A Vertically Integrated Online Radiology Curriculum Developed as a Cognitive Apprenticeship: Impact on Student Performance and Learning

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Rationale and Objectives: The principles of Collins' cognitive apprenticeship model were used to design a radiology curriculum in which medical students practice radiological skills using online case-based modules. The modules are embedded within clinical third-year clerkships, and students are provided with personalized feedback from the instructors. We describe the development of the vertical online radiology curriculum and evaluate its impact on student achievement and learning process using a mixed method approach.

Materials and Methods: The curriculum was developed over a 2-year period. Student participation was voluntary in the first year and mandatory in the second year. For quantitative curriculum evaluation, student metrics for voluntary versus mandatory groups were assessed using independent sample *t* tests and variable entry method regression analysis. For qualitative analysis, responses from a survey of students about the value of the curriculum were organized into defined themes using consensus coding.

Results: Mandatory participation significantly improved ($p = .001$) the mean radiology examination score (82 %) compared to the voluntary group (73%), suggesting that mandatory participation had a beneficial effect on student performance. Potential preexisting differences in underlying general academic performance were accounted for by including mean basic science grades as the first variable in the regression model. The significant increase in R^2 from .16 to .28 when number of radiology cases completed was added to the original model, and the greater value of the standardized beta for this variable, suggest that the curriculum made a significant contribution to students' radiology examination scores beyond their baseline academic performance. Five dominant themes about curricular characteristics that enhanced student learning and beneficial outcomes emerged from consensus coding. These themes were (1) self-paced design, (2) receiving feedback from faculty, (3) clinical relevance of cases, (4) gaining confidence in interpreting radiological images, and (5) transfer of conceptual knowledge to actual practice.

Conclusions: The vertically integrated online radiology curriculum can positively impact student performance and learning process in the context of the cognitive apprenticeship model.

Key Words: Cognitive apprenticeship; medical student education; mixed methods; online learning; vertical curriculum.

INTRODUCTION

Radiological imaging is widely acknowledged as an essential element of modern medical practice. Accordingly, increasing attention has been given to the importance of preparing medical students to become responsible users of medical imaging by including radiology in the curriculum. Methods of teaching radiology range from stand-alone clerkships composed of dedicated blocks of time, to longitudinal or vertically integrated clerkships in which content is distributed throughout the year and coordinated with other topics (1–3). The primary rationale for favoring a vertically integrated approach is that it promotes context-specific learning with relevant radiology material presented alongside corresponding clinical conditions and patient contact (4).

Presenting material in a vertically integrated manner fosters durable learning by making the material relevant to students' practical, real-life clinical work (5–8). These same precepts form the foundation of Collins' cognitive apprenticeship theory, which emphasizes purposeful practice of target skills within the functional context of their use (9). The cognitive

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apprenticeship model promotes active problem solving and transfer of conceptual knowledge from the abstract stage to the phase of successful execution of the target task in a practical, authentic framework. This model is germane to all types of cognitive learning, including clinical medical education. According to this learning framework, preexisting cognitive skills are reinforced by repeated attempts to execute the target process under the guidance of an expert practitioner. Performance of the targeted task in successive approximations of proficiency replicates the gradual growth of expertise, similar to what occurs in a traditional apprenticeship.

Using the principles of the cognitive apprenticeship, we designed a vertically integrated radiology curriculum that requires students to actively practice radiology skills by analyzing weekly case-based imaging modules embedded within corresponding third-year required clinical clerkships. The radiology cases are synchronized in content and time of presentation with relevant clinical scenarios that students encounter in their concurrent clerkships. The curriculum uses a unique online format that provides students with customized feedback from the instructor. The purpose of this article is to describe the development and implementation of an online vertically integrated radiology curriculum over a 2-year period and to evaluate the impact of the curriculum on student achievement and learning process using a mixed method approach that combines both quantitative and qualitative data analysis.

TABLE 1. Number of Cases and Sample Case Topics for Radiology Curriculum, Sorted by Corresponding Clinical Clerkship

Clerkship	Number of Cases	Sample Case Topics
Medicine	8	• Left lung atelectasis/ Malposition of endotracheal tube • Cavitary lung lesion/ Tuberculosis • Squamous cell carcinoma of lung
Surgery	8	• Renal cyst/renal stone • Cholecystitis • Free intraperitoneal air
Family Medicine	6	• Osteoarthritis of hand • Congestive heart failure • Pneumothorax
Pediatrics	6	• Pyloric stenosis • Intussusception • Pneumonia
OB-Gyn	6	• Early pregnancy dating • Ectopic pregnancy • Ovarian torsion
Neurology	4	• Spinal cord compression • Stroke • Intracranial epidural hematoma

MATERIALS AND METHODS

The study design was reviewed by our medical school's Institutional Review Board and was exempted from further review and monitoring.

Curriculum Development

Curricular assessment several years ago revealed the lack of robust formal radiology education at our medical school. To address this gap, we designed a radiology curriculum in a longitudinal, or vertical, format beginning in the first and second preclinical years and extending into the third-year clinical clerkships. The third-year component of the curriculum, which is part of a broader overarching three-year vertical radiology curriculum, forms the basis of this report. The longitudinal structure of the radiology curriculum allows flexibility in timing so that the radiology curricular topics correspond to and intersect with topics covered in both preclinical courses and clinical clerkships, which are presented in a traditional horizontal fashion in defined blocks of time.

In the preclinical years, the learning objectives are to become familiar with the fundamental principles of different imaging modalities and to recognize and understand the appearance of normal anatomy and pathological conditions. The material is presented as a series of online, systems-based modules available for self-study on a school website, and is synchronized with topics covered in concurrent anatomy, pathology, and physical diagnosis courses. Students are required to pass a multiple-choice radiology examination at the end of each of the first and second years. The objectives of the third-year curriculum are to be able to interpret and provide differential diagnoses for radiological images in a given clinical context, and to gain non-interpretative skills by understanding appropriate imaging workup of common clinical conditions.

Case Selection

Students received weekly clerkship-specific imaging cases for interpretation as they rotated through six core clinical clerkships. The number of cases that a student saw in a clerkship corresponded to the clerkship's duration (Table 1). During their third year, each student encountered 38 cases, chosen by the radiology curriculum directors from a pool of 172 available cases (Table 1). The topics were derived from the objectives of our institutional vertical radiology curriculum and the Alliance of Medical Student Educators in Radiology's National Medical Student Curriculum in Radiology (https://www.aur.org/Secondary-Alliances.aspx?id=141) (10). A website developed by our school provided imaging curricular content as a complementary resource (http://www.stritch.luc.edu/lumen/MedEd/Radio/curriculum/radiology-curric1_f.htm).

Case Presentation

A case consisting of a clinical scenario, radiological images, and questions were sent to students at the beginning of each week using a locally developed web-based computer appli-