* 2011;31(8):785-789. doi:10.1016/j.nedt.2011.05.007

61. Leblanc VR. Review article: simulation in anesthesia: state of the science and looking forward. *Can J Anaesth.* 2012;59(2):193-202. doi:10.1007/s12630-011-9638-8

RADIOLOGIC
TECHNOLOGY

Statement of Ownership, Management and Circulation as of 8-31-23

Radiologic Technology
Publication No. 0033-8397
6 issues annually; bimonthly
Price $8.65 per year, included in member dues.

Publisher: American Society of Radiologic Technologists, 15000 Central Ave SE, Albuquerque, NM 87123-3909.

Owner: American Society of Radiologic Technologists, 15000 Central Ave SE, Albuquerque, NM 87123-3909.
No other known bondholders, mortgages or other security holders.

Circulation	Average	Actual
A. Total No. of Copies	117,094	95,131
B. Paid and/or Requested		
1. Outside-County Mail Subscriptions	114,551	94,444
2. In-County Subscriptions	0	0
3. Sales Through Dealers, Carriers and Vendors	0	0
4. Other Classes Mailed Through the USPS	299	254
C. Total Paid and/or Requested Circulation	114,850	94,698
D. Nonrequested Distribution		
1. Outside County	45	49
2. In-County	0	0
3. Distributed Through the USPS by Other Classes of Mail	0	0
4. Distributed Outside the Mail	0	0
E. Total Nonrequested Distribution	45	49
F. Total Distribution	114,895	94,747
G. Copies Not Distributed	2,199	384
H. Total	117,094	95,131
I. Percent Paid and/or Requested Circulation	98.08%	99.54%

I certify that the statements made by me above are correct and complete.
Kayla Zehr,
Scientific Journal Managing Editor