

Multisite Implementation of Radiology-TEACHES (Technology-Enhanced Appropriateness Criteria Home for Education Simulation)

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Abstract

Purpose: After encouraging results from a single-institution pilot, a novel case-based education portal using integrated clinical decision support at the simulated point of order entry was implemented at multiple institutions to evaluate whether the program is scalable and results transferable. The program was designed to fill key health systems' science gaps in traditional medical education curricula, ultimately aiding the transition from volume to value in health care. The module described uses commonly encountered medical vignettes to provide learners with a low-stakes educational environment to improve their awareness and apply curricular content regarding appropriate resource utilization, patient safety, and cost.

Methods: In 2016 and 2017, the team implemented the modules at eight US medical schools. A total of 199 learners participated in this institutional review board–approved study; 108 completed the module, and 91 were in the control group.

Results: The module group had higher posttest scores than their control group peers, after controlling for pretest scores ($\beta = 4.05$, $P < .001$). The greatest knowledge gains were on questions related to chest radiography (22% improvement) and adnexal cysts (20.33% improvement) and the least on items related to pulmonary embolism (0.33% improvement). The majority of learners expressed satisfaction with the educational content provided (70.4%) and an increased perception to appropriately select imaging studies (65.2%).

Conclusions: This program is promising as a standardized educational resource for widespread implementation in developing health systems science curricula. Learners at multiple institutions judged this educational resource as valuable and, through this initiative, synthesized practice behaviors by applying evidence-based guidelines in a cost-effective, safe, and prudent manner.

Key Words: Education, simulation, clinical decision support, CDS, high-value health care, health systems science, HSS

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INTRODUCTION

In 1999, *To Err Is Human*, from the Institute of Medicine, was the shot over the bow that drastically changed the course of our health care system [1]. For nearly 20 years, the health care system has been trying to evolve to meet the

quadruple aim of population health management, improved patient experience, reduced cost of care, and improved provider well-being. In addition, there is increased focus on providing high-value health care for patients (value = outcomes/cost) [2,3]. A requirement of high-

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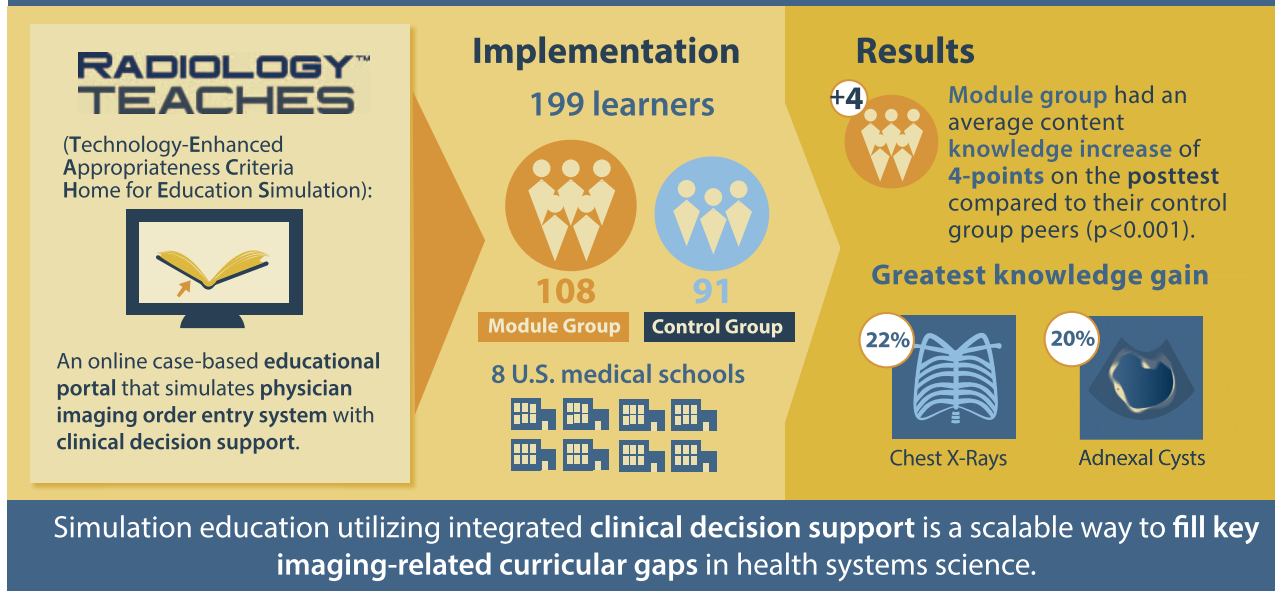
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Feasibility of multi-institution implementation of Radiology-TEACHES



JACR VISUAL ABSTRACT

reliability organizations is standardization and reliable reproducibility. However, medical education curricula around the country vary tremendously. It is unlikely that we will reduce variability and waste unless we educate using a more universal approach, with embedded consistent methods to assess and provide benchmarked feedback to learners. These efforts must cross inter- and intrainstitutional educational silos and be implemented and coordinated throughout medical education. Aligned with the goal of high reliability, efforts have been under way to improve evidence-based practice aided by clinical decision support (CDS) at the point of care; however, learner exposure in education curricula is extremely variable.

Contemporaneously, there are increasing efforts to enhance medical education via improved adult learning principles and integration of technology into medical education, including virtual patients, simulation, e-learning, and mobile health technologies. A specific call to reform radiology education was made through a white paper authored by Straus et al [4] in 2014. At many institutions, radiology education consists of classroom lectures and observational reading-room electives. This reform must include an expanded scope of radiology across the continuum of medical education and focus beyond learners passively familiarizing themselves with medical images. Curricula should include health systems science (HSS), appropriate imaging utilization, imaging-related safety, appropriate use of intravenous contrast, and cost [5]. The ACR provides a resource

to fill some of these knowledge gaps with the ACR Appropriateness Criteria, but their use among medical students has been low [6,7]. Approximately 95% of medical students rotating on radiology clerkships ultimately pursue specialties other than radiology [4,8]. We must ask if we are properly preparing this overwhelming majority of students to request imaging appropriately and safely for the screening, diagnosis, and surveillance of patients. Given the cost and scale of this issue, we cannot assume they will acquire this knowledge and integrate it into their practice behaviors through an apprenticeship model of “see one, do one, teach one.” We have a tremendous need for an innovative, systems-based, and collaborative approach to radiology education with the aim of high-value health care.

How can this shared goal be achieved? Following Kolb’s theory, simulation is increasing in prevalence as a form of experiential learning through deliberative practice [9]. Used commonly for procedural and skills training, an expanded scope of simulation is gaining recognition as a valuable and safe learning environment for clinical knowledge assimilation, reasoning, and cognition [10,11]. Most education curricula lack evidence-based and consistent guidance regarding HSS, appropriate use of diagnostic resources, imaging-related safety, and cost [12]. Additionally, there is a paucity of objective information regarding when to grant learners the autonomy to make patient-centered, entrustment decisions [13]. Our founding team recognized

an opportunity to address this significant gap in medical education through the creation of Radiology-TEACHES (Technology-Enhanced Appropriateness Criteria Home for Education Simulation), a program aimed to create knowledge through transformative experience. Radiology-TEACHES is an online portal that uses case vignettes integrated with a digital representation of the ACR Appropriateness Criteria for diagnostic imaging (ACRSelect®) to simulate the process of ordering imaging studies with CDS. Learners receive this evidence-based feedback at the virtual point of order entry, thereby better understanding appropriate imaging utilization and empowering them to provide value for patients. The platform was previously piloted with medical students at a single institution, resulting in improved ability of learners to more appropriately select imaging examinations and a strong perceived value among the participating students [8]. In this report, we evaluate whether the pilot's positive results are transferable across multiple institutions and, if so, whether this resource should be offered as a standardized educational resource and assessment tool for adoption into medical school curricula nationally.

METHODS

Using an education portal built within a content management system and integrated with a clinically available CDS resource, we partnered with eight academic institutions from around the United States to perform a multisite study. Institutional review board approval was obtained at each participating institution.

Portal

The education portal is designed to provide learners with a self-directed, digital learning, simulation education environment that can be implemented in an asynchronous and longitudinal curriculum. The modules are within CORTEX, a content management system provided by the ACR. CORTEX is integrated with a clinically available CDS web service (ACRSelect) using an application programming interface. Learners receive instant feedback regarding their answers and have immediate access to the relevant evidence-based CDS while analyzing the cases, synthesizing their decisions and formulating practice behaviors in this low-stakes environment [8]. Representative examples from the portal are shown in [Figures 1, 2, and 3](#). Additional information regarding the portal can be found online [14].

Vignettes

Cases were authored by a team of five academic radiologists with subspecialty training and clinical practice in emergency radiology, body imaging, neuroradiology, musculoskeletal

imaging, and breast imaging. A total of 21 case vignettes were included in the module. A common theme among the cases was Choosing Wisely® topics, given their widespread validation, vetting, and global interest [15]. From the imaging-related Choosing Wisely topics, companion cases were authored to highlight commonly encountered clinical scenarios with available appropriateness criteria found within the CDS web service. Topics covered included preoperative chest radiography, adnexal cyst, headache, low back pain, rhinosinusitis, pediatric head trauma, pediatric febrile seizure, and pulmonary embolism.

Participating Sites

The participating sites were Augusta University, Cooper Medical School of Rowan University, Montefiore Medical Center, Penn State Hershey Medical Center, the University of Chicago Hospitals, the University of South Carolina School of Medicine Greenville, the Uniformed Services University of Health Services, and Wake Forest School of Medicine.

An initial meeting was held to allow interested programs to view demonstrations of the Radiology-TEACHES program, and the logistics of introducing the program at individual schools were discussed. Physician leaders from each program identified administrative program coordinators at their sites to serve as points of contact. A central administrative coordinator at the ACR trained the program coordinators on how to use the CORTEX platform in a conference call and served as a resource for questions or technical issues with the program. The coordinators then scheduled availability of the module at their institutions on the basis of their programs' implementation plans. Each program was allowed flexibility to offer the modules at a time that was most suitable for their institution and curriculum. This flexibility was included to best evaluate whether the benefit of the modules was transferable to different institutions and curricula. To track the implementation method at each institution, participating institutions were asked to complete a protocol form that outlined the demographics of the participating learners, when in the curriculum the module was performed, and details of how the module was implemented. The module was most commonly integrated into elective radiology clerkships.

Pretest and Posttest

Learner knowledge was assessed before starting and after completing the modules using a 24-item multiple-choice test. Items for the assessment were created by the curriculum team, covering the seven Choosing Wisely topics: low back pain (six items), adnexal cyst (three items), pulmonary embolism (three items), rhinosinusitis (three items),

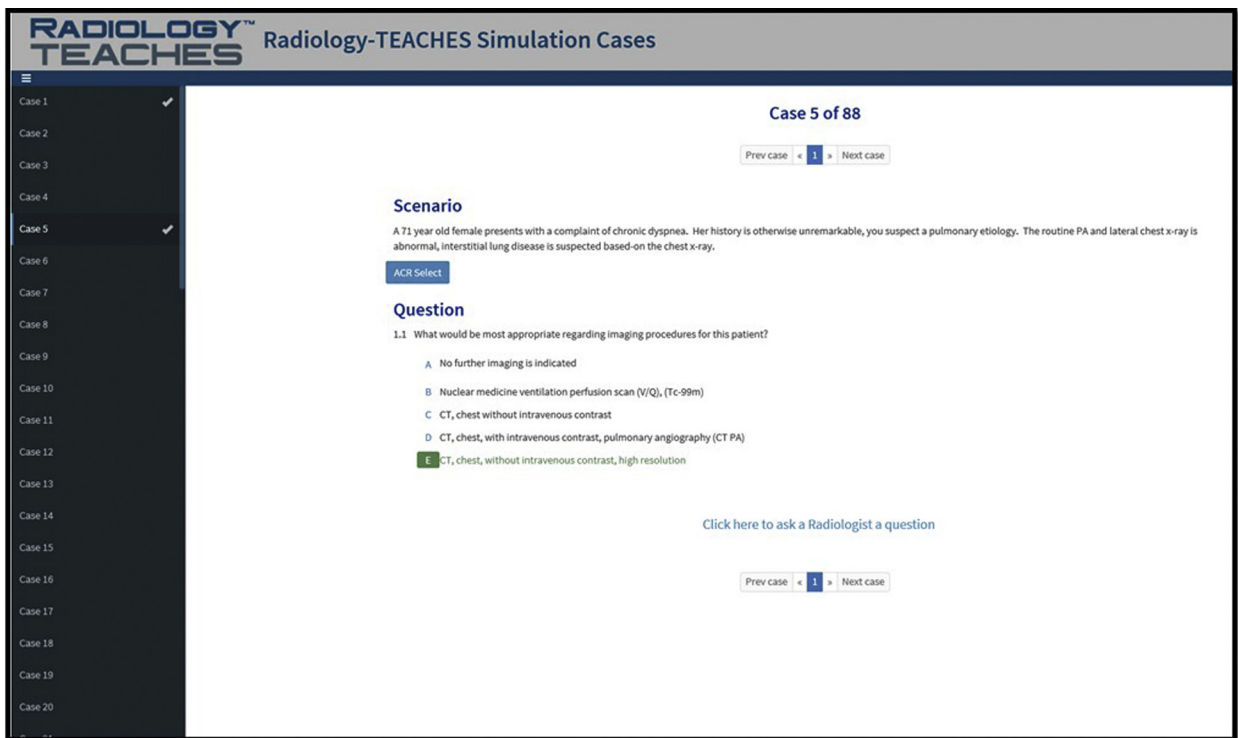


Fig 1. Example of a case vignette provided to learners during the simulation modules. The interface includes access to the integrated clinical decision support resource, immediate feedback for their answers, and the ability to send a question directly to a radiologist educator.

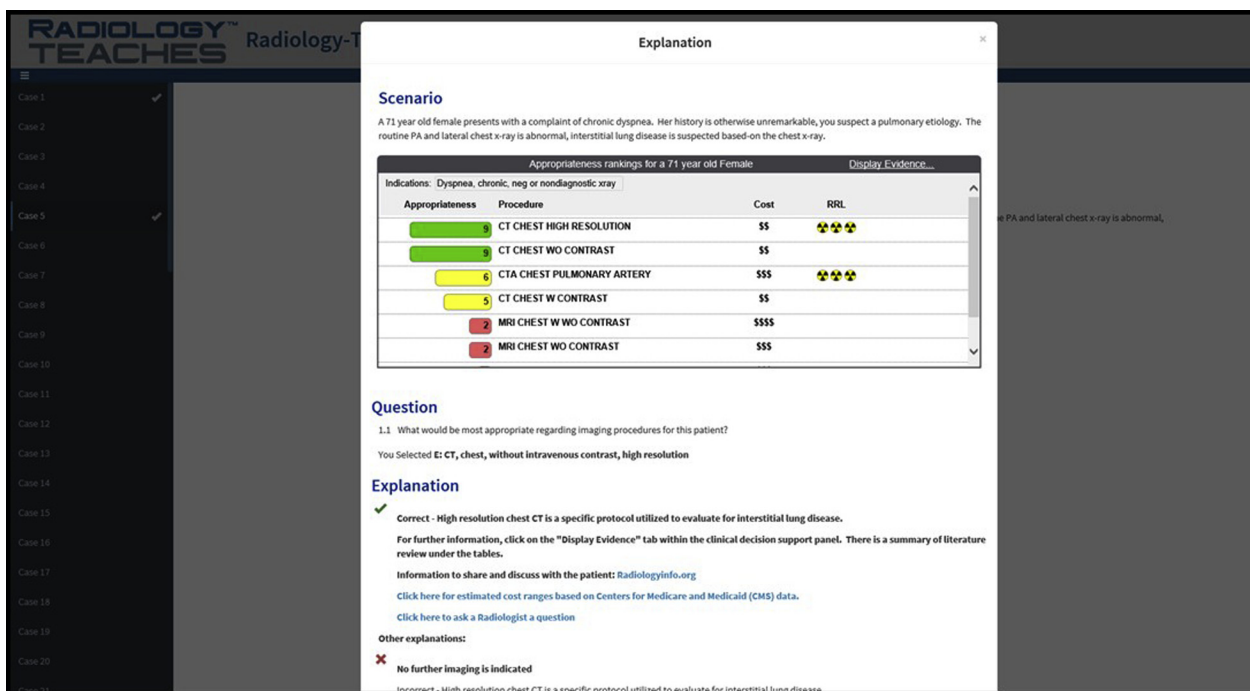


Fig 2. Example of decision support feedback the learners received while doing the simulation modules. Feedback included appropriateness score of the examination, relative cost of the examination, relative radiation dose of the examination, and how intravenous contrast would be best ordered for CT and MRI.

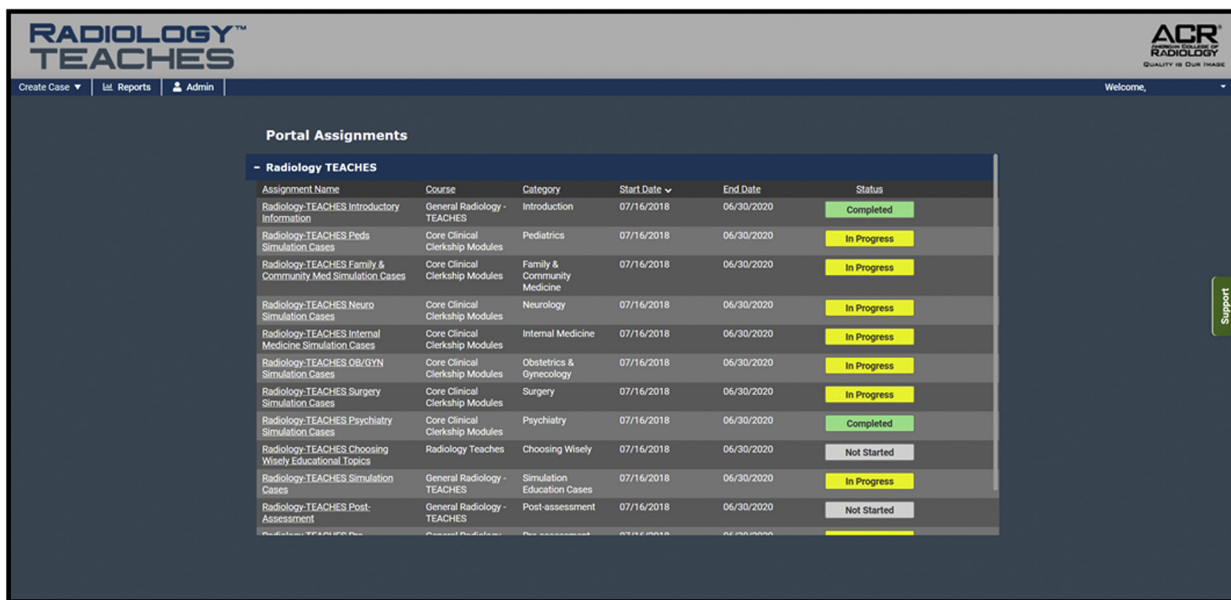


Fig 3. The portal dashboard used by learners to navigate through the simulation modules.

pediatric head injury (three items), uncomplicated headache (three items), and preoperative chest radiography (three items).

Simulation Education

After completing the pretest, learners performed the education simulation module.

Postassessment

After completion of the module and posttest, students were asked to respond to an anonymous survey regarding their satisfaction with the content, format, and learning experience. The survey consisted of six Likert-type items on which students indicated their levels of agreement with each statement on a five-point scale (from “strongly disagree” to “strongly agree”) as well as an opportunity for students to explain their ratings if they chose to do so. The postsurvey also included two open-ended questions regarding desired improvements to the education portal and the CDS tool.

Statistical Analyses

For the purpose of the analysis of differences between the treatment and control groups, only the five sites that implemented the module as mandatory and with third-year medical students (M3) (sites A-E) were included. This was done to decrease bias from unmeasurable heterogeneity in student groups (eg, features of self-selected students, inability to separate out third- and fourth-year students).

First, means and SDs for the sites were calculated to provide an initial exploration of the data. Next, to determine

the differences in posttest scores between the treatment and control groups, a multilevel regression approach was used. This analysis allowed us to identify differences in student posttest scores while also accounting for the nesting of students within institutions as well as other variables that may have affected differences in posttest scores. The model is as follows:

$$\begin{aligned}
 \text{Posttest}_{ij} = & \gamma_0 + \gamma_1(\text{Group}_{ij}) + \gamma_2(\text{Pretest}_{ij}) \\
 & + \gamma_3(\text{DateofPre}_{ij}) \\
 & + \gamma_4(\text{DaysBetween}_{ij}) \\
 & + \gamma_5(\text{Group}_{ij} \times \text{Pretest}_{ij}) \\
 & + \gamma_6(\text{Pretest}_{ij} \times \text{DateofPre}_{ij}) \\
 & + u_{0j} + e_{ij},
 \end{aligned}$$

where Posttest_{ij} is an individual student’s posttest score, Group_{ij} is a dummy-coded variable for participation in the control (0) or module (1) group, Pretest_{ij} is the student’s pretest score centered at the grand mean, DateofPre_{ij} is the numerical representation of the date the student took the pretest for which 0 denotes the first day of the multisite implementation, DaysBetween_{ij} is a count of the number of days between the student’s pre- and posttest, u_{0j} is the random effect of site membership, and e_{ij} is random error. Additionally, two interaction terms were included to capture any additive effect of group membership or time within the academic year on students’ pretest performance.

Postsurvey rating data were explored descriptively using percentages by response option, and open-ended comments were analyzed for common themes using content analysis.

RESULTS

A total of 199 students across eight institutions participated in the multisite implementation of Radiology-TEACHES between July 2016 and June 2017. Of those students, 108 participated in the module, and the remaining 91 were in the control group. Sites differed in implementation, with six sites offering the module to only M3 students and two sites offering the module to M3 and fourth-year medical students. Additionally, those that required participation varied in how they assigned students to the module and control groups. Three sites alternated cohorts of students offered the intervention, whereas the other three randomly offered students within each cohort the intervention. Cohorts ranged in size from 1 to 40 students (Table 1). Sites also varied in the amount of time between the pre- and posttest, with some sites administering the posttests as few as 3 days after the

Table 2. Means and SDs for student content knowledge across analyzed groups

Treatment Group	n	Pretest		Posttest	
		M	SD	M	SD
Control group	63	12.00	3.45	11.84	3.44
Module group	72	13.25	2.56	16.62	2.56

pretest, whereas others waited more than 1 month. Additionally, some sites had students take the assessments at the same time, whereas others were able to complete them independently.

An initial inspection of the descriptive statistics aggregated across all sites showed that the module groups had an average increase from pre- to posttest, whereas the control groups did not have any increase (Table 2).

Results from the multilevel model are provided in Table 3. The variance components in the unconditional model (a model with no predictors) indicate that approximately 15% of the variance in posttest scores

Table 1. Site implementation information

Site	Students	Assignment	Control Group				Module Group			
			Number of Cohorts	Number of Students	Days Between Tests		Number of Cohorts	Number of Students	Days Between Tests	
					Mean	SD			Mean	SD
A	Mandatory, M3	Alternating cohorts	1	2	32	—	2	9	23.00	1.41
B	Mandatory, M3	Random within cohorts	1	2	7	—	1	7	7	—
C	Mandatory, M3	Random within cohorts	2	6	10.50	0.71	2	6	10.50	0.71
D	Mandatory, M3	Alternating cohorts	3	13	9.00	1.73	6	23	9.17	2.79
E	Mandatory, M3	Random within cohorts	1	40	8	—	1	27	8	—
F	Mandatory/voluntary, M3*	Alternating cohorts	5	27	3.00	0.00	5	25	3.00	0.00
G	Voluntary, M3 and M4	—	0	—	—	—	1	5	11	—
H	Voluntary, M3 and M4	—	0	—	—	—	1	1	18	—

Note: M3 = third-year medical student; M4 = fourth-year medical student.

Table 3. Results from multilevel model predicting student posttest scores

	Unconditional Model		Full Model	
	Coefficient	SE	Coefficient	SE
Fixed effects				
Intercept	15.4204*	0.849	12.321*	1.599
Group			4.053*	0.558
Pretest			0.908	0.533
Date of pretest			-0.005	0.005
Days between pre- and posttest			0.087	0.594
Pretest × group			-0.133	0.182
Pretest × date of pretest			-0.001	0.002
Random effects				
τ_0^2	2.704		0.000	
σ^2	15.181		8.539	
-2 log-likelihood	758.1		672.6	
AIC	764.1		690.4	

Note: AIC = Akaike information criterion.

* $P < .01$.

occurred across institutions (intraclass correlation coefficient = 0.15), so we proceeded with the full model to account for this between-institution variance. Once variance between sites was taken into consideration in the full model, we found that students who participated in the module group had a statistically significant average content knowledge increase of about 4 points on the posttest compared with their peers in the comparison group, $t(124) = 7.261, P < .001$. Additionally, no other variables in the model were significant predictors of students' posttest scores, meaning that the outcome was not predicted by prior knowledge as captured on the pretest, the number of days between the tests, the time of the academic year in which the activity was completed, or student distribution between the control and module groups.

For the students in the module group, the greatest subject matter gains were seen in questions related to preoperative chest radiography (22% increase) and adnexal cyst (20.33% increase), whereas students struggled with the items related to pulmonary embolism (0.33% increase) (Table 4).

Although 108 students completed the module, there were 115 postsurvey responses. Surveys were collected in an entirely different system and were completely anonymous, making it impossible to identify duplicate entries. Overall, the majority of learners were positive when asked about

Table 4. Module group student average change from pre- to posttest by topic area

Topic Area	Number of Questions	Percentage Change
Lower back pain	6	14.50
Adnexal cyst	3	20.33
Pulmonary embolism	3	0.33
Rhinosinusitis	3	12.33
Pediatric head injury	3	11.33
Uncomplicated headache	3	16.67
Chest radiography	3	22.00

their satisfaction with the unit and its educational value, with 60% or more respondents agreeing or strongly agreeing with all of the related statements on the post-evaluation (Table 5).

DISCUSSION

We describe a successful multisite implementation of a case-based radiology education portal with integrated CDS. The education simulation module with integrated CDS at the point of order entry was successfully implemented at eight medical schools from around the country. The program focuses on the safe and appropriate use of imaging and is designed to fill key gaps in traditional medical education curricula to aid in the transition from volume to value in health care. The module uses commonly encountered medical vignettes to provide learners with a low-stakes education environment to improve their awareness and apply curricular content regarding evidence-based medicine, patient safety, cost, and patient-facing educational resources.

Wide variation in how and when radiology is incorporated into medical school curriculum exists. This variation makes a standardized study across the multiple institutions extremely challenging, resulting in analytic limitations of this study given inherent variation across sites, including sampling and implementation, with the possibility that there are unaccounted sources of variation across institutions that may have influenced outcomes. However, this potential limitation also provided each site the flexibility to integrate the module into its curriculum at a point that optimized all learners' experience and to demonstrate that regardless of where the module was integrated, there was consistent improvement in knowledge, reinforcing the potential for broad, flexible implementation. Although results of this

Table 5. Percentage of students selecting each category of agreement level on the postevaluation and comment themes for each item

Survey Question	Strongly Disagree (%)	Disagree (%)	Uncertain (%)	Agree (%)	Strongly Agree (%)	Positive Comment Themes	Critical Comment Themes
I was satisfied with the education CONTENT provided by the education portal with integrated ACRSselect clinical decision support (CDS).	2.60	10.40	16.50	58.30	12.20	Content was helpful/ useful; good explanations	Format was difficult to use; small breadth of information; needed more in-depth explanations
The education portal significantly enhanced my learning experience.	3.50	13.90	22.60	52.20	7.80	Concise cases/ explanations; helped with thinking about practice	Format was difficult to use; needed more in-depth explanations
The education portal should be integrated into the curriculum at my medical school.	2.60	10.40	21.70	50.40	14.80	Supports understanding decision making; not enough exposure to this content in current curriculum	Only integrate with improved format; integrate as a resource/option
I would recommend the education portal to my classmates and colleagues.	3.50	11.30	22.60	52.20	10.40	Good content/ explanations; useful/helpful	Format was difficult to use; need more support for understanding content
After using the education portal, in the future I am more likely to use clinical decision support when choosing imaging examinations for my patients.	2.60	4.30	18.30	47.00	27.80	Increased understanding of ordering; support is useful/helpful	Format was difficult to use
After utilizing the portal, I am more prepared to appropriately select imaging studies for my patients.	2.60	9.60	22.60	45.20	20.00	Now know how to access information; helpful; increased confidence/ preparedness	Need more practice/ information/in-depth explanations

study are confined to a simulated environment, prior studies have shown that online curriculum and simulation positively affect provider behavior and patient outcomes [16-19].

Students who completed the module demonstrated increased knowledge related to appropriate imaging

compared with their peers at the same institution who did not complete the module. This result was not influenced by the timing of the module during the academic year, suggesting that students were not gaining knowledge related to imaging elsewhere in the curriculum throughout the year

and that there was a benefit to exposure regardless of timing. Additionally, the number of days between the pre- and posttest was not a significant predictor of students' posttest knowledge, suggesting that modules could be flexibly implemented and still benefit learners. Furthermore, the qualitative outcomes suggest that the majority of learners enjoyed the experience and found value in its supplementation of their curriculum. Difficulties were related largely to the portal format, indicating that clearer instructions on use may be warranted in future applications and technology upgrades in future versions of the portal.

Too frequently, radiology medical education has consisted of didactic lectures in large auditoriums or learners observing radiology studies being dictated during a radiology elective. This approach is passive and focused primarily on image interpretation, which does not accurately reflect how most medical students will use medical imaging in their clinical practice. In many cases we have failed to adequately educate our current and future referring medical providers. The current generation of learners seeks a more active learning environment, technology based, and interactive with immediate and continuous feedback [20]. Radiology-TEACHES fills these needs in many ways. Benefits are transferable, and the program can be successfully integrated into radiology education curricula in various ways. Thus it provides a bridge between clinical information and the cognitive processes of decision making, diagnosis, and practice behaviors. All of this is provided in a low-stakes learning environment that removes the risk for compromising patient care or increasing cost. Learners are provided immediate feedback and the opportunity to pursue supplemental self-directed learning and patient-centered educational resources. Radiology-TEACHES provides the opportunity to close gaps in curricula and decrease intra- and interinstitutional educational variability. It is doubtful that we will successfully decrease unexplained clinical variance as long as unexplained educational variance is widespread.

A readily available standardized resource lowers the barriers to implementation in an era of strained educational resources and faculty members. Longitudinal integration of modules throughout the curriculum provides an opportunity to have these critical concepts available at the point of each learner's greatest inquiry and impact on depth of knowledge. Students are excited to start bridging their preclinical and clinical curricula with the addition of online educational resources, especially when used in a hybrid learning environment [21]. This educational resource has the potential to fill a need for standardized competency-based assessment as well as a remediation tool to complement developing HSS curricula [12]. Given the omnipresent roles of medical imaging in health care diagnosis, disease screening, and surveillance, radiology

medical education must expand to more completely encompass the curricular content needed to deliver high-value care to our patients.

In this study, we have successfully performed and reviewed a multisite implementation of a high-value radiology medical student education resource that simulates image ordering assisted with integrated CDS. Our work demonstrates the feasibility of widespread adoption of this technology in various settings and times within the medical school curriculum. Radiology-TEACHES is a program scalable to the broader national level. Potential for future inquiry includes interprofessional education, team-based care, longitudinal outcomes, and best practices of implementation.

TAKE-HOME POINTS

- Simulation education is a scalable resource to teach curricular components of HSS related to imaging.
- Providing readily available and easily implemented resources is an attractive way to reduce the barriers to standardize medical education curricula, with the aim of decreasing unexplained clinical variance.
- The current generation of learners is attracted to technology-enhanced learning that can be self-directed and performed in an asynchronous learning environment.

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