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EMPOWERING RURAL AND REMOTE HEALTH PROFESSIONALS TRAINING: A COST-EFFECTIVE SKIN SUTURING SIMULATOR FOR MOBILE LEARNING IN CLINICAL SKILLS ACQUISITION

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ABSTRACT

Introduction: This study aimed to develop a cost-effective suturing and knot typing simulator that aligns with the expectations of experts, addressing the need for affordable yet high-quality medical training tools. The focus was on assessing the efficacy of a silicone skin suture task trainer, created through a 3D printed mold, for use in mobile learning, specifically in rural and remote contexts.
Methods: Rural and remote trainees participating in a skills acquisition workshop, engaged in a 90-minute suturing simulation station. They received minimal feedback from physician educators to simulate independent practice. After the practice, they completed a survey assessing the acceptability and feasibility of the simulator for the intended training purpose, as well as providing feedback for future improvements.
Results: Results from quantitative data revealed the simulator's potential to develop competence (4.2 out of 5) and confidence (4.1 out of 5). Participants expressed a readiness to practice suturing independently using the simulator (4.3 out of 5). Notably, the realism of the simulator was identified as an area for improvement in terms of anatomical correctness (3.6 out of 5) and accuracy (3.4 out of 5), while durability scored high (4 out of 5). Participants found the simulator easy to use (4.4 out of 5) and well-suited for developing cognitive (4.4 out of 5) and psychomotor skills (4.2 out of 5) related to suturing and knot typing. Several improvements were noted, especially in the areas of anatomical representativeness, material selection, and interactions between the simulator and clinical tools.
Conclusions: This paper outlines the acceptability and feasibility of the simulator, designed to complement an online learning management system for hands-on clinical skill learning within the mobile learning paradigm. Despite high self-efficacy and educational value scores, concerns about realism suggest a need for a hybrid design approach that balances costs and anatomical fidelity in simulator development.

KEYWORDS

Simulation-Based Education, Mobile Learning, Additive Manufacturing, Rural and Remote Education, Suturing Techniques, Clinical Education

1. INTRODUCTION

The rising popularity of Simulation-Based Education (SBE) in healthcare training stems from its ability to offer a platform for healthcare professionals to master essential procedural skills before applying them to real patients (Kothari et al., 2017). Typically, situated in simulation laboratories, most SBE activities facilitate the teaching and learning of crucial competencies and skills necessary for healthcare professionals (Al-Elq, 2010). These simulated environments serve as experiential classrooms, providing nursing students with a practical, clinical-like setting without jeopardizing patient safety. This instructional model is known as the Centralized Model of Simulation-Based Education (Ce-SBE), where learners convene at a simulation lab to practice skills using commercially available simulators under supervision and expert feedback (Barth et al., 2022).

A notable feature of SBE is its adaptability to mobile learning, enabling learners to practice hands-on clinical skills beyond the confines of simulation laboratories, from the comfort of their homes or other locations. This approach is termed the Decentralized Model of Simulation-Based Education (De-SBE) (Barth et al., 2022). To implement De-SBE successfully, two technological prerequisites are essential: a dedicated Learning Management System (LMS), and an affordable, flexible, and portable simulator (Barth et al., 2022).

In previous work, we proposed a theoretical, evidence-based model for structuring remote, online psychomotor skills acquisition through LMS (Dubrowski et al., 2021). This system comprises four main components aligned with the elements of deliberate practice, encompassing: a) opportunities for hands-on repetition; b) mechanisms to enhance motivation and consistency in LMS usage; and c) provision of accurate feedback. Hands-on practice is a key component to distinguish remote and online LMSs for psychomotor skills acquisition from those designed for cognitive and affective skills. Various methods, from take-home task trainer simulators, to off-the-shelf solutions, to DIY (do it yourself) approaches can enable facilitation.

Building on our prior work with additive manufacturing (AM) (Clarke et al., 2022; Micallef et al., 2022), we have developed an inexpensive simulator suitable for De-SBE, specifically targeting suturing and knot-tying skills. These fundamental procedural clinical skills necessitate ongoing manual practice to foster the required hand-eye coordination and dexterity. Medical students, nurses, and paramedics stand to benefit from the opportunity to hone these skills wherever and whenever they find convenient (Barth et al., 2022).

The objective of this study was to produce an inexpensive suturing and knot typing simulator that met the quality and functionality expectations of experts (Micallef et al., 2021). Thus, this study aimed to assess the perceived efficacy of a cost-effective silicone skin suture task trainer, crafted from a 3D printed mold, for use in De-SBE.

2. MATERIALS & METHODS

Participants: A total of fourteen junior rural and remote physicians participated in one, two-hour workshop. This was hosted during the 30th Annual Rural and Remote Medicine Course hosted by the Society of Rural Physicians of Canada (SRPC) in Niagara Falls, Ontario in April 2023. They practiced the suturing skills using the suturing simulator developed, as well as animal models (porcine feet), under limited supervision (two tutors who answered questions). This participant group was selected as they practice in rural and remote areas and therefore they understand the context in which wheel simulators are intended to be used.

Simulator development: The development of the simulator was done through a two-step process. The mold was designed through the Fusion360**™** software application. It was then printed using an Ultimaker S5 3D printer using Ecotough**™** filament material. The silicone skin was made using the two-part Ecoflex**™** 00-20 FAST, mixed with Silc-Pig**™** colouring for pigmentation. The assembly was done in a three-steps: 1) a layer of silicone was poured to cover half the volume of the mold and left to cure; 2) then a layer of mesh was placed on the cured silicone, followed by a second layer of silicone poured on top; 3) finally, the simulator was left at room temperature to cure in the mold for 60 minutes before it was removed. Both the 3D printed mold and the silicone skin suture task trainer were designed and manufactured in the Ontario Tech University, maxSIMhealth laboratory

Data collection setup: Each participant was provided with a needle driver, suturing scissors, sutures (4-0), surgical tape, anesthetic (lidocaine), skin forceps, latex gloves, 18-gauge needle, syringe, (right), as well as the suturing simulator (left).

Figure 1. Experimental set up that was used for data collection. Left panel: Tools provided to the participants during the workshop; right panel: skin suture simulator

Procedure: Before each skill development session, all participants were asked to complete a consent form and were provided time to raise any questions or concerns about the study. Each participant then completed a 90-minute suturing stimulation station during the conference workshop, where they received approximately 10 minutes of instruction from a physician educator followed by time to practice their suturing technique independently. The two physician educators circulated during this time and were available for additional assistance if the students required it. The educators were instructed to provide minimal feedback in order to simulate independent practice. The last 5 minutes of the session were designated for participants to complete workshop evaluation forms.

3. DATA COLLECTION INSTRUMENT AND ANALYSES

Quantitative data: At the end of the two-hour workshop, all participants were asked to fill out workshop evaluation forms. In addition to standard educational quality improvement evaluation forms collected routinely by SRPC (which were not used for this study) a short survey questionnaire that evaluated the simulator was distributed to participants. The survey, following a modified version of the Michigan Standard Simulation Experience Scale (MiSSES) template, was used to assess the fidelity, functionality, and the teaching quality of the simulator (Seagull & Rooney, 2014). There were three main sections to the survey: (1) self-efficacy; (2) realism and; (3) educational value and overall rating. In total, there were nine, 5-point Likert scale questions. The survey was developed as a Google Forms, but a printed version was provided to the participants.

Qualitative data: The survey also included five open-ended prompting questions designed to elicit qualitative responses from participants: (1) Please comment on how the simulator may improve your self-efficacy; (2) Please comment on how the simulator's realism could be improved; (3) Please suggest any changes you would make to the simulator; (4) Please suggest specific ways to improve your learning experience; (5) Provide alternative simulators that you may have used to train this skill in the past, and how does it compare to the current simulator. These comments were transferred verbatim into a single Google Sheet document for analysis.

To enhance the rigor of the thematic analysis, two researchers were involved in the coding process. Each researcher independently read through every comment, identifying and developing initial coding themes. Following this initial coding phase, the researchers engaged in a collaborative session during which they compared their independently generated themes. Through an hour-long online discussion, the researchers aligned their coding themes, identifying overarching themes that were common across the comments (Braun & Clarke, 2006).

Subsequently, each researcher independently reviewed all the comments using the newly established codebook based on the agreed-upon themes. The thematic analysis was conducted using Google Sheets, providing a structured and collaborative platform for organizing and synthesizing the data. In the final step of the analysis, the agreed-upon themes were synthesized, and supporting comments were selected to illustrate each theme.

4. RESULTS

Quantitative data: The survey data were considered ordinal data and are presented as mean and standard deviations (SDs) for each question (Jamieson, 2004; Norman, 2010). This was chosen as our participant numbers were low and the objective of the analysis was to inform the design rather than to provide evidence of validity. The results from the survey are broken down into quantitative data and qualitative data.

The results for the quantitative data (Figure 2) indicate that the simulator has the potential to develop competence (4.2 out of 5) and confidence (4.1 out of 5), and the participants expressed that they would be able to practice the suturing skills independently with this simulator (4.3 out of 5). The realism of the simulator appeared to be its weakest point in terms of the overall anatomical correctness (3.6 out of 5) and accuracy (3.4 out of 5), while the durability was scored high (4 out of 5). Finally, the participants perceived the simulator to be easy to use (4.4 out of 5), and well suited for independent development of both cognitive (4.4 out of 5) and psychomotor skills (4.2 out of 5) related to suturing and knot typing.

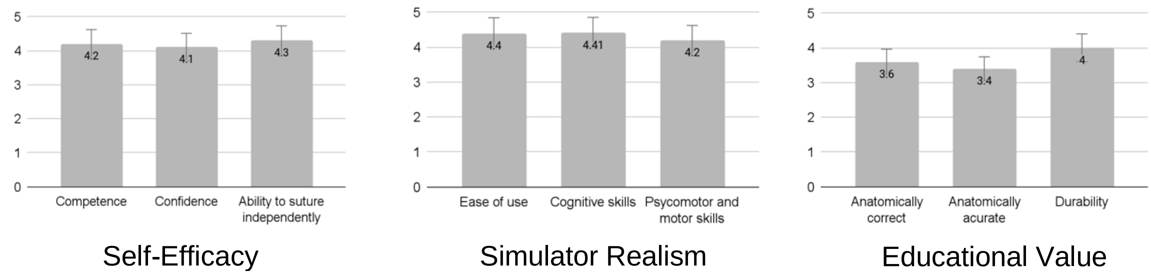

Figure 2. Averages and standard deviations were obtained from the surveys on the 5-point Likert scale in the areas of self-efficacy, the simulator's realism, and the educational value of the simulator

Qualitative data: The participants provided a total of 21 short-answer comments, evenly distributed among the four prompting questions. Through an hour-long online discussion, the researchers aligned their coding themes, identifying four overarching themes that were common across the comments. These were:

Simulator Realism: One of the comments suggested uncertainty about the simulator's superiority over other training methods. Issues like flatness, lack of mimicry of skin layers, and the need for increased tensile strength in plastic suggests a focus on making the simulator more realistic to enhance training. "The simulator worked but not sure it would have been better than other ways" (Participant 3).

Material Properties: Comments about the simulator being too rubbery, the need for layers, and the influence of glue in silicone highlight the importance of the materials used in the simulator. Improving these properties could contribute to a more authentic training experience. Furthermore, a number of participants described issues with the thread ripping through the silicone too easily which suggests that more attention needs to be paid to the interaction between medical tools and the simulator. "Still quite rubbery. Does not mimic the layers of skin well." (Participant 8). "Thread ripped threw the simulator too easily and gripped the needle/ thread too strongly" (Participant 10).

Cost and Alternatives: Comparisons between pig skin, foam, plastic models, and orange peel highlight considerations of cost, fidelity, and ethical concerns (as in the case of using animals). That is, although the simulator was developed to be a cost-effective ($5.00 USD) alternative, non-standardized simulators such as animal and plant-based ones were perceived as cheaper yet effective simulators that can be used in low-stakes De-SBE training. "Orange was better. Pig skin is more pliable" (Participant 10).

Skill Level and Background Knowledge: The need to clarify the skill level or background knowledge required for advanced levels suggests consideration for tailoring the simulator to different proficiency levels in surgical training. “Clarify skill level/ideal background knowledge needed to do advance level” (Participant 8).

5. DISCUSSION

This idea of using online LMS technology geared toward mobile learning, such as the one described here and referred to as De-SBE, for health professions training in psychomotor, and clinical skills was tested in the past (Habti et al., 2021). However, this mobile learning model was tested in a major urban center and with a group of highly specialized trainees. Specifically, the participants, senior surgical trainees, learned a hand-sewn bowel anastomosis procedure, using a custom-designed online, LMS with the results indicating that the surgical residents liked this training platform and found that it helped improve their understanding of the technique (Habti et al., 2021). Because the De-SBE paradigm requires both a dedicated LMS to provide information, guidance, and feedback (Dubrowski et al., 2021), as well as cost-effective simulators accessible to the learners where they are. This ensures they are suitable for deployment in rural and remote contexts and used for generalists training. The principle of mobile learning, and the multidimensional aspects of education, present ample opportunity for the integration of simulators through the learning management system. The current project tested the acceptability and feasibility of such simulators, as well as sought end-point users’ feedback on how the simulator could be improved to deliver the desired learning outcomes.

The rural and remote learners expressed high self-efficacy scores after practicing the suturing skills on the simulator. In the realm of learning clinical skills through cost-effective simulators in the context of mobile learning, a high self-efficacy score indicates individuals' confidence in their capacity to adeptly acquire and apply these skills in real life situations on patients. Self-efficacy, as defined in psychology, encapsulates an individual's belief in their competence to execute such skills (Micallef et al., 2023). These results suggest that the simulator was deemed both an acceptable and feasible option, affording the individual learners the opportunity to hone in on their skills in a controlled environment. Additionally, because of the lightway construction and highly reduced costs of manufacturing, the simulator provided a more cost-effective alternative to purchasing these simulators from industry, and/ or traveling to an urban simulation center, i.e. Ce-SBE model, for training (Siraj et al., 2021). When considering mobile learning for rural and remote health care provider’s training, the flexibility and accessibility of our solution highlights the potential impact on skill development, without the need to travel and leaving patients unattended (Doucet et al., 2017).

Furthermore, the simulator received very high scores (4.2 out of 5) on the educational value it carried. In the realm of contemporary health professionals’ education, especially in the context of rural and remote training, a high score on the educational value of a simulator signifies a recognition among learners of the simulator's effectiveness as a pedagogical instrument (Micallef et al., 2023). This recognition extends beyond the mere utilization of simulation technology, encompassing its potential to enhance the learning experience and foster skill acquisition. The amalgamation of clinical skill acquisition and cost-effective simulators, coupled with online learning technologies underscores the dynamic evolution of health professionals' education methodologies. The positive relationship between a high educational value score and the integration of mobile learning suggests that learners acknowledge the transformative impact of ubiquitous access to educational resources. This alignment reflects a paradigm shift in health professionals' education, where learners increasingly recognize the versatility and convenience of mobile learning in conjunction with hands-on simulation experiences (Guérard-Poirie et. al., 2023; Blouin et. al., 2023; Pelletier et. al., 2023). Future iterations of this simulator’s implementation, and data collection should consider a larger sample size.

Although the learners reported high self-efficacy and high educational value of the simulator, they also highlighted areas for improvement of the physical and anatomical features of the simulator. The feedback gathered revealed several areas for improvement, primarily centered around simulator realism. Participants expressed uncertainty regarding the simulator's superiority compared to other training methods, citing issues such as flatness, a lack of mimicry of skin layers, and a need for increased tensile strength in the plastic components. To enhance the training experience, there is a clear call for improvements in simulator realism, ensuring that it more accurately mirrors the complexities of human anatomy (Hamstra & Dubrowksi, 2005). One participant remarked, “The simulator worked, but not sure it would have been better than other ways", emphasizing the importance of addressing these concerns with realism to establish the simulator as a preferred and effective training tool.

Another critical aspect for refinement lies in the material properties of the simulator. Participants noted that the simulator felt too rubbery, lacked layers, and exhibited issues with the thread ripping through the silicone too easily. These comments underscore the significance of selecting and refining materials to create a more authentic training experience (Habti et al., 2021). Attention to detail in the interaction between medical tools and the simulator has also been identified as a critical, necessitating adjustments to material properties to better simulate the tactile and structural aspects of real tissue. Furthermore, considerations around cost-effectiveness and alternatives emerged, with participants comparing the simulator to various materials such as pig skin, foam, plastic models, and even orange peels. While the simulator was designed to be cost-effective the participants perceived alternatives, such as animal and plant-based simulators, as potentially cheaper and effective options for low-stakes training. Balancing cost, fidelity, and ethical concerns becomes paramount in refining the simulator's design to meet the diverse needs of surgical training (Siraj et al., 2021). Lastly, participants highlighted the importance of clarifying the skill level or background knowledge required for advanced levels of training, emphasizing the need to tailor the simulator to different proficiency levels in surgical training to maximize its educational impact.

In conclusion, the suturing simulator was considered a functional and cost-effective simulator with a cost of approximately $5.00 USD. This is because it was designed and produced following a design-to-cost approach, meaning cost was the most important constraint taken into consideration throughout the process (Siraj et al., 2021). Because of the cost-effective nature of the simulator, and its overall acceptability as a training tool, this simulator is ideal for use in the De-SBE context, especially when combined with a dedicated LMS (Wahab & Dubrowski, 2022).

6. CONCLUSION

This paper described the acceptability and feasibility of a simulator designed to complement an online learning management system to provide hands-on learning of clinical skills within the mobile learning paradigm. The simulator was an acceptable and feasible learning tool, as evidenced by high self-efficacy and educational value scores. However, the participants also expressed concerns about the realism of the simulator, suggesting a hybrid design approach, which places equal attention on costs and realism.

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