Remote Ultrasound Training Systems for Early Breast Cancer Detection in Resource-limited Areas

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Context

Breast cancer is the most common malignancy among women worldwide and remains a leading cause of cancer-related mortality (R. Sha et al., 2021). Early detection is key to improve survival rates (Crosby D. et al., 2022). Among the existing clinical tools for breast cancer detection, mammography is the gold standard for screening (Geisel J. et al., 2017). However, it is often unavailable in resource-limited areas due to high equipment and maintenance cost, the need for an extensive infrastructure, and the shortage of trained specialists (Malherbe, K. et al., 2025), leading to the unequal access to healthcare given the delays in diagnosis and therefore treatment.

An alternative to mammography is ultrasound, which offers several advantages: it is low-cost, portable, radiation-free, and adaptable to diverse clinical needs (Iacob, R. et al., 2024), serving as an essential tool in the process of breast cancer early detection (Sood, R. et al., 2019; Alruily, M. et al., 2024). It is typically helpful for distinguishing between cysts and solid masses, and provides rapid access to imaging after palpable lumps are detected through a Clinical Breast Examination (CBE) (Lehman, C.D. et al, 2014). Therefore, ultrasound can be used for the early detection of suspicious tissue, empowering physicians when advising on whether the patient must travel to a medical center for further examinations. Additionally, ultrasound has demonstrated higher sensitivity in dense breast tissue than mammography, making it particularly suitable for younger populations (Yuan, W. H et al., 2020).

However, the diagnostic efficacy of ultrasound is highly operator-dependent, including the process of image acquisition and interpretation (Catalano,O et al., 2023; Berg, W.A et al., 2006). Even if AI-based algorithms are reaching impressive levels of accuracy in diagnosing, the quality of the obtained ultrasound images relies on the operator's skills (Bahl,M et al., 2024). Thus, AI-based systems can be used as reference tools, but image interpretation is still based on the trained specialists' experience and knowledge (Dan, Q et al., 2024).

All in all, ultrasound is a promising tool for early breast cancer detection given it is portable and low cost, but rural areas still lack qualified radiologists that can capture images adequately and interpret them (Karera, A et al., 2024). Although non-radiologists present in these areas, such as nurses and general practitioners, can be taught to use ultrasound, there is a lack of organization of ultrasound teaching methods and structured programmes for learning in remote settings (Nix, K et al., 2021).

Problem and Objective

This doctoral project aims at developing a remote training system for early breast cancer detection with ultrasound in resource-limited areas, aimed at non-radiologists.

The primary **problem** this PhD research addresses is the lack of understanding of how remote collaboration systems can be used by expert radiologists to train non-experts in remote areas on detecting breast cancer early using ultrasound. The main **objective** is socio-technical: to design, implement and validate a remote collaboration system that can be used to effectively transfer skills across geographical borders on early breast cancer detection using ultrasound, including both the acquisition and interpretation of images. Then, to develop a collaborative training methodology for resource-limited areas. The **impact** of this work will be to empower remote communities with early breast cancer detection and reduce inequalities of access to healthcare.

Brief Overview of the State of the Art

Practical training is important in the ultrasound learning process. Traditional teaching techniques, such as lectures and seminars, have been found insufficient in developing robust image acquisition skills (Recker, F et al., 2024). Collaborative work has also been shown to be more efficient and welcomed in ultrasound training than traditional methods, such as peer-assisted learning (PAL) (Dickerson, J et al., 2016) and telemedicine (Daum, N et al., 2024). Peer-to-peer and collaborative ultrasound training are effective and cost-efficient (Recker. F et al., 2024), and tele-based approaches can connect students in remote or underserved regions with experts in urban areas (Dreyfuss, A et al., 2020), which can be employed to direct image acquisition by novice providers and also increase diagnostic accuracy when combined with expert mentorship (Olivieri, P. P et al.,2018).

Currently, remote ultrasound education methods can take many forms, including online courses, real-time video conferencing, store-and-forward imaging, and web-based educational resources (Daum, N et al., 2024). Typical setups include dual video streams—one showing the ultrasound screen, and another capturing the trainee's hand movements via webcam, for example, using Philips Lumify + Reacts platform (Soni, N et al., 2021); tele-HHUS STOCK (Zhou, Y.-J et al., 2023). However, these setups lack the ability to objectively assess whether trainees have completed comprehensive and standardized breast scanning protocols, such as the clock-face method or full-quadrant coverage. This is critical, as breast ultrasound requires careful navigation of complex anatomy with significant individual variation in tissue density, gland distribution, and breast positioning. Without systematic coverage, lesions may be missed, and diagnostic accuracy compromised. Additionally, these systems typically do not monitor the force applied during scanning, even if probe pressure greatly affects image quality and lesion visibility.

Furthermore, current systems overwhelmingly rely on synchronous mentoring (Yi-Kang Sun et al., 2021), which limits scalability and accessibility in low-bandwidth or mentor-scarce settings. There is limited research on asynchronous feedback mechanisms, which are essential for training in resource-limited environments. Finally, while most systems focus on image acquisition, fewer offer structured training for interpreting sonographic findings (Nilam J Soni et al., 2021). Especially in rural areas, there is still a lack of unified approach for ensuring a long-term transfer of skills from remote expert to local on-the-field non-radiologists (Zhou, Y.-J et al., 2023).

Research Questions

To develop a sociotechnical system for training non-radiologists in remote areas to detect breast cancer in early stages, through ultrasound, the candidate will explore the following research questions.

1. What are the specific challenges from the perspective of non-radiologists when learning to perform breast ultrasound examinations?
2. How can remote collaboration systems support non-radiologists in learning both (1) to efficiently move and position the ultrasound probe, and, (2) to interpret ultrasound images?
3. How to evaluate knowledge transfer and retention to clinical settings in resource-limited areas?

Theoretical Foundations

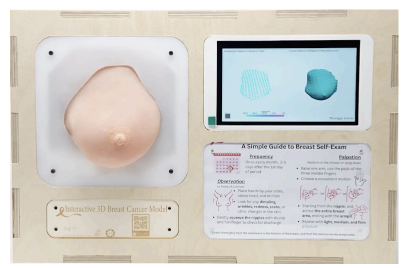
This research is grounded in socio-technical systems theory, which emphasizes the integration of technology with social practices to create user-centered and sustainable solutions. This work will build from situated learning theory, to examine learning in authentic contexts (Lave, J & Wenger, E, 1991) and support the design and implementation of collaborative approaches. Moreover, cognitive apprenticeship (Collins, A et al., 1991) will provide a lens of analysis to examine ways of learning through working under expert supervision. Human-Computer Interaction (HCI) principles further inform the intuitive and user-friendly design of training interfaces to enhance user engagement and learning outcomes. Building on research in Computer-Supported Cooperative Work (CSCW) (Koschmann, 1996), this study will investigate how remote ultrasound training can be structured for effective knowledge transfer.

Approach and Methods

The approach can be summarized as *transmitting knowledge in lieu of transporting experts*. We will develop remote collaboration tools that expert radiologists can use to teach non-radiologists in resource-limited areas, on how to perform breast examinations with ultrasound. For this, the candidate will follow a human–centered approach of understanding, building, and evaluating, as described below.

WP1: Identification of Training Needs. Breast tissue is typically scanned in either a radial/antiradial or transverse/longitudinal pattern, and suspicious areas need to be identified on 2D images. Learning to perform correct ultrasound examinations involves several skills, for example, pressure must be applied evenly to get the correct direction of the scan (Ihnatsenka, B et al., 2010). As a first step, the candidate will expand the existing knowledge on specific challenges and requirements for ultrasound training, identifying key barriers in skill acquisition and image interpretation. These complexities of learning ultrasound will be identified by collecting data through qualitative fieldwork involving interviews and situated observations with radiologists, clinical educators, trainees, and associated medical personnel, and analyzed through Thematic Analysis (Braun, V., & Clarke, V., 2006). We have already identified, contacted, and discussed at length with the following clinicians: Dr. Salma Ayadi (AP-HP, Pitié-Salpêtrière); Dr. Jean-Marc Levaillant (commission nationale d'échographie du CNGOF); Dr. Ying Peng (Peking University Third Hospital). These clinicians have stated interest and support for this project.

WP2: Socio-technical System Design. Using the understanding gained in WP1, we will design novel tools that contribute to a remote collaboration system for teaching ultrasound breast examination. We will rely on existing ultrasound devices such as the Echopen to explore how to teach both the capturing of the image and its interpretation. For example, a sensor-based breast simulator developed by Ziqi Yi during master's study could support non-radiologists in synchronous and asynchronous training based on materials provided remotely by expert radiologists (e.g., video tutorials), and, it could support experts in gathering performance metrics for their review. The model has the capacity to capture both the location and the pressure signal, data that can be recorded and processed to analyse if the trainee covered all areas of the breast and performed in a systematic trajectory.



Regarding the skills transfer on image interpretation, we envision the use of a portable ultrasound probe where the expert guides in real time the non-expert during a patient examination, teaching how to interpret the image. This could also take place asynchronously, for example, if the trainee annotates the captured volumetric data that the expert can comment on. In this WP, the candidate will develop a pilot training program between a center of expertise and a remote area, with the help of an NGO.

WP3: Evaluation and Deployment. With the system developed in WP2, the candidate will conduct a first lab evaluation using qualified professionals for the tele-mentorship aspects, as well as medical students for demonstrating the effectiveness of the system for peer-to-peer learning. Finally, the candidate will establish a training program with the help of an NGO (for example, IARC), to understand how to deploy the system in a rural area, recording the continuous performance emphasizing the long-term skill maintenance and societal impact.

Evaluation of the Contributions

To evaluate skill acquisition, expert radiologists will rate videos of performance before and after trainees undergo training, using standard performance ratings such as OSATS (Niitsu,H et al.,2012). Moreover, these clinicians will provide ground truth in ultrasound images regarding cancer detection. To evaluate skill retention, we will use questionnaires to follow-up with participants months after training.

Nature of digital collaboration (1 page max)

This PhD research explores technology-mediated collaboration in the context of remote ultrasound training through **telementoring**, focusing on how non-experts in resource-limited settings interact with remote experts to get experiences in breast ultrasound with the portable device. The research investigates different dimensions of collaboration:

1. Function

The primary function of collaboration in this study is knowledge transfer and skill development without geographic limitations in breast ultrasound diagnosis. The system will mix two types of remote collaboration which facilitates real-time communication between mentors and trainees through video, voice, and interactive annotations in breast ultrasound, while also supporting asynchronous knowledge sharing via recorded sessions, and perhaps even automated feedback tools. Collaboration also extends by collective feedback from peers.

2. Type

Both synchronous and asynchronous. Synchronous collaboration: Real-time telementoring lets remote experts guide trainees during live ultrasound scans, offering direct feedback and hands-on instruction; Asynchronous collaboration: Trainees can receive expert feedback after having uploaded imaging and diagnose, promoting flexible learning and reducing dependence on real-time availability.

3. Time Scale

From Short-Term to Long-Term Interactions. **Short term (hours to days):** Real-time guidance during ultrasound scanning sessions + Feedback cycles where trainees submit cases and receive expert reviews; **Long term (months to years):** The research aims to establish a long-term collaboration model, where trainees will actually maintain the skills.

4. Group Size

For the remote mentorship, this will happen 1 to 1. For the peer-to-peer learning, this will include groups of between 5 to 10 students.

5. Space

The research primarily focuses on remote collaboration, from medical center to remote department, where experts provide guidance to trainees located in resource-limited areas; In some cases, hybrid collaboration may occur, where local supervisors assist in initial training while remote experts handle advanced guidance and case reviews.

6. Long-Term Vision

The research aims to develop a **sustainable model of digital collaboration** that integrates into existing healthcare training structures, enabling continuous professional development for medical practitioners in underserved areas.

Contribution to digital collaboration: Expected results and Impact (1 page max)

This PhD research aims to contribute to digital collaboration in medical education by developing and validating a telementoring-based training system for breast cancer early detection based on portable ultrasound devices. The study will focus on how remote collaboration technologies can improve the accessibility and effectiveness of ultrasound training in resource-limited settings. The expected contributions of this research are as follows:

Empirical
The project will generate empirical data on current challenges in skill transfer regarding ultrasound examination. Moreover, this thesis will provide empirical data on novel practices that emerge in remote ultrasound training, measuring skill improvement, diagnostic accuracy, and knowledge retention among trainees. It will explore how digital collaboration enhances the confidence and decision-making abilities of healthcare providers using portable ultrasound devices. Findings will provide insights into the barriers and facilitators of adopting telementoring systems in real-world clinical settings.

Technological
A key outcome of this project will be a telementoring system prototype, designed, tested and iteratively improved with the participation of clinical collaborators and end users. This system will be low-cost and scalable for a broader applicability in resource-limited regions. The system will be designed to be interoperable with existing telemedicine infrastructure, with integration into digital health networks.

Theoretical
We also expect to develop theory on knowledge transfer from domain experts to non experts more generally—beyond ultrasound examination.

Societal
The development of a long-term collaboration model in breast ultrasound training in rural areas. Aiming at designing sustainable digital collaboration models for medical training, supporting healthcare resource equality.

We expect research findings to be disseminated through journal articles and conference presentations in fields such as HCI, CSCW, as well as medical education and telemedicine.

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