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# Medical students' experiences of self-directed, simulator- based point-of-care ultrasound education: a qualitative study

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# Medical students' experiences of self-directed, simulator-based point-of-care ultrasound education: a qualitative study


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## Abstract

**Background:** Point-of-care ultrasound (POCUS), including focused cardiac ultrasound (FCU), is increasingly incorporated into undergraduate medical curricula, but conventional hands-on teaching is difficult to scale because it depends on limited expert faculty. Self-directed e-learning and simulation may reduce this dependency, but it remains uncertain where educator inputs is most valuable and how learners experience progression toward human scanning.

**Methods:** We conducted a qualitative evaluation of first- and second-year medical students enrolled in two elective POCUS courses at The University of Melbourne. Thirteen students participated in semi-structured interviews informed by the Theoretical Domains Framework; data was analysed using reflexive thematic analysis. A separate ten-item survey provided descriptive contextual data from 44 students.

**Results:** Four interrelated themes were developed: (1) making the invisible tangible: simulation as an enabling foundation; (2) supported autonomy: flexibility without isolation; (3) progressing toward real-world practice: from simulation to human and clinical scanning; and (4) integration gives POCUS educational and clinical meaning. simulation made unfamiliar anatomy, image interpretation and probe manipulation tangible; students valued the flexibility of self-directed learning but required timely feedback when unable to judge their own performance; transition to human scanning introduced anatomical variability, patient-centred considerations and greater clinical responsibility, increasing the perceived need for supervision; and curricular integration strengthened relevance and motivation but highlighted the need for longitudinal reinforcement. Survey responses were favorable overall: 95.5% were satisfied with the course, 90.9% considered the pre-reading effective, and 90.9% considered the course effective in teaching the ultrasound techniques covered. However, only

59.1% (26/44) respondents considered the practical component sufficient to provide confidence for future patient use.

**Conclusions:** Students valued the flexibility and accessibility of self-directed simulator-based learning as a useful foundation for POCUS, but not as a substitute for feedback or supervised progression toward human scanning. A progressively scaffolded model may support scalability by concentrating expert input on performance feedback, troubleshooting and transition to real-world practice. Prospective studies should evaluate objective competence, skill retention, clinical transfer and educator-resource requirements.

**Keywords:** point-of-care ultrasound; focused cardiac ultrasound; medical education; simulation; flipped classroom; self-directed learning; thematic analysis

## Introduction

Point-of-care ultrasound (POCUS) allows clinicians to obtain focused diagnostic information at the bedside and is established across emergency medicine, critical care, anaesthesia and other acute-care settings [1]. As access to portable ultrasound has expanded, medical schools have increasingly incorporated POCUS into undergraduate teaching. A 2020 national survey of US medical schools found that 57% of responding schools had an approved POCUS curriculum, but 94% reported implementation barriers, most commonly limited trained faculty, curricular time and equipment [2]. By 2024-2025, an Australian survey found that approximately two-thirds of responding schools had an approved POCUS curriculum, although the required longitudinal exposure over four years remained uncommon [3].

The faculty requirement is especially important for focused cardiac ultrasound (FCU), where traditional educational models combine theoretical teaching with closely supervised small-group scanning. Such models can provide high-quality instruction but are difficult to deliver

to large student cohorts. Electronic learning has been used successfully to replace some lecture-based content, and ultrasound simulators provide repeatable access to normal and pathological findings without requiring patients or healthy volunteers [4-6]. However, evidence regarding the optimal balance between independent learning and educator supervision remains uncertain. For example, Cawthorn and colleagues found electronic modules effective for introductory FCU interpretation, while sonographer-led practical teaching produced better scanning performance than fully self-directed simulator practice in their student cohort [4]. In contrast, a self-directed simulator course for novice physicians produced strong image-acquisition outcomes while substantially reducing instructor dependence [5].

The scalability question may therefore be less about whether educators can be removed and more about which learning can occur independently, where uncertainty emerges, and when expert educator input adds sufficient value to justify the resource required. The University of Melbourne introduced two elective Discovery subjects using predominantly self-directed e-learning and simulator-based POCUS training: a first-year Foundations of POCUS course covering vascular, lung, cardiac, abdominal and pelvic ultrasound, and a second-year Cardiac POCUS course focused on FCU. Both courses were designed to minimise dependence on continuous in-person expert instruction while retaining structured online teaching and assessment. The aim of this study was to explore medical students' experiences of self-directed, simulator-based POCUS education and identify factors that enable or impede learning and translation of simulator-acquired skills toward clinical practice.

## Methods

### Study design

This study used a qualitative design based on semi-structured interviews to explore medical students' experiences of predominantly self-directed, simulator-based POCUS education (Appendix 1). Analysis was predominantly inductive and semantic. A separate ten-item survey provided descriptive contextual data (Appendix 2)..

### Setting and educational intervention

Participants were first- and second-year medical students enrolled in elective Discovery POCUS subjects at The University of Melbourne during semester 1, 2023. The 12-week Foundations of POCUS subject outlined in figure 1, covered ultrasound principles and vascular, lung, cardiac, abdominal and pelvic applications. The four-week Cardiac POCUS subject outlined in figure 2, focused on standard cardiac views, simulator-based cases and clinical integration. Both combined online tutorials and knowledge checks, self-directed simulator practice, online logbook tasks and scheduled synchronous sessions with an academic. These sessions addressed equipment use, assessment requirements and difficulties arising during each learning block. Human scanning was informal, student-arranged and not a required component.

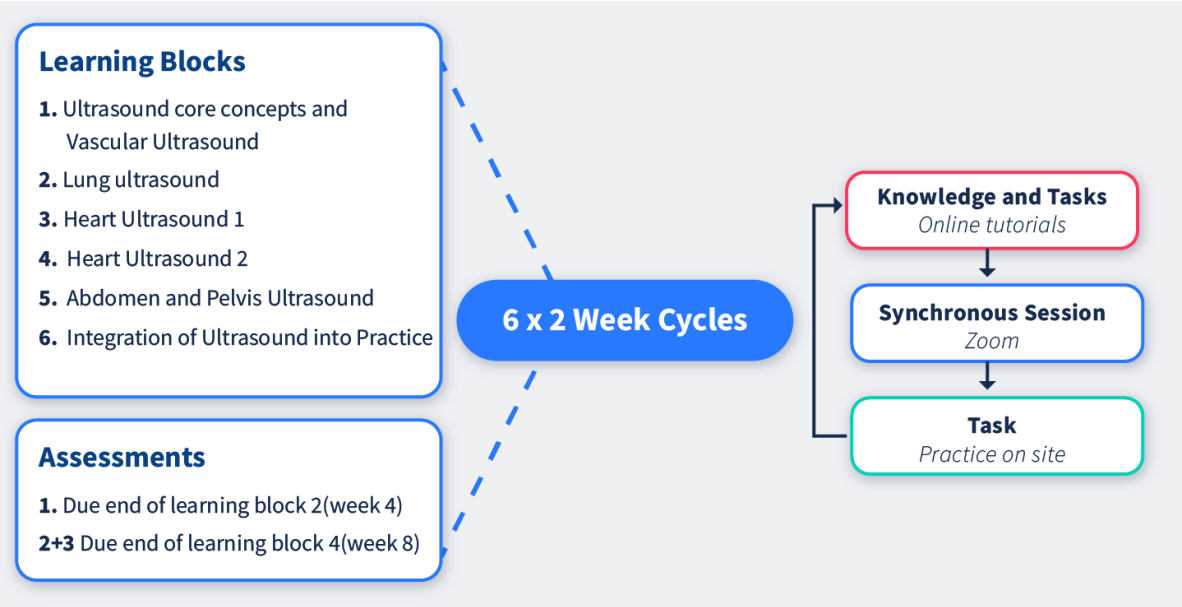



Figure 1. Structure of the Foundations of POCUS course.

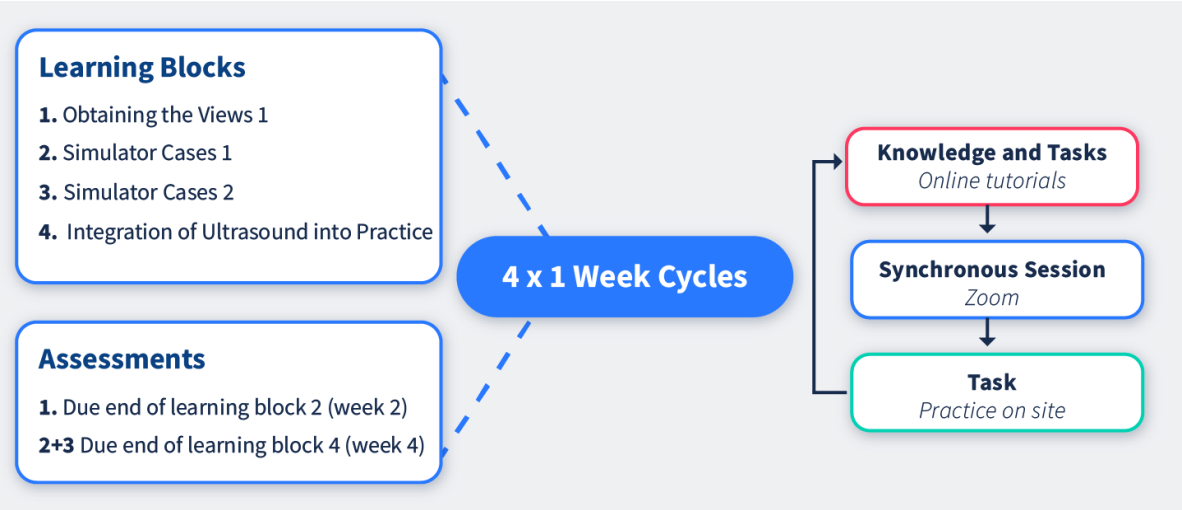



Figure 2. Structure of the Cardiac POCUS course.

## Participants and recruitment

Students with practical FCU or POCUS training equivalent to at least one week during the preceding two years were excluded. All eligible students were invited to participate by administrative staff within the ultrasound education group. The interview sample comprised all volunteers who provided written consent; recruitment was pragmatic and was not guided by a formal saturation threshold.

## Data collection

Interviews were conducted via Zoom and lasted approximately 20-30 minutes. The Theoretical Domains Framework (TDF) informed the breadth of the interview guide but was not used as a deductive coding framework [14]. Interviews explored experiences of simulator-based learning, barriers to skill acquisition, transition to human scanning, peer learning, feedback and assessment, integration with the broader medical curriculum, and perceived clinical relevance. The TDF was used to inform data collection only and was not used as a coding framework.

Interviews were conducted by one of two investigators. The primary researcher was a clinician-educator involved in course design, teaching and assessment. A co-investigator who was independent of the medical-student teaching and assessment programme conducted the remaining interviews. All course teaching and assessment had been completed and students' results finalised before interviews were conducted.

Interviews were audio-recorded and transcribed verbatim using Sonix AI, an institutionally approved platform. Transcripts were de-identified before analysis and audio files were subsequently deleted. Illustrative quotations were de-identified prior to reporting, and participant identifiers were not included to further protect confidentiality.

## Survey

The contextual survey comprised ten five-point Likert items addressing pre-reading, confidence for future clinical use, perceived effectiveness of the course, duration, desire for further training in the same style, satisfaction, perceived effects on anatomy and physiology/pathophysiology knowledge, anticipated future use of ultrasound, and desire for additional ultrasound training during medical school.

## Qualitative analysis and reflexivity

Data were analysed using Braun and Clarke's six-phase reflexive thematic analysis [13]. Both researchers independently read all interview transcripts. The primary researcher coded the complete dataset inductively and developed preliminary themes. The second researcher reviewed the coding and thematic structure, prompting reflexive discussion of alternative interpretations, negative cases and theme boundaries. This process sought interpretive depth rather than inter-rater reliability or coding consensus.

The primary researcher's involvement in the courses provided contextual understanding but could also have influenced participant responses and interpretation. Reflexivity was maintained through explicit consideration of the researcher's assumptions, completion of assessment before interviews and review by the second researcher independent of the teaching programme.

## Ethical considerations

The study was approved by The University of Melbourne Human Research Ethics Committee (Ethics ID 25857). All interview participants provided written informed consent, and participation or non-participation did not affect course grades or progression.

# Results

## Participants

Thirteen students participated in semi-structured interviews and 44 students responded to the descriptive survey. Most participants reported no previous practical ultrasound experience; the remainder described only limited prior exposure.

**Descriptive survey findings**

Survey responses outlined in table 1 were generally favorable: 42/44 (95.5%) were satisfied with the course, 40/44 (90.9%) considered the pre-reading effective for knowledge delivery, 40/44 (90.9%) considered the course effective in teaching the ultrasound techniques covered, 41/44 (93.2%) considered the course duration adequate, 39/44 (88.6%) wanted more ultrasound training in the same style, and /4444 (100%) considered that they would benefit from further ultrasound training during medical school. Confidence regarding future patient use was less consistent: Confidence regarding future patient use was less consistent: 26/44 (59.1%) agreed or strongly agreed that the practical component provided sufficient confidence, while 12/44 (27.3%) disagreed or strongly disagreed. Thirty-eight (86.4%) reported increased understanding of anatomy, 35 (79.5%) reported increased understanding of physiology/pathophysiology, and 38 (86.4%) planned to use ultrasound in future practice

(Table 1).

| **Survey item** | **Agree/Strongly agree** | **Neutral** | **Disagree/Strongly disagree** |
|---|---|---|---|
| Pre-reading effective for knowledge content | 40/44 (90.9%) | 3/44 (6.8%) | 1/44 (2.3%) |
| Practical component sufficient for confidence with future patient use | 26/44 (59.1%) | 6/44 (13.6%) | 12/44 (27.3%) |
| Overall course effective in teaching techniques covered | 40/44 (90.9%) | 3/44 (6.8%) | 1/44 (2.3%) |
| Course duration long enough | 41/44 (93.2%) | 3/44 (6.8%) | 0/44 (0%) |

| | | | |
|---|---|---|---|
| Would like more ultrasound training in this style | 39/44 (88.6%) | 2/44 (4.5%) | 3/44 (6.8%) |
| Satisfied with the course | 42/44 (95.5%) | 2/44 (4.5%) | 0/44 (0%) |
| Increased understanding of anatomy | 38/44 (86.4%) | 4/44 (9.1%) | 2/44 (4.5%) |
| Increased understanding of physiology/pathophysiology | 35/44 (79.5%) | 6/44 (13.6%) | 3/44 (6.8%) |
| Plan to use ultrasound in future practice | 38/44 (86.4%) | 6/44 (13.6%) | 0/44 (0%) |
| Would benefit from further ultrasound training during medical school | 44/44 (100%) | 0/44 (0%) | 0/44 (0%) |

Table 1. Descriptive survey responses (n=44). Likert categories are collapsed for concise presentation.

**Qualitative findings**

Four interrelated themes were identified from the interviews, describing how students experienced self-directed, simulator-based POCUS education and how their learning needs evolved as they progressed towards clinical application. The themes, subthemes and representative quotations are summarised in Table 2

**Theme 1: Making the invisible tangible - simulation as an enabling foundation**

Students consistently described hands-on simulation as a central component of their learning. For novice learners, ultrasound initially combined unfamiliar anatomy, image interpretation and probe manipulation. The simulator helped connect these elements by allowing students to manipulate the probe while simultaneously visualising the resulting ultrasound image and its anatomical relationships.

> "The theory that seems very conceptual and abstract until you're actually doing it on the mannequin really kind of solidified in my mind."

Students described the simulator as translating theoretical knowledge into a more tangible form. The ability to relate surface probe position to internal three-dimensional anatomy complemented conventional anatomy teaching, and hands-on simulator practice was described as particularly useful for consolidating theoretical understanding.

Simulation also reduced the initial cognitive difficulty of ultrasound. Students described ultrasound images as unfamiliar at first, but repeated interaction with the simulator, probe orientation and machine controls progressively made them easier to understand. One participant recalled that initial images appeared as "all just shades of grey" before becoming more interpretable with familiarity.

The simulator also provided an environment in which learners could make mistakes, repeat views and take time to resolve uncertainty without consequences for a patient.

> "It's a lot easier to practice on a piece of plastic than it is a real person that you don't want to view just as a learning opportunity."

Students therefore appeared to value simulation not simply because it reproduced clinical ultrasound, but because it deliberately removed some of the complexity of clinical practice. It provided a controlled environment in which basic probe handling, anatomical orientation and image recognition could be developed before the additional demands of human scanning were introduced.

However, participants generally understood simulation as foundational rather than sufficient. The clear, reproducible and idealised images that assisted initial learning also distinguished the simulator from real-world ultrasound. Some students described human images as substantially noisier and more difficult to interpret, while others anticipated difficulty adapting to anatomical variation, body habitus and patient positioning. These limitations did not diminish the perceived value of simulation; rather, they defined its role as an accessible entry point into a more complex clinical skill.

### Theme 2: Supported autonomy - flexibility without isolation

**Students generally valued the autonomy afforded by the predominantly self-directed course design. Online resources and flexible simulator access enabled learners to organise study around other academic, employment and personal commitments. For some, self-direction was itself an educational benefit.**

> "It's nice that at a graduate level to actually be given that sense of autonomy... go ahead, guide your own learning."

Students also valued being able to revisit online resources or attempt practical tasks independently before consulting instructional material. One student described working through simulator steps first and then using the corresponding video to confirm whether the approach was correct.

Difficulties arose not from independence itself, but when self-direction produced unresolved uncertainty. Ultrasound required learners to judge whether images had been acquired and interpreted correctly, and some participants felt they lacked a mechanism to confirm this.

> "I'm worried about the fact that maybe I've just been, like, learning the wrong thing."

Importantly, participants did not uniformly respond to this uncertainty by requesting more scheduled teaching. They distinguished between educator contact that addressed a learning need and teaching that repeated information already available asynchronously. Synchronous sessions were considered less useful when they simply restated pre-reading, but more useful when they involved active case discussion, problem solving or clarification of practical difficulties.

This distinction suggested that students valued educator involvement most when it allowed them to apply, clarify or extend existing knowledge rather than receive the same material in another format.

### Peer collaboration as an informal scaffold

Peers frequently became an important source of support. Students described working in pairs or small groups, comparing images, troubleshooting difficult views and identifying errors that an individual learner might miss.

> "They're sort of optimally positioned to pick up anything that you might have missed, or that you're doing wrong."

However, peer learning had limits. When all students in a group were uncertain, collaboration could generate discussion without establishing which interpretation was correct. Peer collaboration therefore complemented rather than replaced expert feedback.

### Feedback closed the learning loop

Assessment was valued most when it confirmed or corrected learning. Short quizzes and practical tasks could help students identify what they had understood, but assessment without timely feedback was perceived as having limited educational value.

> "I feel like I didn't get that feedback, so I didn't actually learn anything from that assessment."

Taken together, these accounts suggest that students wanted independence without educational isolation. Self-directed learning was generally acceptable and often desirable, provided learners had structured resources, peer support and a mechanism for obtaining timely confirmation when uncertainty exceeded what they could resolve themselves.

## Theme 3: Progressing toward real-world practice - from simulation to human and clinical scanning

Participants generally viewed simulation as preparation for rather than a substitute for scanning real people. Exposure to human scanning varied between students and was not a standardised component of the courses. Nevertheless, participants consistently identified additional challenges that emerged as ultrasound learning moved from the controlled simulator environment toward real-world clinical practice.

### Human scanning reintroduced anatomical and technical complexity

Students recognised that real-person ultrasound involved greater anatomical variability, less predictable image quality and greater difficulty obtaining standard views. Participants described simulator images as relatively idealised and anticipated a substantial learning curve when encountering patients with variable anatomy and comorbidities.

*"It was so much more difficult to see in a real person than on the simulator."*

Others described real ultrasound images as noisier or less immediately recognisable than simulator images; one participant recalled a real scan appearing as "a blur of grey and black". Transitioning to a real person therefore required more than reproducing a learned sequence of probe movements. Learners needed to adapt technique to the individual and determine whether difficulty obtaining an image reflected their own skill, patient anatomy or the inherent limitations of the examination.

**Real-world practice also introduced the patient**

Scanning a human introduced considerations largely absent during simulator practice, including consent, privacy, dignity, positioning, probe pressure, examination duration and patient comfort. Students recognised that unlimited experimentation was acceptable on a simulator but not necessarily on a patient. Human scanning was therefore not simply a technically harder version of simulation; it required students to integrate technical performance with patient-centred behaviour.

Several students consequently felt that supervision became more important during transition to clinical scanning. Learners who were prepared to practise independently on the simulator often wanted someone more experienced available when working with real people, particularly to confirm probe position, image quality or interpretation.

**Peer scanning as a potential intermediate step**

Participants frequently expressed interest in gaining experience with human ultrasound before being expected to scan patients clinically. In some interviews, students themselves suggested peer scanning as one possible bridge.

*"Even if we were just told to pair up and practice on each other."*

In other interviews, peer scanning was introduced explicitly by the interviewer. The finding is therefore best interpreted cautiously: when peer scanning was explored, students generally considered it a potentially useful intermediate learning opportunity between simulation and clinical practice. Students did not view peer scanning as a replacement for simulation, but as a way to experience normal human anatomy, tissue variability and probe handling after basic skills had first been developed in a controlled environment.

Participants also identified implementation considerations. Privacy, voluntary participation and physical comfort were prominent concerns, particularly when examinations required partial undressing. Views regarding group composition varied, supporting flexible arrangements that respect individual preference rather than a single mandatory grouping model.

**Clinical practice added a further level of complexity**

Participants recognised that using POCUS clinically required skills beyond acquisition of an interpretable image. Clinical use involved deciding when ultrasound was appropriate, adapting to workflow, interpreting findings in context and communicating those findings.

*"If I do find something, I wouldn't really know how to present it coherently."*

The data therefore suggested a progression in learning complexity: self-directed simulator practice, followed by human scanning, followed by supervised clinical application. Rather than each stage replacing the preceding one, progressively real-world environments introduced new technical, interpersonal and clinical demands. Correspondingly, targeted feedback and supervision appeared to become more valuable as learners moved toward settings in which uncertainty had greater consequences.

### Theme 4: Integration gives POCUS educational and clinical meaning

Participants described POCUS learning as particularly valuable when it connected with the wider medical curriculum and developing clinical practice. These connections occurred through reinforcement of anatomy and pathology, incorporation into case-based reasoning and recognition of potential future clinical uses.

#### Curricular alignment reinforced learning

Students frequently described POCUS as complementing concurrent anatomy, physiology and pathology teaching. One participant particularly valued occasions when ultrasound teaching aligned with the organ system currently being studied.

> *"It was so complementary to like the anatomy teaching and everything that we were receiving."*

Another student described learning pneumothorax through ultrasound before encountering it in the core curriculum, meaning that later conventional teaching reinforced a concept that was already familiar. These accounts suggested that exact simultaneity may be less important than meaningful curricular connection: POCUS could reinforce previously learned concepts or provide an experiential framework for material taught subsequently.

#### POCUS broadened awareness during clinical reasoning

For some participants, the course altered what they considered when working through clinical cases. One student described beginning to ask:

> *"Okay, so how can ultrasound help?"*

Other students described a broader appreciation of where POCUS might sit in clinical assessment. However, this finding should not be interpreted as evidence that the course transformed clinical reasoning for all students. One participant initially stated that their approach to patients "probably hasn't changed too much" before subsequently describing increased awareness of ultrasound when diagnostic uncertainty remained. The immediate effect was therefore better characterised as an expanded diagnostic repertoire and awareness of POCUS, rather than established change in independent clinical practice.

**Clinical relevance increased motivation and supported longitudinal learning**

Students frequently linked motivation with seeing how ultrasound might eventually be used in patient care. Early acquisition of a practical skill that would ordinarily be expected later in training was perceived positively.

> *"I'm building the foundations of a skill that I may use in my future career."*

Early introduction also created concern that skills could decay if there were no opportunities for subsequent practice. The interviews therefore supported early introduction followed by longitudinal reinforcement, rather than either a single early course or complete deferral of ultrasound until later clinical training.

Together, these themes describe a **progressively scaffolded learning pathway** in which simulation facilitates foundational skill acquisition, self-directed learning provides flexibility, and targeted feedback and supervision become increasingly important as learners transition towards human and clinical scanning (**Table 2**).

## Discussion

### Principal findings

This study explored how medical students' experienced predominantly self-directed, simulator-based POCUS education, and where educator support remained important as learning progressed toward clinical practice. Four interrelated findings emerged. Simulation made an unfamiliar technical skill more accessible by linking anatomy, probe movement and image formation while allowing safe repetition. Students valued the flexibility of self-directed learning, but autonomy became less secure when they could no longer judge whether their technique or interpretation was correct. Transition to human and clinical scanning reintroduced technical, interpersonal and clinical complexity. Finally, POCUS learning gained relevance when integrated with the wider medical curriculum and future practice. Taken together, these findings support a model of supported autonomy rather than either fully independent or continuously supervised learning. The two independent course surveys provided complementary context: responses were strongly favourable regarding course satisfaction and effectiveness, yet confidence for future patient use was appreciably lower. This distinction reinforces the qualitative finding that perceived success in a simulator-based course should not be equated with readiness for unsupervised clinical application.

### Self-directed learning and the flipped classroom

Students' experiences align closely with flipped classroom principle, whereby foundational content is acquired asynchronously and synchronous contact is reserved for active learning, application and feedback. Students valued learning theoretical material flexibly and at their own pace, while educator interaction was valued when it helped learners solve practical problems, clarify uncertainty or apply knowledge. Ultrasound-specific evidence similarly suggest that e-

learning can achieve comparable knowledge and practical outcomes while reducing face-to-face teaching requirements [7,8]. Our findings add a qualitative dimension to this literature. Students did not equate self-directed learning with learning entirely alone. Instead, they described supported autonomy: routine learning could occur independently, but learners wanted access to support when they reached the limits of their ability to self-correct. This distinction may be particularly important in skill-based education, where completion of a task does not necessarily demonstrate that it has been performed correctly. Previous POCUS studies similarly suggest that introductory knowledge and simulator-based skills can be acquired with reduced instructor dependence [4,5,6]. The relevant question may therefore be not whether instructors are required, but which components of learning specifically require expert involvement.

**Feedback as a scalable educational resource**

A recurrent difficulty was uncertainty about whether images were being acquired or interpreted correctly. Although peers, instructional videos, automated questions and reflective logbooks all provided useful scaffolding, these mechanisms were less successful when the learner could not independently determine whether their performance was correct. This distinguishes instruction from feedback: reducing continuous instruction does not eliminate the need to calibrate performance against an external standard.

This creates an opportunity for greater educational efficiency. Rather than supervising every learner, expert input could be concentrated at formative checkpoints, submission of selected images for asynchronous review, brief targeted practical sessions, remote review, or access to an educator when predefined difficulties arise. Future studies should therefore examine the optimal dose and timing of supervision rather than simply comparing fully supervised with fully self-directed learning.

**Peers can extend - but may not replace - expertise**

Peer collaboration supported troubleshooting, error recognition and engagement, but had an inherent ceiling when all learners were uncertain. This is consistent with evidence suggesting that peer-assisted POCUS teaching can achieve outcomes comparable with expert-led teaching for some learning tasks [9,10]. These findings support viewing peers as one level within a teaching hierarchy rather than as a complete substitute for expertise. This facilitates collaborative approach, particularly with repetition, routine troubleshooting and shared problem solving, while expert educators can be reserved for uncertainties that cannot be resolved within the peer group. This approach potentially extends teaching capacity without assuming that peer instruction can replace expertise entirely.

**Progressing toward real-world practice**

Simulation was highly valued because it deliberately simplified the early learning, allowing students to develop probe-handling, and image recognition without concerns about patient discomfort or the consequences of prolonged examination [12]. However, this simplification also created a gap between simulator performance and real-world scanning. Participants anticipated or experienced several new sources of complexity when moving to humans: anatomical variability, body habitus, poorer image quality, patient positioning, probe pressure, communication, consent, privacy and patient comfort. Clinical practice added further requirements, including determining when POCUS be performed, recognising its limitations, integrating findings with other clinical information and communicating results

These findings support a staged model of real-world exposure rather than a dichotomy between simulation and patient-based teaching. Simulation can deliberately remove complexity during initial skill acquisition; subsequent learning can then reintroduce complexity through human

scanning and supervised clinical application. Peer or healthy-volunteer scanning may offer an intermediate stage, although this peer-scanning findings require cautious interpretation because the possibility was explicitly introduced by interviewers in some interviews. A recent Australian FCU feasibility programme used online learning, simulator practice and repeated supervised patient scanning over a longitudinal period, demonstrating the feasibility of such staged progression [11].

The need for supervision may therefore be dynamic rather than fixed. A novice may require relatively little expert involvement while repeating a well-scaffolded simulator exercise but considerably more when first encountering anatomical variability, an unfamiliar patient or uncertain pathology. Efficient programmes should match educator input to the learner's stage and degree of uncertainty rather than provide uniform supervision throughout.

**Integration and longitudinal reinforcement**

Participants valued POCUS when it reinforced concurrent anatomy, physiology and pathology teaching or was incorporated into case-based clinical reasoning. Similar curricula have used ultrasound to reinforce preclinical anatomy and physical examination while introducing practical POCUS skills early in training [8,12]. However, early introduction creates a need for subsequent reinforcement. Despite increasing undergraduate POCUS uptake, longitudinal exposure throughout medical school remains uncommon [3]. A single early course may provide useful foundations without ensuring that those skills are retained or become clinically usable.

Our findings support a longitudinal model in which the educational function of POCUS changes as learners progress. Early in training, ultrasound may make anatomy and physiology tangible. Simulator practice can establish basic image-acquisition skills. Human scanning introduces anatomical variability and patient interaction, while clinical placements allow POCUS to be

integrated into real patient assessment and decision-making. Such a model does not require identical teaching intensity at every stage; longitudinal scalability may instead depend on deploying different teaching resources according to what learners need.

**Implications for scalability and future research**

The principal implication of our study is not that self-directed learning should be replaced with more supervision. Doing so would risk recreating the faculty bottleneck that scalable simulation-based education is intended to overcome. Instead, the central question is: **How do we use a scarce expert teaching resource most efficiently?**

Future studies should determine when educator contact is required, whether feedback can be delivered asynchronously, which activities can be supported by peers or other educators, and how much supervised human scanning is necessary. Importantly, outcomes should extend beyond simulator performance to real-person image acquisition and interpretation, clinical integration, skill retention and educator resource utilisation. The educational objective is not to minimise educator time at all costs, but to identify the minimum effective expert input required to produce durable and transferable learning. This may be the most useful application of flipped-classroom principles to FCU education. Foundational knowledge and routine simulator practice can occur through scalable asynchronous resources; peers can facilitate repetition and collaborative problem solving; and scarce expert contact can then be concentrated on higher-value activities - feedback, troubleshooting, application and progression to real-world practice.

**Strengths and limitations**

This study provides detailed learner perspectives across two undergraduate POCUS courses and addresses an educational problem directly relevant to institutions attempting to provide ultrasound training at scale. The inductive analysis allowed students' experiences of self-

direction, simulation, feedback and clinical translation to be examined as interconnected elements rather than predetermined components of the course design.

Several limitations should be considered. First, interview participation was voluntary and the participants may have had particularly positive or negative experiences, introducing volunteer bias. Second, the participants were drawn from elective POCUS courses at a single institution and findings may not transfer directly to mandatory curricula, other medical programmes or learners with different prior experience. Third, the primary researcher was involved in course design, teaching and assessment, which may have influenced both participant responses and interpretation of the data, although teaching and assessment had been completed and results finalised before interviews, and a researcher independent of the teaching programme contributed to reflexive review of the analysis. Fourth, the interviews assessed perceptions rather than objective competence, and variable informal exposure to human scanning precluded conclusions about the amount required for competency. Finally, peer scanning was interviewer-prompted in some interviews and should therefore be interpreted as a potentially acceptable educational strategy rather than a wholly emergent finding.

## Conclusion

Medical students valued self-directed, simulator-based POCUS education for its flexibility, reduced initial complexity and opportunities for repeated practice, but required greater support when uncertainty arose and as learning progressed toward patients. Peer learning and structured resources provided useful scaffolding but did not eliminate the need for expert feedback. The scalability challenge may therefore be less about removing expert educators than deploying their expertise where it adds greatest value. A flipped, progressively scaffolded model concentrating expert input on feedback, troubleshooting and transition to real-world practice warrants prospective evaluation.

## Declarations

### Ethics approval and consent to participate

Approved by the University of Melbourne Human Research Ethics Committee in accordance with the Declaration of Helsinki (Ethics ID 25857). Written informed consent was obtained from all participants.


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### Competing interests

None declared

### Author contributions

### Data availability

All data supporting the findings of this study are available within the paper and its Supplementary Information.

### Consent to Publish declaration:

Not applicable

### Author Contributions

KB - Concept and Design of study, Data acquisition, Data analysis, interpretation of data, Manuscript drafting, Manuscript revision

RR - Data acquisition, Data analysis, interpretation of data, Manuscript drafting

KS - Data acquisition, Data analysis, interpretation of data, Manuscript drafting

AS - Data analysis, interpretation of data, Manuscript drafting, Manuscript revision

DC - Concept and Design of study, Manuscript drafting, Manuscript revision

## References


1. Moore CL, Copel JA. Point-of-care ultrasonography. N Engl J Med. 2011;364(8):749-757.
2. Russell FM, Zakeri B, Herbert A, Ferre RM, Leiser A, Wallach PM. The state of point-of-care ultrasound training in undergraduate medical education: findings from a national survey. Acad Med. 2022;97(5):723-727. doi:10.1097/ACM.0000000000004512.
3. Russell FM, Park R, Campbell M, Lemen L. Point-of-Care Ultrasound in Undergraduate Medical Education: A National Survey. J Ultrasound Med. 2025;44(12):2335-2340. doi:10.1002/jum.70021.
4. Cawthorn TR, Nickel C, O'Reilly M, Kafka H, Tam JW, Jackson LC, Sanfilippo AJ, Johri AM. Development and evaluation of methodologies for teaching focused cardiac ultrasound skills to medical students. J Am Soc Echocardiogr. 2014;27(3):302-309. doi:10.1016/j.echo.2013.12.006.
5. Canty DJ, Barth J, Yang Y, Peters N, Palmer A, Royse AG, Royse CF. Comparison of learning outcomes for teaching focused cardiac ultrasound to physicians: a supervised human model course versus an eLearning-guided self-directed simulator course. J Crit Care. 2019;49:38-44. doi:10.1016/j.jcrc.2018.10.006.
6. Canty DJ, Royse AG, Royse CF. Self-directed simulator echocardiography training: a scalable solution. Anaesth Intensive Care. 2015;43(3):425-427.
7. Hempel D, Sinnathurai S, Haunhorst S, Seibel A, Michels G, Heringer F, Recker F, Breitkreutz R. Influence of case-based e-learning on students' performance in point-of-care ultrasound courses: a randomized trial. Eur J Emerg Med. 2016;23(4):298-304. doi:10.1097/MEJ.0000000000000270.
8. Nelson BP, Hojsak J, Dei Rossi E, Karani R, Narula J. Seeing Is Believing: Evaluating a Point-of-Care Ultrasound Curriculum for 1st-Year Medical Students. Teach Learn Med. 2017;29(1):85-92. doi:10.1080/10401334.2016.1172012.
9. Bapuji R, Eagles D, Ferreira N, Hecht N, Zhang Y, Woo MY, Cheung WJ, Ly V, Pageau P. Comparison of peer-assisted learning with expert-led learning in medical school ultrasound education: a systematic review and meta-analysis. CJEM. 2024;26(3):188-197. doi:10.1007/s43678-024-00663-x.
10. Winter L, Neubauer R, Weimer J, Dietrich CF, Wittek A, Schiestl L, Marinova M, Schäfer VS, Strizek B, Recker F. Peer teachers as ultrasound instructors? A systematic literature review of peer teaching concepts in undergraduate ultrasound education. BMC Med Educ. 2024;24:1369. doi:10.1186/s12909-024-06345-7.
11. Brooks KS, Barrett J, McKenzie D, Canty D. A pilot feasibility study of teaching focused cardiac ultrasound to Australian medical students in a structured program. BMC Med Educ. 2025;25(1):1572. doi:10.1186/s12909-025-08016-7.
12. Canty DJ, Hayes JA, Story DA, Royse CF. Ultrasound simulator-assisted teaching of cardiac anatomy to preclinical anatomy students: a pilot randomized trial of a three-hour learning exposure. Anat Sci Educ. 2015;8(1):21-30. doi:10.1002/ase.1452.
13. Braun V, Clarke V. Using thematic analysis in psychology. Qual Res Psychol. 2006;3(2):77-101. doi:10.1191/1478088706qp063oa.
14. Atkins L, Francis J, Islam R, O'Connor D, Patey A, Ivers N, et al. A guide to using the Theoretical Domains Framework of behaviour change to investigate implementation problems. Implement Sci. 2017;12:77. doi:10.1186/s13012-017-0605-9.

*Table 1. Descriptive survey responses (n=44). Likert categories are collapsed for concise presentation*

| Survey item | Agree/Strongly agree | Neutral | Disagree/Strongly disagree |
|---|---|---|---|
| Pre-reading effective for knowledge content | 40/44 (90.9%) | 3/44 (6.8%) | 1/44 (2.3%) |
| Practical component sufficient for confidence with future patient use | 26/44 (59.1%) | 6/44 (13.6%) | 12/44 (27.3%) |
| Overall course effective in teaching techniques covered | 40/44 (90.9%) | 3/44 (6.8%) | 1/44 (2.3%) |
| Course duration long enough | 41/44 (93.2%) | 3/44 (6.8%) | 0/44 (0%) |
| Would like more ultrasound training in this style | 39/44 (88.6%) | 2/44 (4.5%) | 3/44 (6.8%) |
| Satisfied with the course | 42/44 (95.5%) | 2/44 (4.5%) | 0/44 (0%) |
| Increased understanding of anatomy | 38/44 (86.4%) | 4/44 (9.1%) | 2/44 (4.5%) |
| Increased understanding of physiology/pathophysiology | 35/44 (79.5%) | 6/44 (13.6%) | 3/44 (6.8%) |
| Plan to use ultrasound in future practice | 38/44 (86.4%) | 6/44 (13.6%) | 0/44 (0%) |
| Would benefit from further ultrasound training during medical school | 44/44 (100%) | 0/44 (0%) | 0/44 (0%) |

*Table 2. Summary of qualitative themes.*

| Theme | Central concept | Key subthemes | Illustrative examples |
|---|---|---|---|
| Making the invisible tangible: simulation as an enabling foundation | Simulation reduced the initial complexity of POCUS by connecting theoretical knowledge, anatomy, probe manipulation and image interpretation in a controlled environment. It provided a safe environment for novice practice. | Connecting theory with anatomy and probe movement | *"The theory that seems very conceptual and abstract until you're actually doing it on the mannequin really kind of solidified in my mind."* |
| | | | Ultrasound images initially appeared as *"all just shades of grey"*, but became progressively more interpretable through repeated interaction with the simulator, probe orientation and machine controls |
| | | Repetition and safe experimentation | *"It's a lot easier to practice on a piece of plastic than it is a real person that you don't want to view just as a learning opportunity."* |
| | | Limitations of idealised simulation | Students recognised that simulator images were clearer and more reproducible than human images and anticipated difficulty adapting to anatomical variability, body habitus and patient positioning. |
| Supported autonomy: flexibility without isolation | Students valued self-direction, but uncertainty created a need for timely confirmation and targeted support. | Flexible self-directed learning | *"It's nice that a graduate level to actually be given that sense of autonomy…go ahead, guide your own learning."* |
| | | Uncertainty and limits of self-correction | *"I'm worried about the fact that maybe I've just been learning the wrong thing."* |
| | | Peer collaboration as an informal scaffold | *"They're sort of optimally positioned to pick up anything that you might have missed, or that you're doing wrong."* Peers supported troubleshooting, although uncertainty could remain when the whole group was unsure. |
| | | Feedback closed learning loop | *"I feel like I didn't get that feedback, so I didn't actually learn anything from that assessment."* Students valued educator contact particularly when it addressed practical problems or unresolved uncertainty. |
| Progressing toward real-world practice: from simulation to human and clinical scanning | Increasing real-world complexity reintroduced technical, interpersonal and clinical complexity and increased the perceived value of supervision. | Human scanning reintroduced anatomical and technical complexity. | *"It was so much more difficult to see in a real person than on the simulator."* Another participant described a real scan as *"a blur of grey and black".* |
| | | Real-world practice introduced the patient | Human scanning required attention to consent, privacy, dignity, positioning, probe pressure, examination duration and patient comfort—considerations largely absent from simulator practice. |
| | | Peer scanning as a potential intermediate step | *"Even if we were just told to pair up and practice on each other."* Peer scanning was viewed as a possible bridge between simulation and patients, although this option was interviewer-prompted in some interviews and should therefore be interpreted cautiously. |
| | | Clinical practice added further complexity | *"If I do find something, I wouldn't really know how to present it coherently."* Students recognised that clinical POCUS also required selecting appropriate indications, interpreting findings in context and communicating results. |

| | | | |
|---|---|---|---|
| Integration gives POCUS educational and clinical meaning | POCUS was most valuable when connected with concurrent learning and future practice. | Curricular alignment reinforced learning | *"It was so complementary to like the anatomy teaching and everything that we were receiving."* POCUS reinforced anatomy, physiology and pathology taught elsewhere in the curriculum. |
| | | Broader awareness during clinical reasoning | *"Okay, so how can ultrasound help?"* Students described greater awareness of ultrasound as a potential diagnostic tool, rather than established change in independent clinical practice. |
| | | Clinical relevance increased motivation | "I'm building the foundations of a skill that I may use in my future career." |
| | | Longitudinal reinforcement and skill retention | Students expressed concern that skills acquired early could decay without opportunities for subsequent practice, supporting repeated exposure throughout medical training. |

## Appendix 1. Semi-structured interview guide

The interview schedule was informed by the Theoretical Domains Framework and used flexibly. Follow-up prompts were adapted to participants' responses.

### A. Baseline demographics

- Name (collected for interview administration and removed during de-identification).
- Age.
- Gender.
- Previous experience with bedside ultrasound modalities.

### B. Experience of the Discovery subject during the simulator phase

- Can you tell me about the ultrasound course you have just completed?
- What did you like or dislike about it?
- What did you find difficult?
- What parts of the course made it easier to complete?

### C. Experience of human or clinical scanning after simulator teaching

- What factors make scanning real patients difficult?
- What factors help when scanning patients?
- In what ways does scanning a patient differ from using the simulator?
- Where relevant, explore views on peer scanning as a possible intermediate learning opportunity.

### D. Impact on practice and clinical thinking

- How has completion of the ultrasound Discovery subject changed your patient assessment?
- Can you provide an example of a change in the way you think about assessing patients?
- What new knowledge or skills have you acquired through the Discovery subject?
- Have you applied any of this knowledge to a specific patient or clinical scenario?

### E. Closing questions

- Would you like to receive a copy of this interview transcript?
- Do you have any additional comments or queries?

## Appendix 2. Student survey

Response options for all items: Strongly disagree; Disagree; Neutral; Agree; Strongly agree.

1. The pre-reading tutorials were effective in delivering knowledge content for the course.
2. The practical component of the course I completed was sufficient to develop enough confidence to use ultrasound on patients in a clinical setting during my further training.
3. Overall the course was effective in teaching the ultrasound techniques covered.
4. The course duration was long enough to be effective.
5. I would like to do more ultrasound training in this style of learning.
6. I was satisfied with the course.
7. The ultrasound course has increased my understanding of the anatomy of the areas studied.
8. The ultrasound course has increased my understanding of the physiology and pathophysiology of the organs studied.
9. I plan to use ultrasound in my future practice.
10. I would benefit from further ultrasound training during medical school.

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1V2.docx
- Table2V2.docx
- Appendix1.docx
- Appendix2.docx