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Longitudinal Simulator-Enhanced Point-of-Care Ultrasound Training for First-Year Medical Students

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Abstract

Background

Point-of-care ultrasound (PoCUS) is increasingly integrated into undergraduate medical education, but scalable approaches for reinforcing early skill acquisition remain limited. High-fidelity simulation may support distributed, self-directed practice while reducing dependence on faculty availability and patient models.

Methods

We conducted a prospective randomized controlled quality-improvement study of 46 first-year medical students at McGill University over six months. We randomized 23 students to the standard PoCUS curriculum plus six facilitator-supported, learner-directed CAE Vimedix simulator sessions and 23 to the standard curriculum alone. Outcome-specific available-case analyses included 22 simulator-enhanced and 16 standard-curriculum participants for practical performance, 23 and 19 for visual ultrasound knowledge, and 16 and 13 group-linked respondents for learner perceptions.

Results

In the practical analysis (22 simulator-enhanced and 16 standard curriculum), simulator-enhanced students achieved higher scores across assessed scan types ($F(1,101) = 6.17$, $p = 0.0146$). The estimated marginal mean difference was 15.21 percentage points (95% CI, 1.95 to 28.48, Hedges' $g = 0.72$). Visual examination scores were higher among simulator-enhanced students (n = 23 vs 19, 65.67% vs 53.36%, mean difference 12.31 percentage points, 95% CI, 3.97 to 20.65, $t(40) = 2.98$, $p = 0.0048$, Hedges' $g = 0.91$). Learner data suggested higher confidence and perceived retention among simulator-trained students.

Conclusions

Supplemental high-fidelity PoCUS simulation was associated with higher end-of-year practical performance, visual ultrasound knowledge, and learner confidence among first-year medical students. These findings support further evaluation of distributed, simulator-enhanced PoCUS training as a scalable adjunct to undergraduate curricula.

Introduction

Point-of-care ultrasound (PoCUS) has become an increasingly important tool in modern clinical practice. Initially adopted in emergency and critical care settings, its use now extends across a wide range of specialties, including internal medicine, family medicine, obstetrics, and anesthesia [1]. Improvements in

ultrasound technology, particularly portability, safety, and accessibility, have contributed to this expansion, making PoCUS proficiency a valuable skill for contemporary physicians [1, 2]. This growing clinical integration has prompted medical educators to introduce ultrasound earlier in training. Many undergraduate medical education (UGME) programs now include PoCUS instruction in pre-clerkship curricula, where it has been shown to enhance anatomical understanding, support physical examination learning, and strengthen clinical reasoning [1, 3, 4]. National and international organizations have similarly emphasized the importance of ultrasound education. For example, the Canadian Medical Student Ultrasound Curriculum outlines foundational competencies expected of graduating learners [3], while international bodies advocate for longitudinal integration of ultrasound training [2].

Despite increasing interest, implementing PoCUS education at the UGME level remains challenging. Hands-on ultrasound training typically requires significant faculty involvement, access to equipment, and availability of suitable models or patients [1, 5]. These logistical constraints can limit both the consistency and scalability of training. In addition, reliance on live scanning introduces variability in anatomy and pathology exposure, reducing standardization of learning experiences [5].

Simulation-based training offers a potential solution to many of these barriers. High-fidelity ultrasound simulators allow learners to practice in a standardized, reproducible environment without depending on patient availability [6, 7]. Such platforms provide controlled exposure to normal and pathological findings and enable deliberate, repeated practice. Previous studies have reported improvements in technical performance and learner confidence after simulator-enhanced training [8, 9]. The CAE Vimedix simulator combines a mannequin-based scanning interface with software-generated sonographic anatomy and pathology, allowing learners to practice probe positioning, image acquisition, and interpretation across standardized scenarios without patient models [9]. Educationally, simulation supports deliberate practice, repeated exposure, and standardized feedback. Brief encounters distributed longitudinally may reinforce learning by allowing students to revisit core scanning tasks rather than relying on one intensive session.

What remains unclear is whether a learner-directed PoCUS simulator adjunct integrated longitudinally into a pre-clerkship curriculum is associated with objective performance beyond the immediate post-training period. Most UGME PoCUS studies assess outcomes immediately after instruction, and evidence on longitudinal reinforcement remains limited, particularly in Canadian contexts [2, 3]. Examining this delivery model may inform programs seeking to expand practice opportunities without proportionally increasing continuous faculty supervision.

To address this gap, we conducted a prospective randomized controlled study evaluating whether supplemental high-fidelity ultrasound simulation was associated with improved end-of-year PoCUS performance among first-year medical students. Our primary objective was to compare practical PoCUS competency between students receiving simulator-enhanced training and those receiving the standard curriculum alone. Secondary objectives were to compare visual ultrasound knowledge and learner perceptions of simulation-based PoCUS education.

Methods

Study Design and Setting

We conducted a prospective, parallel-group randomized controlled quality-improvement study over six months (December 17, 2024, to June 17, 2025) at McGill University's Faculty of Medicine and Health Sciences in Montreal, Canada. We embedded the study within the first-year pre-clerkship undergraduate medical curriculum and used an intended 1:1 allocation to the simulator-enhanced intervention or standard-curriculum control group.

Due to the educational nature of the intervention, participant blinding was not feasible. However, outcome assessors were blinded to group allocation and were not involved in delivering the supplemental simulator sessions.

Participants and Randomization

We invited first-year medical students in the 2024–2025 academic cohort to participate voluntarily during mandatory curricular activities. Students were eligible if they were enrolled in McGill University's undergraduate medical program and provided written informed consent. We excluded students with prior formal ultrasound training or clinical ultrasound experience beyond the standard undergraduate curriculum.

We enrolled 46 students and randomized 23 to the simulator-enhanced group and 23 to the standard-curriculum group using a computer-generated sequence created by an independent researcher who was not involved in outcome assessment. Allocation was concealed until assignment. Outcome availability differed by assessment: practical data were available for 22 simulator-enhanced and 16 standard-curriculum participants, while visual-examination data were available for 23 and 19 participants, respectively. Reported reasons across missing or unusable records included justified absence, failure to finish within the allotted time, and unreadable practical-assessment records.

All participants continued to receive the standard ultrasound instruction embedded within the undergraduate curriculum.

Intervention

Students randomized to the intervention group received simulator-based ultrasound practice in addition to the standard first-year curriculum. Over six months, they attended six structured sessions (approximately one per month) using a CAE Vimedix high-fidelity ultrasound simulator already owned by McGill University's Steinberg Centre for Simulation and Interactive Learning for routine educational use. CAE Healthcare did not provide the simulator or support this study.

We scheduled sessions to align with concurrent ultrasound topics, including cardiac views, the focused assessment with sonography in trauma (FAST) examination, and lung ultrasound. Session objectives aligned with local UGME learning objectives and competencies described by the Canadian Point-of-Care Ultrasound Society (CPoCUS), a national point-of-care ultrasound certifying body.

Students practiced identifying key sonographic anatomy, positioning and manipulating the probe, acquiring and optimizing images (including depth and gain), completing required views, and recognizing common artifacts. Sessions were facilitator-supported but learner-directed. Volunteer faculty members or senior medical students oriented learners to the Vimedix platform and answered technical questions while learners completed assigned scanning tasks independently. Across six sessions, intervention participants received approximately 90 minutes of simulator-based practice, with each session lasting approximately 15 minutes.

Control Condition

Students randomized to the control group participated only in the standard first-year ultrasound curriculum. This curriculum included scheduled lectures and instructor-supervised live scanning sessions covering core PoCUS applications, including FAST examination, basic cardiac echocardiography, lung ultrasound, abdominal aorta screening, and pelvic/bladder assessment. Control participants did not have access to the Vimedix simulator during the study period.

Outcome Measures

At six months, we evaluated practical scanning competency as the primary outcome. Secondary outcomes were visual ultrasound knowledge and image interpretation and post-intervention learner perceptions.

Practical Ultrasound Competency

Hands-on ultrasound skill was assessed using a modified version of the Ultrasound Competency Assessment Tool (UCAT) [10], a validated checklist-based instrument for evaluating point-of-care ultrasound performance. The UCAT was adapted to align with first-year UGME learning objectives and reviewed by the local undergraduate competency committee.

During a structured OSCE-style assessment, participants performed scan tasks corresponding to core PoCUS applications taught during the academic year. Both groups completed the assessment on live models under standardized station conditions. Certified Independent Practitioner PoCUS instructors credentialed through CPoCUS directly observed performance and scored technique in real time using standardized UCAT criteria. Participants completed abdominal free-fluid, pneumothorax, and pleural-effusion stations. For each scan type, we summed the applicable UCAT criteria and converted the score to a percentage of available points (0–100) for analysis and display. The modified instrument contained

30 points across the three stations. Examiners were blinded to group allocation. The complete modified UCAT used for practical assessment is reproduced in Online Resource 1 (Fig. S1).

Visual Ultrasound Knowledge Examination

Participants completed a computer-based visual ultrasound examination administered immediately following the practical assessment. The examination was developed in alignment with first-year curriculum content and CPoCUS competency guidelines.

The assessment included ultrasound images and video clips of scans and pathologies covered during the academic year. Students identified anatomical landmarks and normal or pathological findings, performed measurements (e.g., aortic diameter), and answered technical interpretation questions. We calculated scores as the percentage of correct responses.

Learner Perception Survey

At the end of the study, we administered an electronic survey with five-point Likert items and optional open-ended questions. Domains included self-reported confidence, perceived retention, intended future PoCUS use, and overall educational experience. Only intervention participants completed simulator-specific items. We used an available-response approach for survey outcomes. Twenty-nine post-survey records could be linked reliably to a study group and were included in between-group analyses, including 16 simulator-enhanced and 13 standard-curriculum respondents. We excluded incomplete records from group comparisons. Figures report the item-level n/N for each response category.

Assessment Procedures and Data Management

Participants attended an end-of-year evaluation session in June 2025 and completed the practical assessment at standardized stations followed immediately by the supervised visual ultrasound examination. We used outcome-specific available-case analyses. Participants contributed to each analysis whenever the corresponding outcome was usable, regardless of whether another assessment component was missing. We did not impute missing outcomes.

Statistical Analysis

We performed all statistical analyses in MATLAB R2025b (MathWorks, Natick, MA) and defined statistical significance as a two-tailed α of 0.05.

We used a linear mixed-effects model to compare practical performance between groups while accounting for repeated scan-type scores within participants. We included group as the primary fixed effect, scan type as a secondary fixed effect, and participant as a random intercept. Because our primary hypothesis concerned overall practical PoCUS performance rather than scan-specific differences, we treated the group effect as the primary model result. The practical analysis included 38 participants with

at least one usable practical score (22 simulator-enhanced and 16 standard curriculum), contributing 107 available scan-level observations. The mixed-effects model accommodated the resulting unbalanced scan-level data. We assessed normality using the Lilliefors test. We compared visual ultrasound knowledge scores for 42 participants (23 simulator-enhanced and 19 standard curriculum) using MATLAB's two-sample t-test with the software's default equal-variance assumption. Survey analyses used the 29 group-linked available responses (16 simulator-enhanced and 13 standard curriculum). We did not impute missing outcomes. Where possible, we report between-group differences with 95% confidence intervals and Hedges' g standardized effect sizes. For practical performance, Hedges' g was calculated from each participant's mean of available scan scores.

Ethics

McGill University's Research Ethics Office reviewed the educational quality-improvement proposal and confirmed that it fell under Article 2.5 of the Tri-Council Policy Statement 2 and did not require research ethics review. All participants provided written informed consent, participation had no impact on academic standing, and we de-identified data before analysis and stored them according to institutional requirements.

Results

We randomized 46 participants (23 simulator-enhanced and 23 standard curriculum). Outcome availability differed across assessments. Practical-assessment data were available for 38 participants (22 simulator-enhanced and 16 standard curriculum), visual-examination data for 42 participants (23 simulator-enhanced and 19 standard curriculum), and group-linked post-survey data for 29 respondents (16 simulator-enhanced and 13 standard curriculum). Missing or unusable outcome records reflected justified absences, assessments not completed within the allotted time, or unreadable practical-assessment documentation.

Practical Exam Performance

Among 38 participants contributing 107 available scan-level scores (22 simulator-enhanced and 16 standard curriculum), students in the simulator-enhanced group achieved higher practical PoCUS performance across the three assessed scan types. In the mixed-effects model, group assignment was significantly associated with performance score ($F(1,101) = 6.17$, $p = 0.0146$). The estimated marginal mean difference was 15.21 percentage points (95% CI, 1.95 to 28.48, Hedges' $g = 0.72$). Scan type was not significantly associated with score ($F(2,101) = 0.09$, $p = 0.917$), and there was no evidence that the group difference varied by scan type ($F(2,101) = 0.71$, $p = 0.495$, Fig. 1).

Visual Exam Performance

Visual examination scores were higher in the simulator-enhanced group (n = 23) than in the standard-curriculum group (n = 19). Mean scores were 65.67% and 53.36%, respectively, with a mean difference of

12.31 percentage points (95% CI, 3.97 to 20.65, t(40) = 2.98, p = 0.0048, Hedges' g = 0.91, Fig. 2).

Survey-Based Confidence Outcomes

Among the 29 group-linked post-survey records included in the available-response analysis (16 simulator-enhanced and 13 standard curriculum), confidence ratings of 4 or 5 for identifying anatomy were reported by 11/16 (69%) simulator-enhanced respondents and 4/13 (31%) standard-curriculum respondents. The corresponding counts were 5/16 (31%) versus 4/13 (31%) for operating ultrasound equipment, 7/16 (44%) versus 5/13 (38%) for acquiring images, 6/16 (38%) versus 1/13 (8%) for interpreting findings, and 9/16 (56%) versus 6/13 (46%) for explaining findings. For explaining findings, 3/16 (19%) simulator-enhanced participants selected 5 (extremely confident), compared with 0/13 standard-curriculum participants (Fig. 3).

Application, Retention, and Teaching Confidence

Survey items on perceived skill retention, clinical preparedness, and teaching confidence also generally favored the simulator-enhanced group (Fig. 4). Confidence ratings of 4 or 5 for retaining PoCUS skills were reported by 14/16 (88%) simulator-enhanced respondents (12/16 agree and 2/16 strongly agree) and 6/13 (46%) standard-curriculum respondents (5/13 agree and 1/13 strongly agree). Preparedness for clinical rotations was reported by 7/16 (44%) and 5/13 (38%), respectively. One of 13 (8%) standard-curriculum respondents strongly agreed, compared with 0/16 simulator-enhanced respondents. Confidence ratings of 4 or 5 for teaching peers were reported by 10/16 (63%) simulator-enhanced and 5/13 (38%) standard-curriculum respondents.

Simulation-Specific Perceptions

Intervention participants reported positive perceptions of the simulation experience (Fig. 5). All 16/16 (100%) respondents agreed that the sessions increased their interest in PoCUS, including 10/16 (63%) who strongly agreed. Positive ratings of 4 or 5 were reported by 12/16 (75%) for simulator realism, 15/16 (94%) for the usefulness of feedback, and 13/16 (81%) for integrating simulators into future medical courses. Responses to preferring the simulator over traditional methods were more neutral: 11/16 (69%) selected neutral, 3/16 (19%) disagreed, and 2/16 (13%) agreed.

An exploratory, post hoc sentiment analysis of open-ended survey responses is reported in Online Resource 1 (Fig. S2).

Discussion

Our study demonstrates that early integration of high-fidelity ultrasound simulation into UGME was associated with higher end-of-year PoCUS performance among first-year medical students. Students who engaged in six months of structured simulator exposure showed higher practical scanning scores, stronger visual ultrasound knowledge, and greater self-reported confidence than peers in the standard

curriculum. These findings build on prior work showing that simulator-enhanced ultrasound training can improve technical performance and learner confidence [8, 9], while extending this evidence to a longitudinal pre-clerkship UGME context.

A key contribution of this work is its assessment after repeated exposure over an academic year rather than immediately after one teaching session. Many UGME PoCUS initiatives report short-term improvements in anatomy learning, physical examination skills, or learner confidence [1, 4], whereas evidence on longitudinal reinforcement remains limited [2]. Our findings are consistent with educational principles of distributed practice and repeated exposure and align with reports of PoCUS skill retention after reinforcement [12]. Because we assessed participants only once at the end of the year, we cannot distinguish retention from superior acquisition or claim longer-term durability. However, the six-month group difference suggests that brief, longitudinal sessions may help consolidate early learning. The educational contribution is therefore not simulator exposure alone, but the integration of a low-dose, longitudinal, learner-directed adjunct with blinded end-of-year assessment.

Equally important is the delivery model. Medical schools frequently cite limited faculty availability, equipment constraints, patient availability, and curricular crowding as barriers to PoCUS implementation [1, 5]. A facilitator-supported, learner-directed simulation model may help mitigate some of these barriers by allowing students to revisit previously taught material in a standardized environment without requiring continuous instructor presence. Unlike live scanning alone, high-fidelity simulators can provide reproducible exposure to anatomy and pathology, repeated attempts, and structured practice opportunities [5–7]. Prior studies of Vimedix and other ultrasound simulation platforms have similarly reported improvements in scanning proficiency and structured skill development [8, 9]. Our data support the feasibility of extending these advantages to novice undergraduate learners within a longitudinal curriculum.

This model may also offer practical implementation value. Learner-directed simulator modules may extend opportunities for reinforcement without proportionally increasing faculty-led teaching time, while preserving faculty involvement in initial instruction and supervision. Future studies should evaluate faculty time, implementation requirements, and educational yield.

Our outcomes also align with competency frameworks that increasingly expect graduating medical students to demonstrate foundational PoCUS skills. In Canada, the national medical student ultrasound curriculum identifies core competencies for undergraduate learners [3]. The applications assessed in our study, including abdominal free fluid, pneumothorax, and pleural effusion, map to clinically relevant PoCUS domains and support the curricular relevance of the intervention. Similar directions are emerging internationally, where ultrasound is increasingly promoted as a tool for integrating anatomy, clinical reasoning, and bedside assessment [1, 2, 4].

Beyond technical performance, confidence gains are also educationally relevant. Self-efficacy may influence whether learners seek further supervised practice, participate in peer teaching, and continue developing PoCUS skills. Our simulator-trained cohort reported greater confidence in identifying

anatomy, optimizing images, interpreting findings, and explaining ultrasound concepts to peers. This finding is consistent with prior work suggesting that intensive PoCUS experiences can support learner engagement and peer-teaching networks [13]. While self-confidence does not itself establish clinical competence, it may contribute to continued skill development when paired with appropriate supervision.

This study has limitations. It was conducted at one institution with a volunteer sample, which may limit generalizability and introduce selection bias. We did not collect baseline demographic or academic characteristics, so we could not assess balance between groups beyond random allocation. Outcome availability differed by group: practical data were available for 22/23 simulator-enhanced participants and 16/23 standard-curriculum participants, while visual-examination data were available for 23/23 and 19/23, respectively. Missing or unusable records were attributed to justified absences, time-limited incompletion, or unreadable documentation. Because practical outcome data were more frequently unavailable in the standard-curriculum group, and failure to finish a timed assessment could relate to performance, the available-case estimate may be affected by some attrition bias. The mixed-effects model also assumes that missing scan-level scores are conditionally missing at random. We assessed outcomes at one end-of-year timepoint. Therefore, we cannot distinguish retention from differential acquisition or determine whether gains persist into clerkship. The intervention group received additional practice, so we cannot fully separate simulator modality from exposure time. Although we assessed both groups on live models and blinded assessors to allocation, transfer to independent clinical scanning remains unknown. Only 29 post-survey records could be linked reliably to study groups. Therefore, learner-perception results may be affected by nonresponse or linkage bias. Future multi-institutional studies should include longer follow-up, clinical transfer outcomes, and prospective implementation and economic evaluation.

In summary, longitudinal simulator-enhanced PoCUS training was associated with higher end-of-year practical performance, visual ultrasound knowledge, and learner confidence. These findings support simulation as a promising adjunct for reinforcing early PoCUS learning in UGME, particularly when implemented as a structured, learner-directed model that can complement existing faculty-led teaching. Multi-center studies with longer follow-up and clinical transfer outcomes are warranted to determine how best to integrate simulator-based PoCUS practice into undergraduate medical curricula.

Conclusion

Supplemental high-fidelity PoCUS simulation was associated with higher end-of-year practical performance, visual ultrasound knowledge, and self-reported confidence among first-year medical students. Students who participated in the simulator sessions achieved higher outcomes across multiple educational domains, suggesting that even brief, distributed exposure to high-fidelity simulation can reinforce foundational ultrasound skills and complement existing curricular instruction. These findings support facilitator-supported simulator practice as a scalable adjunct to undergraduate PoCUS curricula, particularly in settings where faculty time, patient availability, or curricular resources may limit opportunities for repeated hands-on practice. Future studies should evaluate whether these gains persist

into clerkship, transfer to live-patient scanning, and justify broader self-directed simulator access, while also exploring the optimal frequency, duration, and timing of simulator-based practice within undergraduate medical education.

Declarations

Competing interests:

The authors declare no financial or non-financial competing interests.

Ethics approval:

McGill University's Research Ethics Office as well as the Associate Dean of the Faculty of Medicine reviewed the educational quality-improvement proposal and confirmed that it fell under Article 2.5 of the Tri-Council Policy Statement 2 and did not require research ethics review.

Consent to participate:

All participants provided written informed consent. Participation had no impact on academic standing.

Consent to publish:

Not applicable. The manuscript contains no identifiable participant information.

AI Declarations

No generative AI tools were used in the preparation of this manuscript.

Funding:

This study received no external or study-specific funding. McGill University's Steinberg Centre for Simulation and Interactive Learning had purchased the CAE Vimedix simulator previously for routine educational activities. It was not acquired for this study. Faculty and senior medical student facilitators volunteered their time, and human-model scanning was performed peer-to-peer.

Author Contribution

E.R.M., S.R., J.R.L., and S.N.D. contributed to the study design. C.M., E.R.M., S.R., D.H., H.Z., and J.R.L. contributed to data generation or acquisition. C.M., E.R.M., S.R., and S.N.D. contributed to the statistical analysis and interpretation. C.M., E.R.M., S.R., and H.Z. drafted the manuscript. All authors reviewed and approved the final manuscript and accept accountability for the work.

Acknowledgement

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Data Availability

De-identified study data are not publicly available because participant consent did not include public data sharing.

References

1. Zeitouni F, Matejka C, Boomer M, Lee VH, Brower GL, Hewetson A, et al. Integration of point of care ultrasound into undergraduate medical education at Texas Tech University Health Sciences Center School of Medicine: a 6-year review. BMC Med Educ. 2024;24:1476. https://doi.org/10.1186/s12909-024-06483-y.
2. Brunel M, Schäfer VS, Recker F. Bringing anatomy to life: the role of clinical ultrasound in undergraduate medical education—a systematic review. Ultrasound J. 2025;17:39. https://doi.org/10.1186/s13089-025-00443-3.
3. Ma IWY, Steinmetz P, Weerdenburg K, Woo MY, Olszynski P, Heslop CL, et al. The Canadian medical student ultrasound curriculum. J Ultrasound Med. 2020;39(7):1279–87. https://doi.org/10.1002/jum.15218.
4. So S, Patel RM, Orebaugh SL. Ultrasound imaging in medical student education: impact on learning anatomy and physical diagnosis. Anat Sci Educ. 2017;10(2):176–89. https://doi.org/10.1002/ase.1630.
5. Recker F, Neubauer R, Dong Y, Gschmack AM, Jenssen C, Möller K, et al. Exploring the dynamics of ultrasound training in medical education: current trends, debates, and approaches to didactics and hands-on learning. BMC Med Educ. 2024;24:1311. https://doi.org/10.1186/s12909-024-06092-9.
6. Doyle AJ, Condron CM. When is synthetic sufficient? Ethical considerations and alternatives in simulation-based ultrasound education. Adv Simul (Lond). 2025;10:2. https://doi.org/10.1186/s41077-024-00327-x.
7. Dietrich CF, Lucius C, Nielsen MB, Burmester E, Westerway SC, Chu CY, et al. The ultrasound use of simulators, current view, and perspectives: requirements and technical aspects (WFUMB state of the art paper). Endosc Ultrasound. 2023;12(1):38–49. https://doi.org/10.4103/EUS-D-22-00197.
8. Powalkar P, Shah N, Patil P, Patil S, Sharma R, Jethwa V, et al. Role of ultrasound simulator in training resident doctors to diagnose obstetric pathologies. J Obstet Gynaecol India. 2024;74(5):460–5. https://doi.org/10.1007/s13224-023-01921-1.
9. University of Virginia School of Medicine, Medical Simulation Center. Ultrasound: the Vimedix ultrasound simulator [Internet]. Charlottesville (VA): University of Virginia; [cited 2026 Jul 17].

Available from: https://med.virginia.edu/medical-simulation-center/equipment/virtual-reality-devices/ultrasound/

10. Bell C, Hall AK, Wagner N, Rang L, Newbigging J, McKaigney C. The Ultrasound Competency Assessment Tool (UCAT): development and evaluation of a novel competency-based assessment tool for point-of-care ultrasound. AEM Educ Train. 2021;5(3):e10520. https://doi.org/10.1002/aet2.10520.
11. Breunig M, Hanson A, Huckabee M. Learning curves for point-of-care ultrasound image acquisition for novice learners in a longitudinal curriculum. Ultrasound J. 2023;15:31. https://doi.org/10.1186/s13089-023-00329-2.
12. Schott CK, LoPresti CM, Boyd JS, Core M, Haro EK, Mader MJ, et al. Retention of point-of-care ultrasound skills among practicing physicians: findings of the VA National POCUS Training Program. Am J Med. 2021;134(3):391–e3998. https://doi.org/10.1016/j.amjmed.2020.08.008.
13. Herbert A, Russell FM, Ferre RM, Wilcox J, Peterson D, Davis J, et al. Two-week intensive medical student point-of-care ultrasound training impact on long-term utilization. BMC Med Educ. 2024;24:884. https://doi.org/10.1186/s12909-024-05866-5.

Figures

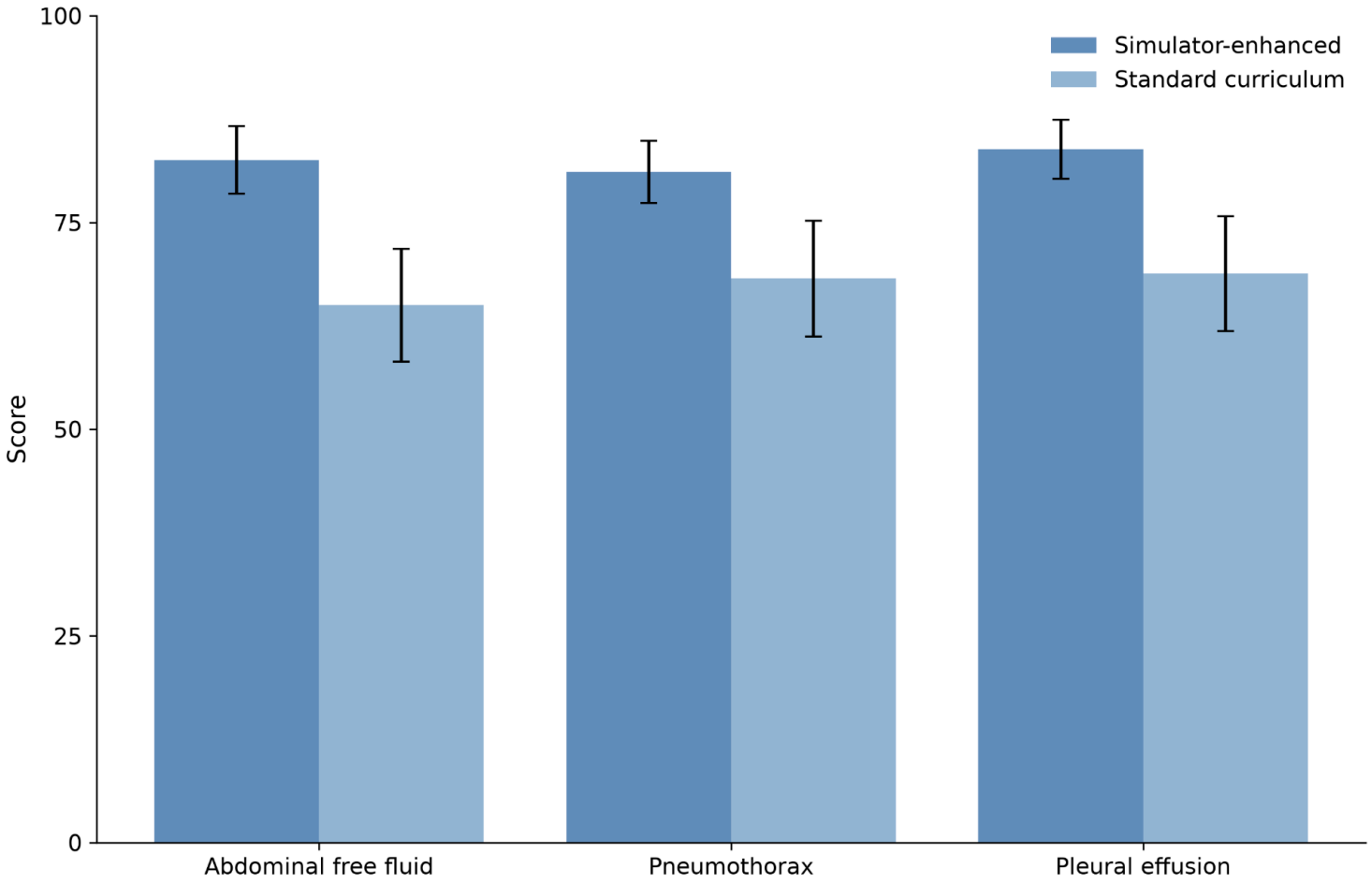


Figure 1

Practical PoCUS performance by training group across assessed scan types. Bars show mean percentages of available UCAT points. Error bars show ±1 standard error of the mean (SEM). Available simulator-enhanced/standard-curriculum counts were 22/16 for abdominal free fluid, 21/15 for pneumothorax, and 19/14 for pleural effusion

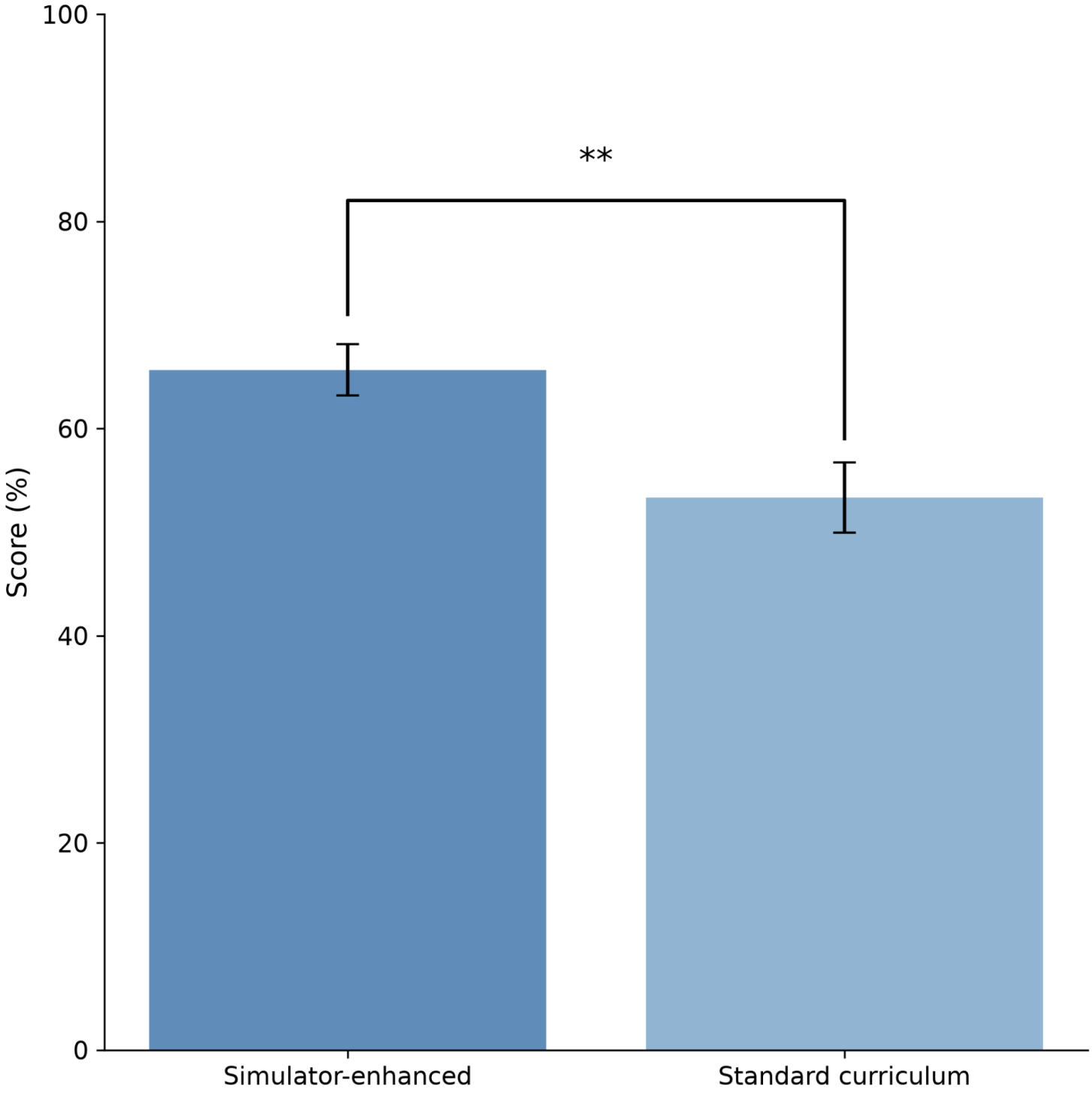


Figure 2

Visual examination performance by training group (simulator-enhanced, n = 23, and standard curriculum, n = 19). Bars show mean percentages. Error bars show ±1 standard error of the mean (SEM)

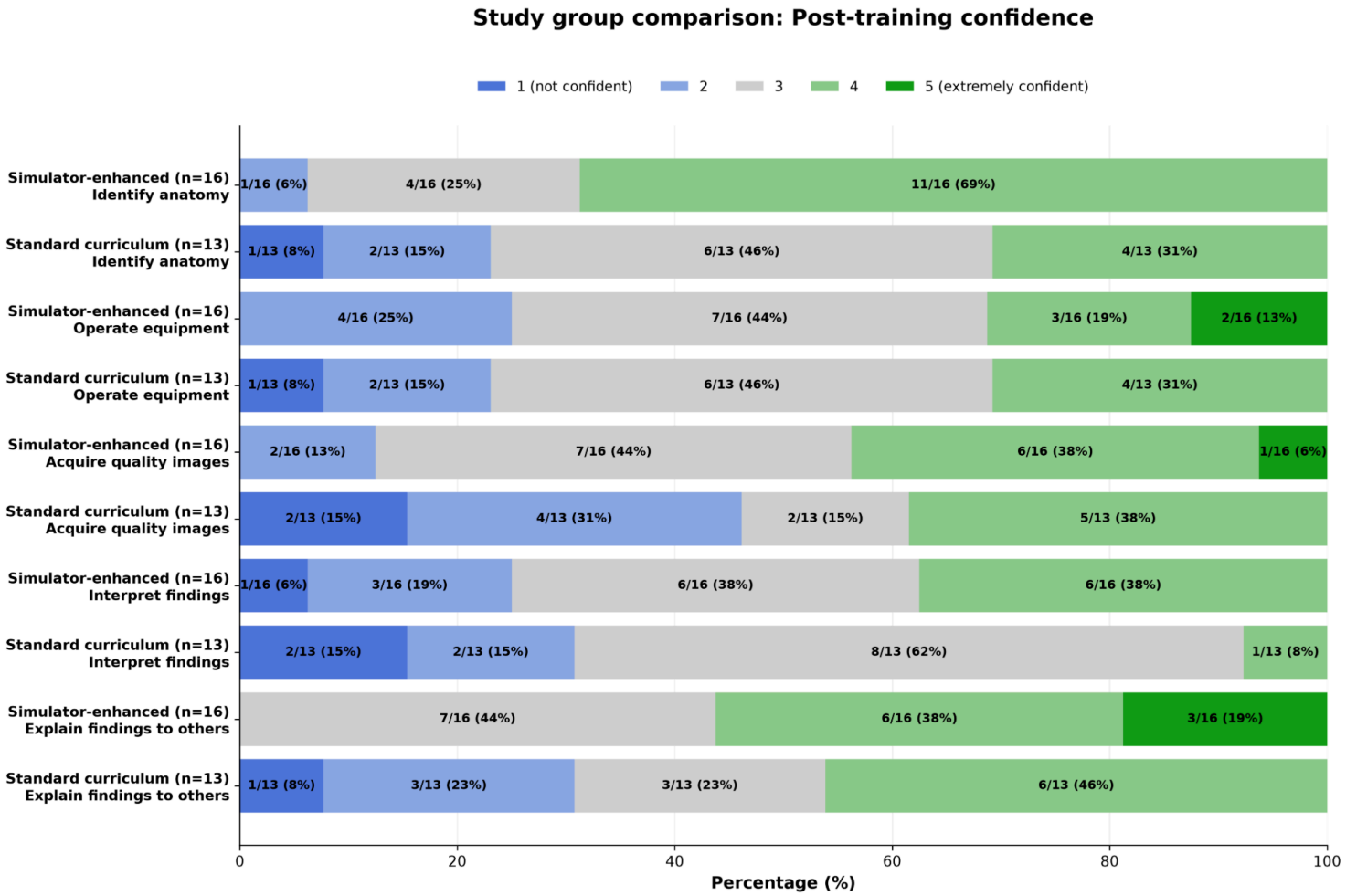


Figure 3

Post-training confidence in ultrasound-related competencies among respondents in the simulator-enhanced (n = 16) and standard-curriculum (n = 13) groups. Labels show n/N (%) for each five-point confidence category, from 1 (not confident) to 5 (extremely confident)

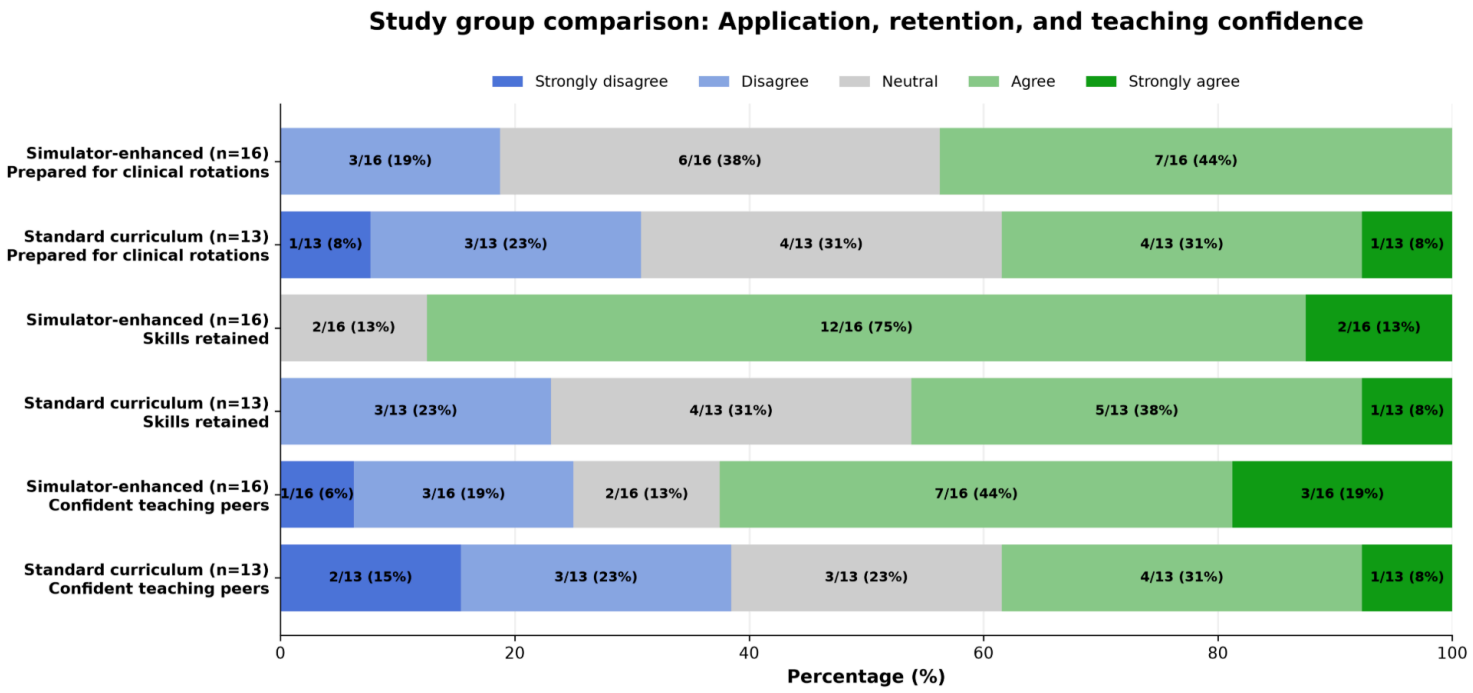


Figure 4

Perceptions of preparedness for clinical application, skill retention, and confidence in teaching peers among respondents in the simulator-enhanced (n = 16) and standard-curriculum (n = 13) groups. Labels show n/N (%) for each five-point agreement category, from strongly disagree to strongly agree

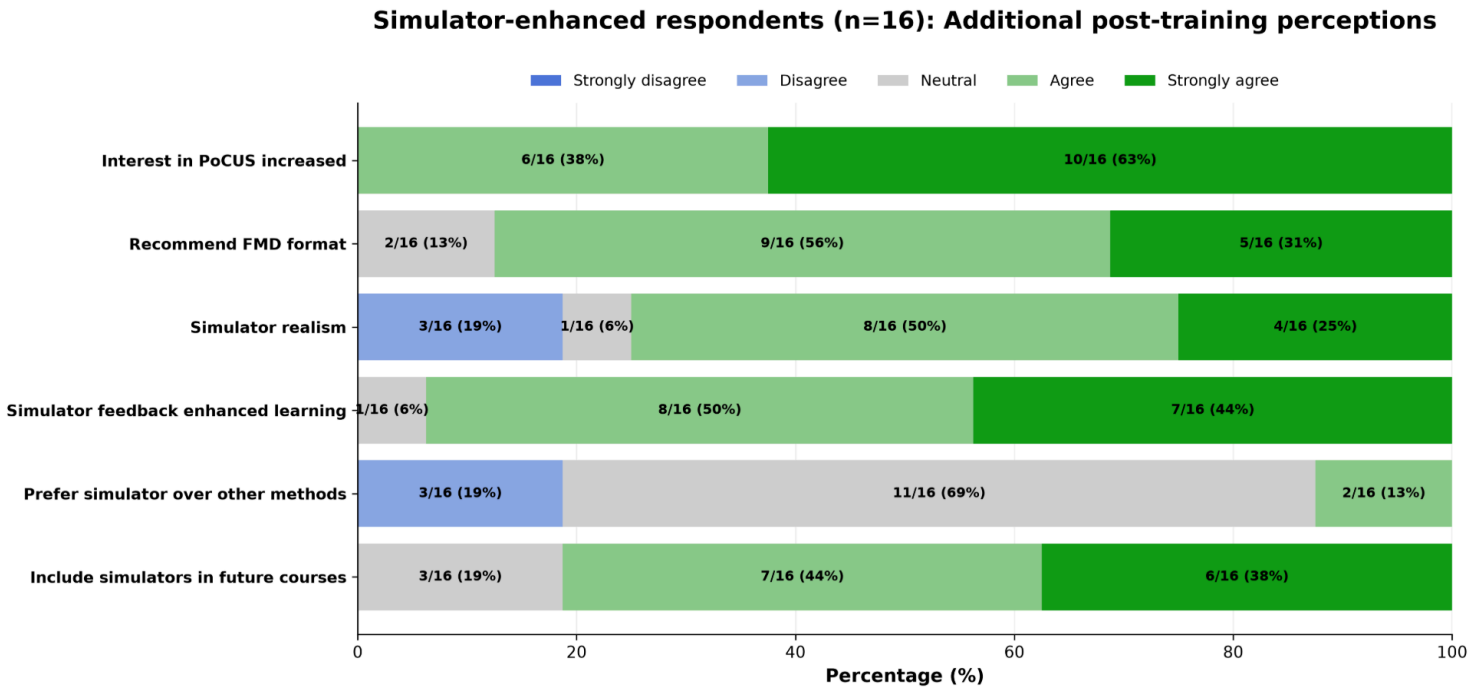


Figure 5

Perceptions of the simulation-enhanced learning experience among intervention respondents (n = 16). Labels show n/N (%) for each five-point agreement category, from strongly disagree to strongly agree

Supplementary Files

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

- ESM1.pdf