Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Radiology Education in the Time of COVID-19: A Novel Distance Learning Workstation Experience for Residents

Casey McRoy, MD, Lakir Patel, MD, Durga Sivacharan Gaddam, MD, Steven Rothenberg, MD, Allison Herring, MD, Jacob Hamm, MD, Lydia Chelala, MD, Joseph Weinstein, MD, Elana Smith, MD, Omer Awan, MD

Rationale and Objectives: The coronavirus disease of 2019 (COVID-19) pandemic has challenged the educational missions of academic radiology departments nationwide. We describe a novel cloud-based HIPAA compliant and accessible education platform which simulates a live radiology workstation for continued education of first year radiology (R1) residents, with an emphasis on call preparation and peer to peer resident learning.

Materials and Methods: Three tools were used in our education model: *Pacsbin (Orion Medical Technologies, Baltimore, MD, pacsbin.com), Zoom (Zoom Video Communications, San Jose, CA, zoom.us), and Google Classroom (Google, Mountain View, CA, classroom.google.com).* A senior radiology resident (R2-R4) (n = 7) driven workflow was established to provide scrollable *Digital Imaging and Communications in Medicine* (DICOM) based case collections to the R1 residents (n = 9) via *Pacsbin.* A centralized classroom was created using *Google Classroom* for assignments, reports, and discussion where attending radiologists could review content for accuracy. Daily case collections over an 8-week period from March to May were reviewed via *Zoom* video conference readout in small groups consisting of a R2-R4 teacher and R1 residents. Surveys were administered to R1 residents, R2-4 residents, and attending radiologist participants.

Results: Hundred percent of R1 residents felt this model improved their confidence and knowledge to take independent call. Seventy-eight percent of the R1 residents (n = 7/9) demonstrated strong interest in continuing the project after pandemic related restrictions are lifted. Based on a Likert "helpfulness" scale of 1-5 with 5 being most helpful, the project earned an overall average rating of 4.9. Two R2-R4 teachers demonstrated increased interest in pursuing academic radiology.

Conclusion: In response to unique pandemic circumstances, our institution implemented a novel cloud-based distance learning solution to simulate the radiology workstation. This platform helped continue the program's educational mission, offered first year residents increased call preparation, and promoted peer to peer learning. This approach to case-based learning could be used at other institutions to educate residents.

Key Words: Cloud-based; Education; Pandemic; Technology; Workstation.

Abbreviations: DICOM Digital Imaging and Communications in Medicine, **COVID-19** SARS-CoV-2 Coronavirus disease of 2019, **SRPM** Senior resident project manager, **PACS** Picture archiving and communication system, **R1** First year radiology residents, **R2-R4** Second through fourth year radiology residents

INTRODUCTION

The coronavirus disease of 2019 (COVID-19) was officially designated as a pandemic by the World Health Organization on March 11, 2020. The global outbreak of cases has prompted public health and governmental initiatives, such as social distancing, to curb infection rates and flatten the incidence curve. Commonly implemented social distancing strategies across radiology departments include increased use of home workstations for remote interpretation by attendings, single station reading rooms at the hospital, and the cancellation of in-person group conferences (1,2). As a result, academic radiology departments face novel obstacles during the COVID-19 pandemic, particularly resident education (3).

Additionally, departments may change the amount of resident participation in diagnostic radiology operations. For example, residents may be redistributed to serve general hospital needs, encouraged to self-study at home, or function more independently in reading rooms. These changes invariably limit the ability for residents to learn from attending radiologists at the workstation, a vital aspect of resident training. At our institution

Acad Radiol 2020; 27:1467–1474

From the Department of Diagnostic Radiology and Nuclear Medicine, University of Maryland School of Medicine, 22 South Greene Street, Baltimore, MD 21201. Received May 20, 2020; revised August 1, 2020; accepted August 2, 2020. **Address correspondence to:** D.S.G. e-mail: siva.gaddam@umm.edu

https://doi.org/10.1016/j.acra.2020.08.001

specifically, first year radiology (R1) residents were instructed to self-study at home, with second through fourth year (R2-R4) residents covering clinical services. For our R1 residents preparing to take call, these operational changes limited in-person workstation learning, and posed significant disruption to their education and call preparation. At the start of the pandemic, the potential duration of this altered workflow was also unclear. While video- and web-based conference platforms for distance learning helped maintain resident education in the form of didactic and case conferences, solutions to simulate the learning experience at the workstation were limited (4,5). To our knowledge, there have been no formalized remote learning solutions which utilize a cloud-based DICOM viewer and personalized case review to simulate independent case interpretation.

To maintain workstation teaching and adequate call-preparation, our institution implemented a cost-effective, novel, cloud-based, HIPAA compliant training model which simulates a workstation-like experience. This platform was specifically designed for preparing first year radiology residents to take independent call, but the core principles and functionality could be used in the education of radiology residents at all levels. For example, the platform could be used to build and present interactive teaching files. Additionally, our initiative aimed to promote peer to peer resident learning.

METHODS

This educational intervention was determined to be not human subjects research and thus exempt by our Institutional Review Board.

Our model relied on integrating three main tools: *Pacsbin (Orion Medical Technologies, Baltimore, MD, pacsbin.com), Zoom (Zoom Video Communications, San Jose, CA, zoom.us), and Google Classroom (Google, Mountain View, CA, classroom.google.com)*. Roles were defined as follows: *R1 residents* = first year radiology residents (n = 9), *senior resident teachers* = second through fourth year radiology residents (n = 7 [R2 = 1, R3 = 2, R4 = 4]), and *senior resident project manager (SRPM)* = a separate R4 resident. R1 residents were encouraged to participate as they were not assigned to clinical service at the hospital. The senior resident teachers volunteered to participate via e-mail response to the SRPM who presented the project proposal to the residency. Over the course of a week, the SRPM and senior resident teachers developed a workflow which aimed to simulate the workstation and readout experience, illustrated in Figure 1. Integration of *Pacsbin, Google Classroom,* and *Zoom* as well as piloting and troubleshooting of the platform was performed by these residents. Two board-certified attending radiologists provided oversight of the cases and reference reports. Workflow steps are further detailed in subsections below. Information technology staff support was not needed during the project, which ran for an 8-week period from March 15 to May 15.

Part A—Creating Case Collections Via *Pacsbin*

Pacsbin is a radiologist-developed cloud-based HIPAA compliant application which can be integrated into an institution's Picture Archiving and Communication System (PACS) system and allows seamless single click transfer of anonymized cases to the cloud. At our institution, faculty and residents have had unlimited (paid) account access to *Pacsbin* for the last 3 years. *Pacsbin* is used at our institution for personal case collection, informal case exchange, and case presentation at teaching conferences. Cases are added to a user's collection

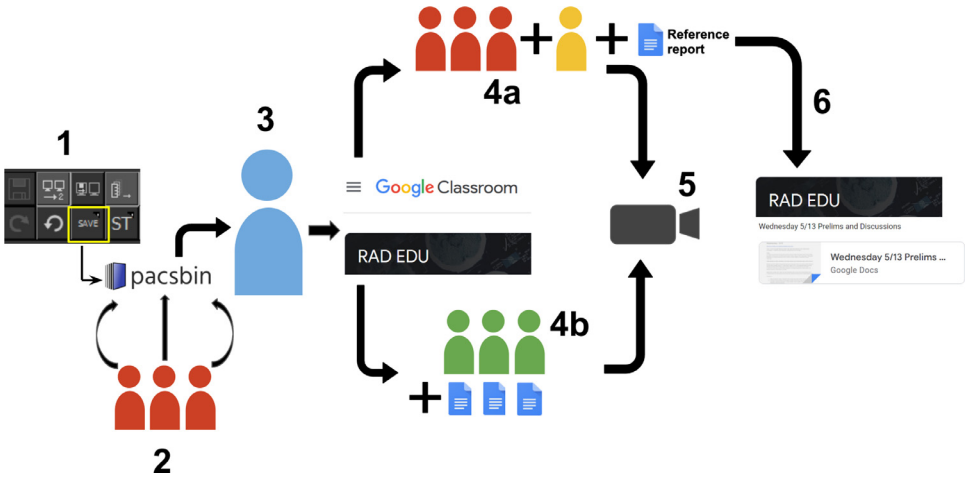

Figure 1. Project flowchart. Schematic diagram outlining the workflow of the peer learning educational model. (1) One click step to add any case from the home institution PACS system to *Pacsbin.* (2) Several senior residents and attendings can share cases from their *Pacsbin* collection with the Senior resident manager. (3) Senior resident manager (blue) adds cases as a daily playlist to the centralized cloud based classroom. (4a) Senior resident teachers (red) collaborate and generate preliminary reports with teaching discussions on Google docs. These reports are vetted by an attending teacher (orange) prior to sending to R1 residents. (4b) R1 residents (green) work on generating their own preliminary reports in a Google docs within the classroom and "submit" their assignment. (5) Video conference small group readout to simulate workstation readout. (6) Following these video readouts, the reference reports are sent to the R1 residents via Google Classroom stream.

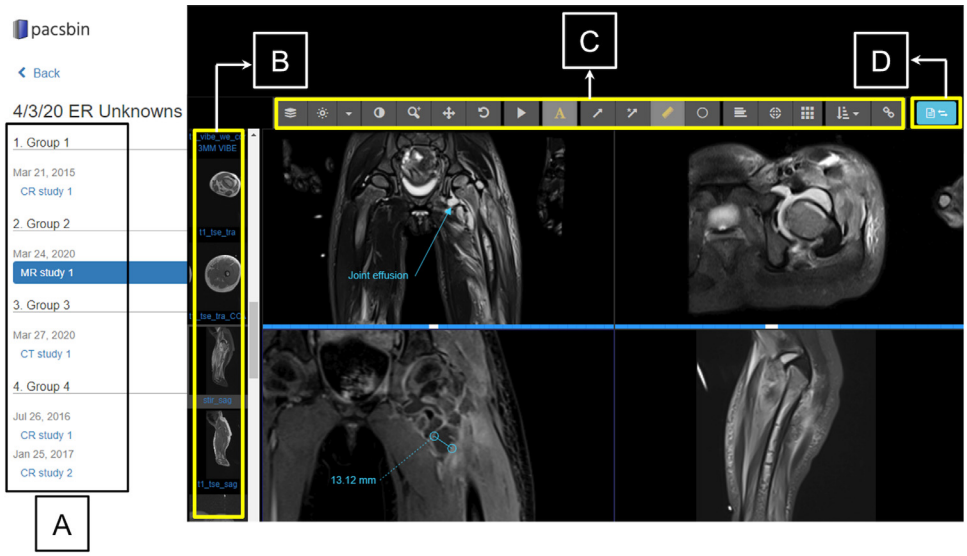

Figure 2. *Pacsbin* simulates a PACS like environment. (A) Collection of anonymized cases for the day to resemble a worklist. (B) Dynamic series selection with drag and drop capability. (C) Full PACS functionality with all commonly used image tools including windowing, zoom/pan, annotation and ROI. (D) Study notes tool allows teaching points, dictated reports, or other discussion to be read while reviewing the case.

and can be organized and shared with other users. Cases uploaded to *Pacsbin* are easily accessible over the internet and studies can be reviewed within the application's *Digital Imaging and Communications in Medicine* (DICOM) viewer with functionality analogous to a PACS workstation (Fig 2). This application allows access to cases without the need for a Virtual Private Network connection to the home institution network. To create a library of cases for this project, senior resident teachers and attendings shared cases with the SRPM via *Pacsbin*.

Using the library of shared cases, the SRPM organized a daily case collection resembling a worklist containing four to five cases spanning several modalities. Each collection of cases was reviewed by the attending radiologists and reflected a diverse array of cases with common emergency room pathology across all subspecialties.

Part B—*Google Classroom* Implementation

Utilizing the *Google Classroom*, a free online centralized coursework management platform, a new course "Rad Edu" was created and the R1 residents were enrolled as "students" while senior resident teachers and attendings were enrolled as "teachers." The daily *Pacsbin* case collection link was added as a new *assignment* created under the *classwork* section (Fig 3B). Along with the link, the assignment provided associated clinical vignettes and was visible on the classroom "stream," a live notification board where additional messages can be posted (Fig 3A).

Within the classroom *Google Drive*, a weekly *Google Docs* titled "Teacher Prelims" was created by the SRPM and shared with all the senior resident teachers and attendings. Senior resident teachers generated preliminary reports along with estimated interpretation time, teaching points, and references. Attending radiologists subsequently reviewed this document to ensure accuracy of the reference reports (Fig 4A). The *comments* function within *Google Docs* was used for constructive and collaborative discussion among teachers (Fig 4B). Once edited and complete, these "teacher prelims" were shared with the R1 residents as published reference reports on the *stream* section the following day after the video conference readout.

Each R1 resident submitted independent interpretations for each case via the *Google Classroom* interface (Fig 5A, B). Once submitted, the senior resident teachers could access all submissions under a centralized *student work* dashboard (Fig 5C).

Part C—Video Conference Readout Sessions and Peer to Peer Learning

The SRPM assigned each senior resident teacher to one or two R1 residents for a given week. Each teacher scheduled a daily video conferencing feedback session via *Zoom*. Attending radiologists were not recruited for readout sessions to promote resident peer to peer learning. Feedback sessions were structured similarly to clinical rotation readouts at the workstation. Using screen share and remote control functionality, R1 residents and senior resident teachers scrolled through and discussed the assigned cases.

Part D—Project Survey

Two weeks after program initiation, the R1 residents were given an anonymous survey to assess the usefulness of the project and how it was addressing their education. Similarly, 4 weeks after program initiation, the senior resident teachers were given an anonymous survey to assess how their roles in the project were influencing their learning and academic

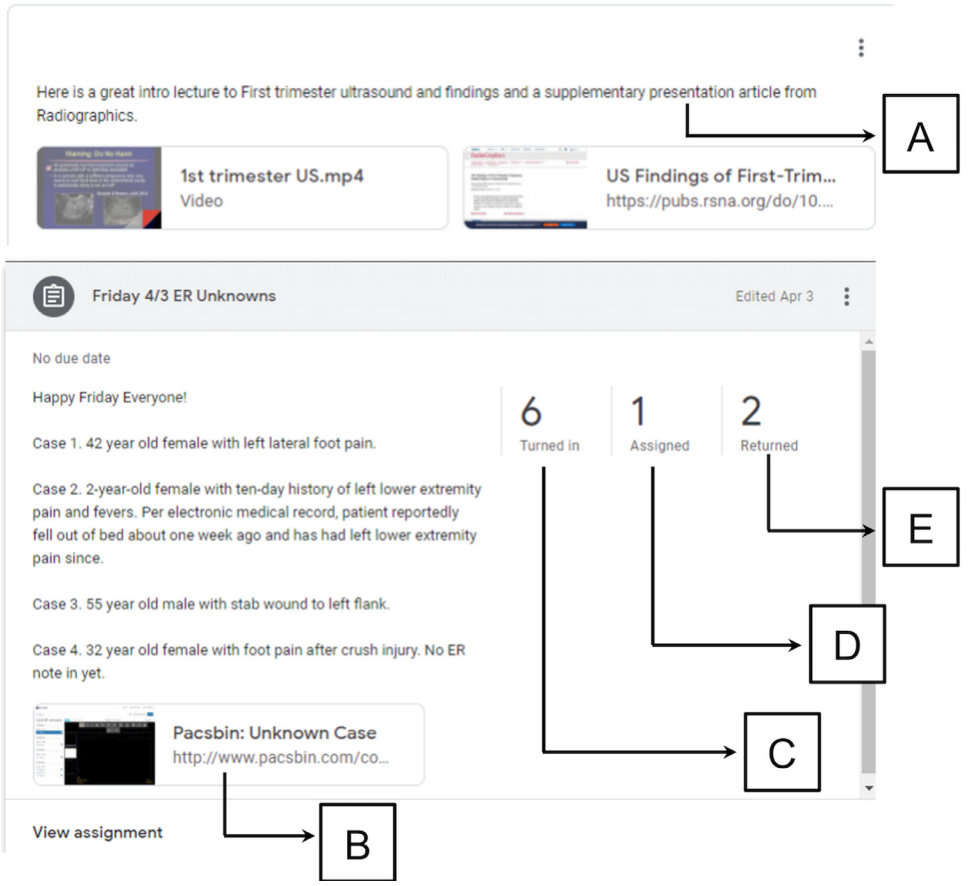

Figure 3. Examples of Google classroom notifications and daily assignment postings. (A) Stream function allows senior residents and attending teachers to add documents and educational resources, such as videos and reference articles, to supplement the case-based experience. (B) Classwork function provides a link to the *Pacsbin* collection of the day, accessible at the bottom of the assignment. (C) Number of R1 residents who turned in preliminary reports but have not had a formal read out. (D) Number of R1 residents who have not yet completed a preliminary report. (E) Number of R1 residents who have received feedback on the preliminary report via video read out.

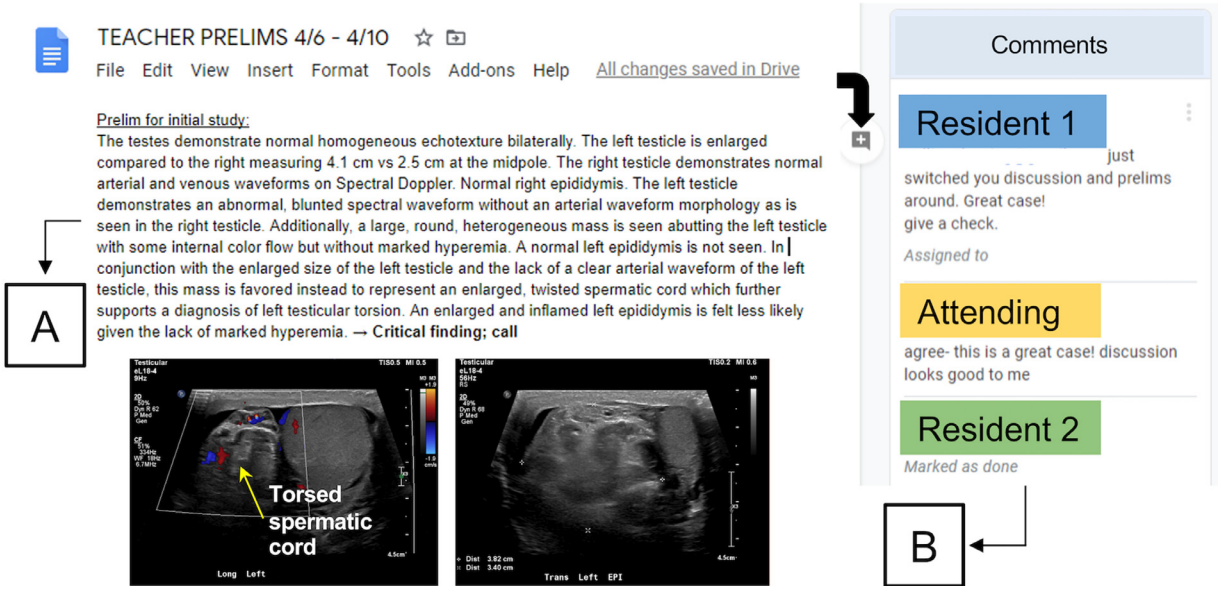

Figure 4. Sample reference report with interactive comments reviewed by senior resident teachers and attendings. (A) Attending-reviewed reference report distributed after formal video readout which include reference annotated images and discussion points. (B) Comment function (curved black arrow) allows for constructive discussion among senior residents and attendings to generate accurate and informative reference reports by collaborating using a Google docs interface.

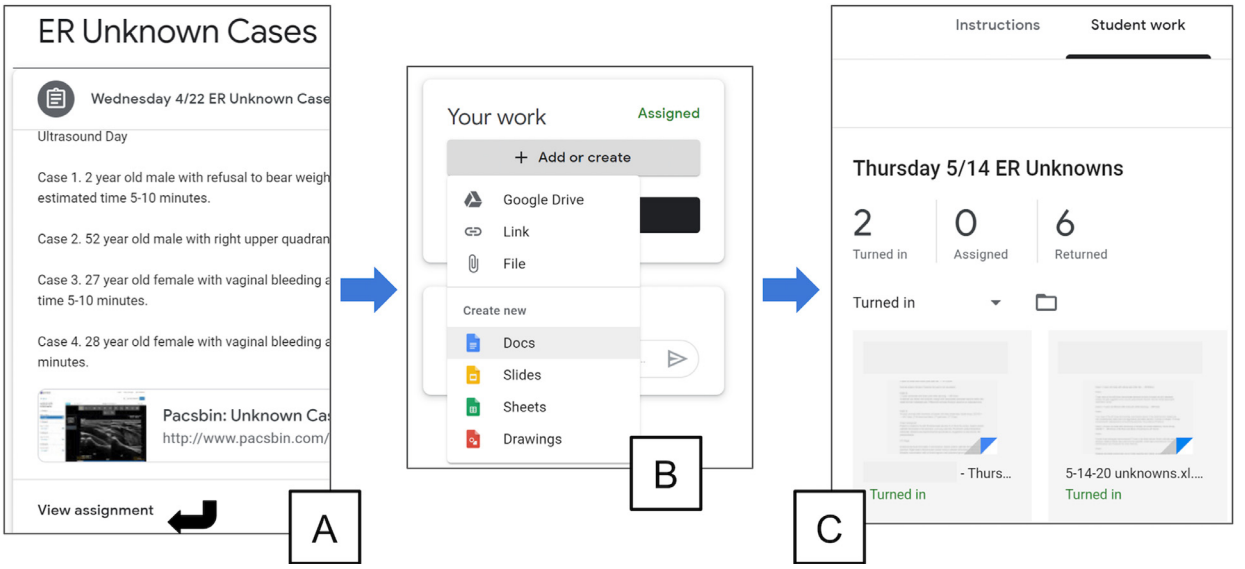

Figure 5. Student assignment submission. (A) R1 residents can view their assignment (curved black arrow) under the Classwork page. (B) After view assignment is clicked, a new window with the option to Add or create a submission will be available for R1 residents to submit their interpretation as reports using Google docs. (C) Submitted student work can be viewed by teachers in a centralized Student work dashboard for each assignment.

development. Attending teachers were given a different anonymous survey to evaluate their assessment of the project 4 weeks after initiation. Survey questionnaires are available as supplementary data (Supplementary files 1-3).

RESULTS

Project Participation

From March 15 to May 15, 2020, a total of 40 case collections were organized and disseminated via this platform. These collections consist of 170 multimodality cases spanning various subspecialties (Fig 6). All nine R1 residents participated with the training program and submitted assignments during the project duration.

Surveys

Response rate to the R1 resident survey at the 2-week mark of the project was 100% (9/9). On a Likert scale of 1-5, with 5 representing very helpful, the project was rated a 5 by eight

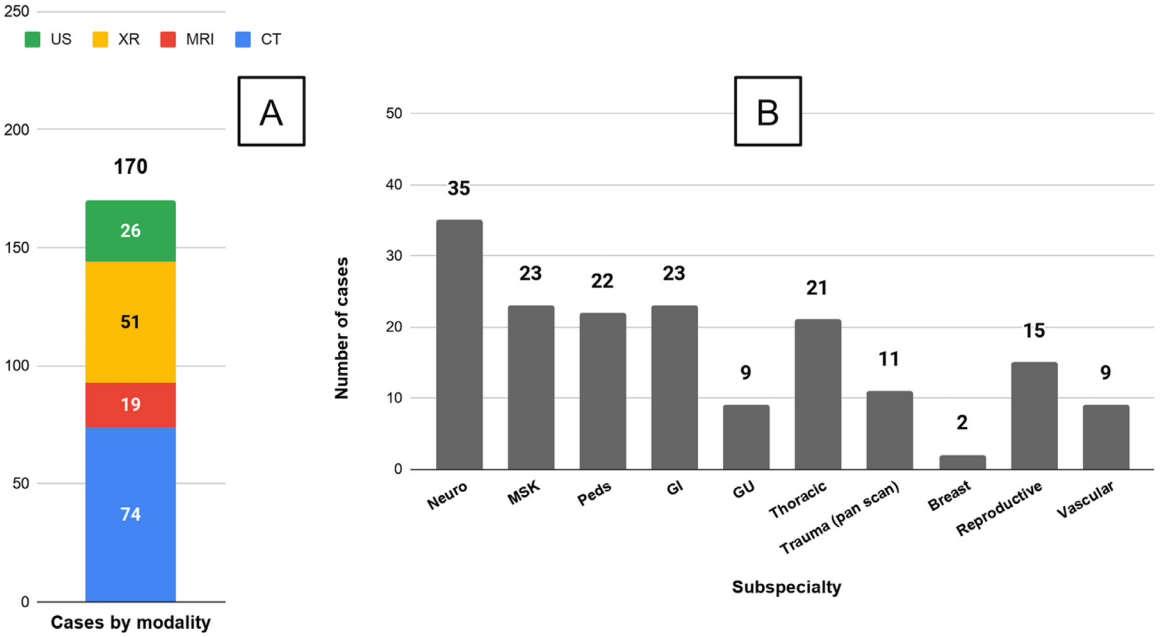

Figure 6. Distribution of cases. (A) Distribution of cases by modality (March 15 to May 15, 2020). (B) Distribution of cases by subspecialty.

R1 residents and rated a 4 by one R1 resident. Nine of nine R1 residents felt "more prepared" for ER call. Only two residents felt the daily caseload was "too much," while the remaining residents graded the volume as "just right." Nine of nine residents reported spending "2-4 hours" on the daily caseload. On a Likert scale of 1-5, with 5 representing very helpful, the reference reports drafted by the senior teachers, and vetted by attendings, mostly scored a 5 (6/9 R1 residents). Seven of nine R1 residents expressed interest in continuing the project even after pandemic related workflow changes subsided.

Response rate to the senior resident teacher survey at the 4-week mark of the project was 100 % (7/7). On a Likert scale of 1-5, with 5 representing very accurate, the selected cases were rated as either a 4 (n = 3/7) or a 5 (n = 4/7) in terms of simulation of cases encountered in emergency radiology. All seven senior teachers responded to the question of "how much has this project prompted your own self-directed learning" with a 5 on a 1-5 Likert scale, with 5 representing very much. Caseload for teachers was mostly rated as "just right" (n = 6/7), with one response of "too little." The majority of teachers preferred giving feedback to R1 residents in small group video readout format (n = 5/7). Two respondents had a change in their level of interest in pursuing academic radiology after participating in this project, one went from "neither interested nor uninterested" to "interested," and another went from "interested" to "extremely interested" (Fig 7).

Response rate to the attending teacher survey was 100% (n = 2). Accuracy of the selected cases in representing emergency department pathology was rated as a 5 (n = 2/2) on a 1-5 Likert scale, with 5 representing extremely accurate. Learning curve in using the involved technology was rated as "very easy" by both attendings. The project was viewed by one attending as "more helpful than traditional didactic lecture"; the other attending felt the project was a supplement to the traditional didactic lecture.

Open ended question responses were also positive. For example, one R1 resident responded "The fact that we have been shown a good number of highly ER relevant cases has definitely helped prepare for the ER. Additionally, having the entire image series, as opposed to limited images available through self-learning resources is really helpful. Also, the one-on-one feedback has really helped understanding efficient prelim style for when I am in the ED." One attending responded "This is an invaluable learning resource for R1s (especially now) since they are currently unable to be on normal rotations at this time. I also really like that it gives them the opportunity to read cases without pressure or interruptions. There are also many benefits to the participating senior residents. It challenges them to make sure that they understand the details of each case so they can explain it to someone else."

DISCUSSION

Radiology residents and institutions are facing unique circumstances during the COVID-19 pandemic. For some training programs, mandatory social distancing protocols shifted the education paradigm. This required residents to rely heavily on self-study resources rather than active participation at the workstation. To maintain an educational balance, our program implemented a cloud-based HIPAA

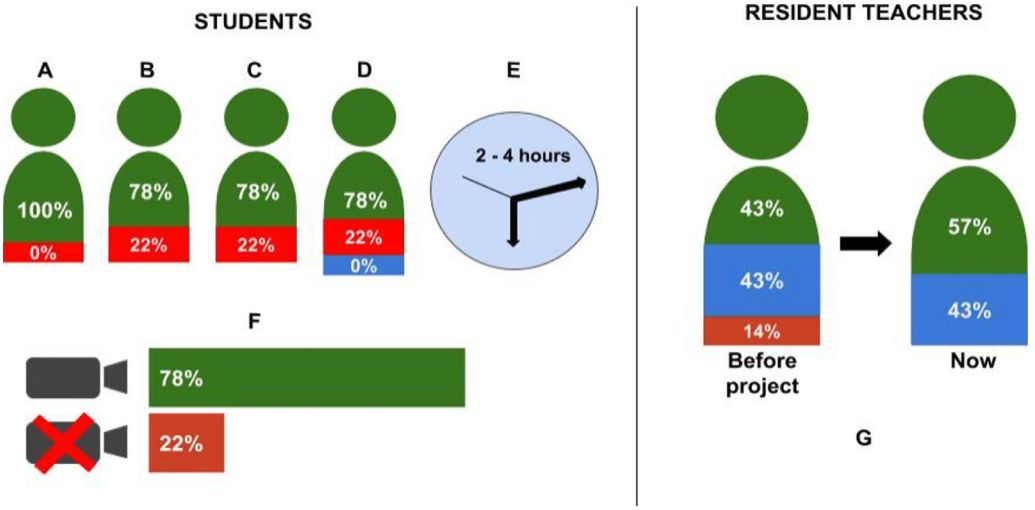

Figure 7. Survey results. (A) Percent R1 residents who felt more prepared for call following this project (Green = yes; Red = No). (B) Percent R1 residents interested in continuing the project following removal of pandemic-related restrictions (Green = yes; Red = No). (C) Percent R1 residents interested in extrapolating this educational platform to specific subspecialties in radiology (Green = yes; Red = No). (D) R1 residents surveyed on appropriateness of case load (Green = Just right; Red = Too much; Blue = Too little). (E) Average hours spent on cases daily. Nine of nine R1 residents spend between 2 and 4 hours per day on cases. (F) Preference of feedback style (Green = Video conference-based readouts; Orange = No video readouts, only markup of submitted preliminary reports via Google docs). (G) Senior resident teachers were surveyed for their interest in pursuing academic radiology before and after participation in this project (Green = extremely interested; Blue = Interested; Orange = Neither interested nor Uninterested).

compliant educational model which brings a remote workstation type experience to residents, without the need for expensive infrastructure. This resident run platform promotes interpretive radiology skills through case review, provides a framework for self-motivated study, and encourages peer to peer learning, all via distance learning. To our knowledge, similar approaches had not been reported in reviews of radiology education before the start of the pandemic (6).

A recurring educational limitation in resident training is the difference between active workstation learning and reviewing select static images within a teaching file. Basic but important principles of radiology including search patterns, windowing, quality control, and reporting are not adequately assessed with static case images. Although innumerable resources including videos, textbooks, articles, databases, and lecture slides are available online, many of these rely on a limited representative image format to present cases. Resources that utilize dynamic capabilities of a PACS DICOM viewer are more reflective of radiology practice and allow for a more enduring learning experience. Institutions elsewhere have described various educational models to address this limitation; however, the majority focus on the education of medical students as opposed to radiology residents (7). For example, integrated DICOM viewer workstations were installed in a reading room to enhance medical student education (8). A different model created a designated multimedia room with several DICOM-based workstations for a centralized educational experience (9). While these models offer a great alternative to existing resources, certain limitations persist. For example, implementing a centralized workstation-based digital room is expensive, and the educational workstations need to be connected to the institutional network. In addition, although there are free third party DICOM viewers available, many are not easily integrated into the home institution's PACS system, making anonymization and case upload cumbersome. Most importantly, these models necessitate residents and educators to be on-site, which is not practical given workflow changes during the current pandemic.

Our model addresses these limitations by allowing residents to work through simulated worklists on a fully functional cloud-based PACS-like interface on their phone, tablet, or personal computer without the need for a virtual private network. The flexibility of *Pacsbin*'s DICOM viewer to be used on a mobile device or tablet aligns with the growing recognition of such devices as "learning aids" among radiology trainees (10). The PACS integrated interface of *Pacsbin* also allows educators to easily set up daily worklists, similar to what a trainee would encounter on clinical service. The unique ability to share cases via *Pacsbin's* cloud-based interface allows several educators to contribute and exponentially increase the number of teaching cases available for review. Furthermore, with the centralized Google classroom along with video conferencing tools, educators are able to collaborate and provide a valuable readout experience seamlessly and remotely.

Survey-based feedback from R1 residents has been near-unanimously positive. Compared to their original self-study plan, most R1 residents felt this project better prepared them for independent call. A majority of residents also expressed interest in continuing the project after the current pandemic-related restrictions are lifted. Expectedly, residents favored feedback and teaching in a video conference format, as opposed to written feedback. A video conference environment allows them to ask pertinent questions and makes the learning experience reciprocal, better simulating daily clinical practice during a radiology residency. Further, the read out experience often employs a Socratic method of teaching in order to expand a resident's understanding of a case and differential diagnoses, which could translate to more confident consultation with referring clinicians (11,12). The embedded *remote control* function in Zoom is well described in recent literature (5), and enhances this simulated readout as it allows the senior resident teacher to analyze how the R1 resident works through a particular case. In addition, supplemental educational resources, such as primary articles, were discussed during the video read out and cited in the reference reports. Together, these employed methods encouraged a flipped learning environment to further direct and frame R1 resident self-study. Literature on flipped learning has shown its effectiveness in developing critical thinking and complex reasoning skills, particularly for radiology education (13). It is also important to note that this model had a positive influence on encouraging senior residents unsure of their career path to pursue an academic radiology career. This is an important observation as radiologists, regardless of practice environment, often assume some sort of teaching role (6).

Our model has some limitations. Case review with attending radiologists is invaluable to resident education. The lack of attending participation in video read out is a limitation, albeit intentional to promote peer to peer learning. Attendings were involved in ensuring accuracy of the reference reports distributed to the R1 residents after video read out. Further, we did not perform an objective assessment of R1 resident knowledge before and after this intervention. Objective measures of knowledge retention would be important if this model is to be used as a call preparation curriculum in the future (14). Although the majority of a radiology resident's education relies on active participation at the workstation, other workflow situations arise that could not be simulated in this model. Assigning study protocols, communicating with referring providers, educating medical students, and performing image-guided procedures all fall in the purview of radiology residents' clinical duties. These aspects of daily practice add a second layer of complexity to the workflow which cannot be accurately replicated on a cloud-based, distance learning platform. Furthermore, surveyed residents also stated the average time spent on an assignment with four complex tertiary care level mixed modality studies was around 2 to 4 hours. While this time investment partially reflects self-study in tandem with case review, it does not accurately mirror the time constraints under which residents often interpret studies while on call. In addition, our model has only been implemented at one academic institution. Further implementation would be necessary across

multiple residency programs to assess the impact of this project, as well as junior resident and educator perceptions of the project on a more generalizable scale.

Future directions will involve addressing these aforementioned limitations. We have already implemented some changes to address the time spent on a certain study by providing suggested time limits for each study. These time limits are assigned by consensus among the senior residents/attendings, and based on the expected time in which a mid-second year radiology resident should make the pertinent findings. These guidelines help residents self-monitor their progress and efficiency in reviewing a study. Varying case volumes and building case collections to include both normal studies and studies with pathology would better approximate daily practice. Other modifications to the current model to better mimic the call environment could be to present additional unknown cases to junior residents during the video read out. This modification could allow R1 residents scroll through unseen cases via the Zoom *remote control* function in a timed fashion, verbally explaining the pertinent findings present in the case. This exercise may better mimic the experience of reviewing a case with a consulting clinician, a frequent occurrence on call and an important skill by which radiologists add value. Additionally, this platform and a growing repository of reviewed reference reports, provides an excellent foundation to build long-term teaching files.

In conclusion, the COVID-19 pandemic has prompted novel approaches to the education of radiology residents. Our program implemented an educational initiative utilizing a cloud-based, HIPAA compliant system which allows remote access to full DICOM studies without compromising valuable aspects of the workstation learning experience. The initiative has positively impacted R1 residents in preparing for independent call, and could be used in future applications for the education of radiology trainees at all levels. Given the ease of implementation of the technologic tools described, we believe this model would be an excellent fit for any institution nationwide.

DECLARATION OF COMPETING INTEREST

None.

ACKNOWLEDGMENTS

The authors would like to thank Dr. Jason Hostetter (University of Maryland) for creating and allowing unrestricted use of *Pacsbin*. The authors would like to thank Ranyah Almardawi for assisting with IRB submission and approval.

FUNDING

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

REFERENCES

1. Mossa-Basha M, Meltzer CC, Kim DC, et al. Radiology department preparedness for COVID-19. Radiology 2020. doi:10.1148/radiol.2020200988.
2. Mossa-Basha M, Medverd J, Linnau K, et al. Policies and guidelines for COVID-19 preparedness: experiences from the University of Washington. Radiology 2020. doi:10.1148/radiol.2020201326.
3. Alvin MD, George E, Deng F, et al. The impact of COVID-19 on radiology trainees. Radiology 2020. doi:10.1148/radiol.2020201222.
4. Lewis PJ, Catanzano TM, Davis LP, et al. Web-based conferencing: what radiology educators need to know. Acad Radiol 2020; 27:447–454. doi:10.1016/j.acra.2019.05.017.
5. Li CH, Rajamohan AG, Acharya PT, et al. Virtual read-out: radiology education for the 21st century during the COVID-19 pandemic. Acad Radiol 2020. doi:10.1016/j.acra.2020.04.028.
6. Sivarajah RT, Curci NE, Johnson EM, et al. A review of innovative teaching methods. Acad Radiol 2019; 26:101–113. doi:10.1016/j.acra.2018.03.025.
7. Rizvi T, Borges NJ. "Virtual Radiology Workstation": improving medical students' radiology rotation. Med Sci Educ 2020; 30:117–121. doi:10.1007/s40670-020-00920-5.
8. Strickland CD, Lowry PA, Petersen BD, et al. Introduction of a virtual workstation into radiology medical student education. AJR Am J Roentgenol 2015; 204:W289–W292. doi:10.2214/AJR.14.13180.
9. Koestner W, Otten W, Kaireit T, et al. Competency-based teaching in radiology—implementation and evaluation of interactive workstation-based learning to apply NKLM-based content. Rofo 2017; 189:1076–1085. doi:10.1055/s-0043-117888.
10. Berkowitz SJ, Kung JW, Eisenberg RL, et al. Resident iPad use: has it really changed the game? J Am Coll Radiol 2014; 11:180–184. doi:10.1016/j.jacr.2013.04.017.
11. Redmond CE, Healy GM, Clifford S, et al. Radiology resident education: in defense of the Socratic method. Acad Radiol 2017; 24:1327. doi:10.1016/j.acra.2017.04.015.
12. Chapman T, Reid JR, O'Connor EE. The Importance of combined teaching methods in radiology resident education. Acad Radiol 2017; 24:1328. doi:10.1016/j.acra.2017.05.015.
13. O'Connor EE, Fried J, McNulty N, et al. Flipping radiology education right side up. Acad Radiol 2016; 23:810–822. doi:10.1016/j.acra.2016.02.011.
14. Khan R, Krupinski E, Graham A, et al. Assessing first year radiology resident competence pre-call: development and implementation of a computer-based exam before and after the 12 month training requirement. Acad Radiol 2012; 19:752–758.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.acra.2020.08.001.