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Development of a cardiopulmonary resuscitation prototype for health education

Desenvolvimento de protótipo de reanimação cardiopulmonar para educação em saúde

Desarrollo de un prototipo de reanimación cardiopulmonar para la educación en salud

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ABSTRACT

Objective: to develop and validate a low-cost prototype for cardiopulmonary resuscitation in adults, with an emphasis on arterial and venous flows, for educational purposes. **Method:** this study, which originated from a course conclusion project to develop a prototype using the design-thinking approach, was conducted at a federal public university in southern Brazil between September and November 2019. Thirteen individuals with expertise in emergency care took part in validation, using a Likert scale instrument consisting of seven items on appearance and usability. **Results:** the prototype was designed using a clothing display mannequin as the main structure. Compressions could be performed on the chest, and a network of ducts simulated blood flows visually, demonstrating blood circulation and intravenous medication injections. **Conclusion:** the prototype was able to enhance teaching and learning on basic and advanced life support, especially when supported by active methodologies.
Descriptors: Health Education; Resuscitation; Simulation Training; Cardiopulmonary Simulation; Blood Circulation.

RESUMO

Objetivo: desenvolver e validar um protótipo de baixo custo para reanimação cardiopulmonar em adultos, com ênfase nos fluxos arteriais e venosos para fins educacionais. **Método:** trata-se de estudo oriundo de trabalho de conclusão de curso, utilizando abordagem do *design thinking* para elaboração do protótipo, realizado em uma universidade pública federal no sul do Brasil, entre setembro e novembro de 2019. Na validação, participaram 13 indivíduos com expertise em Urgência e Emergência, sendo utilizado um instrumento com escala *Likert*, composto por sete itens sobre aparência e usabilidade. **Resultados:** o protótipo foi idealizado usando um manequim de exposição de roupas como estrutura principal. Além do tórax permitir compressões, uma rede de ductos que simulam os fluxos sanguíneos demonstrou visualmente a circulação sanguínea e a injeção de medicações intravenosas. **Conclusão:** o protótipo possui capacidade de potencializar o processo de ensino-aprendizagem em suporte básico e avançado de vida, especialmente quando sustentado por metodologias ativas.
Descritores: Educação em Saúde; Simulação; Treinamento por Simulação; Reanimação Cardiopulmonar; Circulação Sanguínea.

RESUMEN

Objetivo: desarrollar y validar un prototipo de bajo costo para reanimación cardiopulmonar en adultos, con énfasis en los flujos arteriales y venosos, con fines educativos. **Método:** este estudio, que se originó a partir de un proyecto de conclusión de curso para desarrollar un prototipo utilizando el enfoque de pensamiento de diseño, se realizó en una universidad pública federal en el sur de Brasil entre septiembre y noviembre de 2019. En la validación participaron trece personas con experiencia en atención de emergencias , utilizando un instrumento de escala Likert que consta de siete ítems sobre apariencia y usabilidad. **Resultados:** el prototipo se diseñó utilizando un maniquí de exhibición de ropa como estructura principal. Se podían realizar compresiones en el pecho y una red de conductos simulaba visualmente los flujos sanguíneos, lo que demostraba la circulación sanguínea y las inyecciones de medicación intravenosa. **Conclusión:** el prototipo fue capaz de mejorar la enseñanza y el aprendizaje sobre soporte vital básico y avanzado, especialmente cuando fue apoyado por metodologías activas.
Descriptores: Educación en Salud; Simulación; Entrenamiento Simulado; Reanimación Cardiopulmonar; Circulación Sanguínea.

INTRODUCTION

Cardiopulmonary arrest (CPA) is a serious condition, often fatal, and patient survival is related to prompt and qualified care[1]. Considered a priority emergency, immediate actions must be taken to prevent the progression of hypoxic-ischemic injuries that cause irreversible harms after a few minutes. It is identified by the absence of palpable central pulse, responsiveness and respiratory movements[2].

Cardiopulmonary resuscitation (CPR) is the primary technique for patients in CPA, by adopting measures to maintain cerebral and myocardial perfusion while cardiac and pulmonary functions are not established, by performing deep and rapid chest compressions, which simulate heart function, as well as ventilations, when performed by trained first-aiders and/or health professionals[3].

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Proper care in CPA directly influences patient prognosis[4]. Basic knowledge of cardiopulmonary resuscitation increases the chances of survival; however, the deficit in the training of professionals and the lack of continuous training for professionals who work in direct assistance undermine the execution of both basic and advanced life support[5]. An alternative to overcome these difficulties include updates and training, in which clinical simulation and the use of simulators are excellent tools[6].

In undergraduate courses in Nursing or Medicine, the CPR approach usually occurs through theoretical classes and simulations, with little retention of knowledge and skills. These skills acquired after training can deteriorate in a short period of time (three to six months), if not practiced[7]. The need for repetitions and the high cost of the simulations carried out in laboratories impel the search for alternatives that enhance this learning through reproducible, economical and reusable mannequins[8].

Strategies that assist in the teaching-learning process of health professionals and students about chest compressions and medication administration during CPR can impact on the quality of learning. A study demonstrates that easy-to-access, low-cost training models can significantly contribute to this or other realities[8].

In this context, the development of a prototype that allows for the visualization of arterial and venous flows during cardiac compressions in CPR is a strategy that will enable the correlation with human anatomy by means of synthetic materials, with the potential to facilitate learning. In addition, it is questioned: How should a low-cost prototype be structured for educational purposes of cardiopulmonary resuscitation in adults? The aim of this study was to develop and validate a low-cost prototype for cardiopulmonary resuscitation in adults, with an emphasis on arterial and venous flows for educational purposes.

METHOD

This is an applied research study with the purpose of solving a specific and practical problem using a qualitative and quantitative methodological design. The study was developed in a federal public university in the South of Brazil, between September and November 2019. It is noteworthy that there are many methods employed in the design for problem solving; however, the one used in this research was based on two authors[9,10] and duly adapted for the development of a health technology, guided by the stages of *Design Thinking* for the reality of nurses who work as designers and problem solvers.

Design Thinking is a methodology used to conduct research studies in the area of education and health, aiming at the design of solutions centered on those who are directly involved with the teaching-learning process[9]. To develop the product of this study, a specific model[10] was adapted by the authors, composed of six stages: 1) Sense Intent; 2) Know the Context; 3) Know the People; 4) Insights; 5) Explore Concepts; and 6) Solutions. Considering the relevance of all the stages for the development of the prototype, this study placed greater emphasis on the description of stages 3, 5 and 6.

At first, the *Sense Intent* stage consisted of a preliminary immersion in order to assist in the identification of potential innovation opportunities and to direct research towards exploration on the theme, using in this first stage the following tools: key facts and patent search.

The *Know the Context* stage comprised a deep immersion in which a full search was carried out, based on a data survey carried out by means of a literature review with respect to themes related to the study object.

The *Know the People* stage included collecting information on the theme with the participants of this stage: teachers and students from an undergraduate course in Nursing and students from a *stricto sensu* postgraduate course in Nursing of a university in the South of Brazil. The inclusion criteria were defined as follows: one year or more of employment with the Nursing department of the educational institution, in addition to having knowledge/experience in the emergency area and/or Intensive Care Unit (ICU) in the case of the teachers. As for the Nursing undergraduate students, they included having completed the core subject related to the ICU and emergency, in addition to having an affinity with the theme, participating in research laboratories or academic leagues. For graduate students, likewise, they included being linked to the institution by enrolling in a master's/doctorate course in Nursing and having knowledge/experience related to emergency and ICU.

The initial approach to the participants took place through direct contact or email. The meeting was scheduled in order to present the research, sign the Free and Informed Consent Form (FICF) and conduct the interview, with a mean duration of fifteen minutes each. The script of the semi-structured interview contained three questions related to CPA, aiming to identify relevant elements to address this theme using a low-cost

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prototype, actions and skills that could be developed, and tools that could contribute to carry out health education with a low-cost prototype.

The interviews were recorded in digital media and transcribed in full; and the data were analyzed according to content analysis[11], exploring the content with investigative techniques. It is noted that data organization occurred by frequency of appearance and groupings by similarity of ideas. They were analyzed and explored for feasibility and relevance for practical implementation. Thus, the analysis process gave rise to four categories: Visual, Similarity with the human anatomy and physiology, Feedback devices and Manipulating the prototype. In the *Insights* stage, the data obtained from the different sources of information, that is, literature review, patents and interviews, were integrated. This stage was an opportunity to understand the expectations and needs of a low-cost prototype to carry out education in cardiopulmonary resuscitation, with subjective questions which enabled answers that brought a series of ideas. All the ideas were analyzed and explored for feasibility and relevance for implementation.

As for the *Explore the Concepts* stage, the relevant ideas were surveyed, aiming at solving the problems that were previously identified. Many alternatives were envisioned, some were considered for this moment and others were documented for potential future approaches.

The *Solution* stage referred to the creation of options based on the concepts generated that fit the context and meet people's needs, that is, to start the elaboration of the prototype and, from the difficulties, create solutions[10]. In this part of project development, the needs for improvement and/or adaptations were observed, aiming at achieving satisfactory functionality for the final product. For being a prototype developed with low costs and handcrafted, it is understood that one or more adjustments are still necessary; thus, this stage was essential for the sequence and success of the project.

Several difficulties were encountered during the creation of the product, the main one being the need to identify a glue that would properly fix the connections of the duct system. At this point, it was crucial to use the method[9] and create options, solving the problem. Finally, after the prototype was developed, its evaluation and validation was carried out by 13 individuals, using a *Likert*-type scale consisting of seven items with five options: strongly agree, agree, partially agree, disagree and don't know. It also allowed for additional observations in a specific space for adding comments and/or suggestions, being self-administered, prepared by the authors of the study.

This research is the product of a course conclusion paper (CCP), in which it followed the legal parameters set forth by Resolution No. 466/12 of the National Health Council, being approved by the Research Ethics Committee (*Comitê de Ética em Pesquisa*, CEP) under CAAE registration: 09096019.0.0000.0121. The participants were identified by the letters P for teachers (“*Professores*” in Portuguese), M for MS students and A for students (“*Acadêmicos*” in Portuguese), followed by the number that represents the sequential order of the interviews.

RESULTS

Thirteen individuals participated in the evaluation and validation of the prototype, including three nurse professors, three MS students at the Graduate course in Nursing, and seven undergraduate Nursing students.

From the data obtained through the *Design Thinking* method, a first concept was devised, which underwent a secondary modification, resulting from a deepening of the needs and motivations expressed by the participants, described in Figure 1. Thus, the statements were categorized and synthesized in the light of the method.

A fiberglass mannequin was used as a matrix for development, which made it possible to carry out structural adaptations. For this, a cut was made in the thoracic region and four adapted springs were inserted, fixed between two boards and screwed with the aid of aluminum tape. For a better adaptation of the wood, the cut part of the chest required filling with expansive foam, which helped in fixing.

After this stage, systems that simulated human-blood flow were made. Priority was given to the use of devices easily found in the daily lives of professionals and students, such as: IV/parenteral nutrition equipment, cannulas, and multi-way equipment, among others. Adding the system to the mannequin, it was noticed that the internal pressure after liquid injection with flow was higher than that which could be supported by the circuit itself. This problem was solved after successive tests with several commercial fasteners.

The blood circuit was arranged in an attempt to meet the priority flows in CPR. Essentially, the flows of the carotid arteries and jugular veins were reproduced, as it is through them that cerebral perfusion and venous return occur. The circuit of vessels consisted of four simple IV equipment (one of enteral nutrition `[blue]), eight cannulas, two devices for transferring solutions, and a tube of glue.

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Category	Participants' comments
Visual	In consensus, the participants reported the importance of using a playful and visual approach in the development of the prototype. They expressed the importance of visualizing the flows during the compressions and that this mechanism enhances the understanding of the process and provides greater safety for performance in the face of cardiopulmonary arrest situations (P1, P3, M2 and M3). They raised the possibility of using lights and colors (P1, P3, M1, A5 and A7). It was also suggested to develop a fully transparent mannequin to allow for a better visualization of the flows during the cardiac compressions (A3). Finally, P3 and A2 suggested the use of transparent materials that are used in the daily lives of health professionals, such as a Levine tube or IV equipment, among others.
Similarity with the human anatomy and physiology	They recommended the proximity to human anatomy and physiology, claiming that this aspect enhances the learning process (P1, P2, M1, M3, A2 and A7). P1, on the other hand, revealed the need for the prototype to present resistance and depth similar to those practiced in a real cardiopulmonary arrest victim. P2 points to the possibility of using 3D printing to bring it even closer to human anatomy.
Feedback devices	Feedback devices (technological support) were seen by the participants as important accessories to assist in the teaching process, especially devices with music that, according to M1 and A3, contribute to train the rhythm and depth of the compressions. P1, P2, M1, M3, A1, A3, A5, A6 and A7 suggested the use of audible devices as an option; M1 also suggested the use of a digital device, such as a stopwatch or some other audible device. A1 and A6 pointed to the possibility of using digital monitors to bring the visual closer to the sound, thus enhancing the teaching process.
Manipulating the prototype	P1, P3, M2, M3, A3 and A7 mentioned that allowing the manipulation of the prototype is extremely important. P1, P2, P3, M3 and A2 proposed the use of materials that allow for the real administration of the medication, as they observed a gap in the theoretical approach in this medication issue. P3 inferred that the theoretical content is currently taught separately from the practice, and that a device offering the manipulation and the real administration of the medication relating the theoretical and practical aspects would be very relevant. Finally, P1 and M1 mentioned that it is essential that the device allows compressions at a depth of 5 cm to 6 cm, as recommended in the literature.

FIGURE 1: Syntactic description of the statements collected and organized in categories. Florianópolis, SC, Brazil, 2019.

After the definition and fixation of the vascular circuit, it was adapted to a propulsion pump for injection of fluids. Soon after, some devices were selected and tested; however, what best suited the mechanism was a blood-pressure measurement device, as shown in Figure 2. The pump was inserted between the springs and the cuff was placed around a vial of saline solution modified with food coloring. Therefore, in order to relate theoretical and practical knowledge, the instrument needed that the compressions were effective, reaching a depth of five to six centimeters, and that they allowed total thorax return as well. Only at this depth did the woods compress the pump, creating pressure on the IV and, consequently, the activation of the liquid circuit.

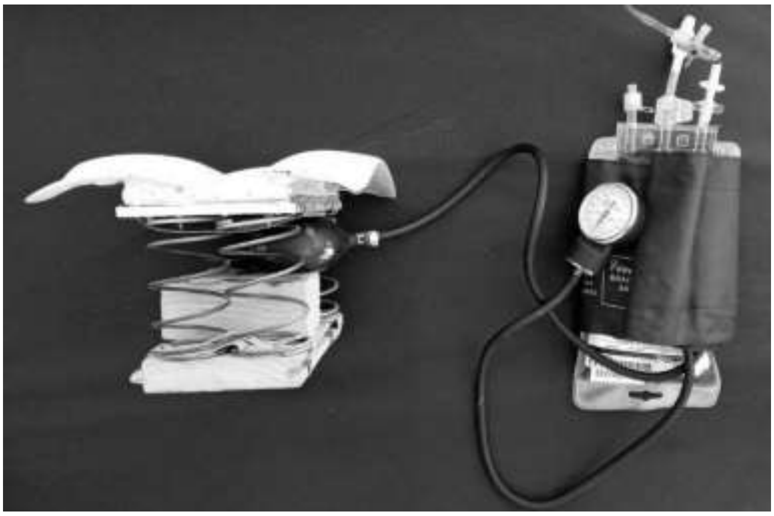

FIGURE 2: Adaptation of the pump and liquid system. Florianópolis, SC, Brazil, 2019

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Then, a mechanism was inserted to allow for the visualization and administration of medications, the performance of flushing (administration, under positive pressure, of saline solution [0.9%] immediately after the end of medication infusion) and elevation of the upper limbs. To achieve this goal, the same perspective used for brain flows was adopted, using materials from everyday practice. Adapted to the flow network of the right limb, an IV equipment with a side injector was connected, which made it possible to administer the medications. The left upper limb, on the other hand, was connected to the propulsion system, a fact that allowed visualizing the progression of the fluid by generating perfusion pressure. Finally, the low-cost prototype was idealized, according to Figure 3.

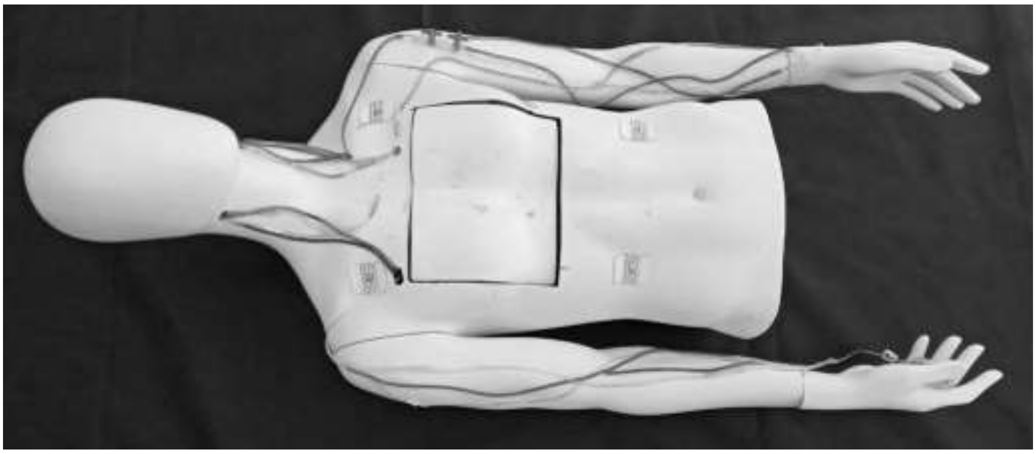

FIGURE 3: Final representation of the low-cost mannequin. Florianópolis, SC, Brazil, 2019

Finally, fulfilling all stages of the methodological framework adopted, the prototype validation process took place during the months of September and October, at the university premises where the research was carried out and in external environments by suggestions from the participants. The evaluators who met the inclusion criteria of the study were part of all the stages. Validation was carried out by means of a structured questionnaire with objective questions and with a specific space for adding comments and/or suggestions.

The final test had a positive validation, as the evaluators unanimously marked the questionnaire with the option "strongly agree" in relation to the prototype created. They stated that the product made it possible to demonstrate the reasons why compression interruptions should be minimized, performing them at the appropriate depth, in addition to making it possible to correlate the practice with the importance of perfusion pressure and the effectiveness of chest compressions.

The cost distribution of the prototype can be classified in the price of the raw materials, in the fiberglass mannequin, and in the IV equipment and glue. The raw material is inexpensive and is promptly available in many countries. In addition, the fiberglass mold is simple and inexpensive. Finally, the manufacture of the prototype is not complicated; it does not require much technical knowledge or technologically advanced equipment and/or facilities. In addition, the technology needed to produce this mannequin can be easily transferred to small- and medium-sized companies. In the study scenario, the cost of the low-cost CPR prototype was around USD 60. In this regard, the cost of the commercial product used for comparison in this study was nearly USD 400.

DISCUSSION

The high cost of the simulators for training and qualification of students and professionals is still the main limitation of their use by health institutions and universities[12]. The use of low-cost simulators facilitates learning, mainly because they have high functional anatomical fidelity[13].

Clinical simulation using a mannequin as a teaching tool is another alternative to stimulate clinical reasoning and is proving to be very important in this context, making it possible to correlate theory and practice, as the students develop skills and acquire knowledge. Furthermore, teaching in this modality sharpens the psychomotor development of those involved in the process. Thus, the predominant inclusion of only one type of teaching modality can be inadequate in professional training[14,15].

In this study, a low-cost CPR mannequin with a simple design was developed. It provides real-time feedback responses by visualizing the progression of fluids in the flow network when the student performs chest compressions at the correct depth. The flow network, connected to the propulsion system, allows visualizing the progression of the fluid by generating perfusion pressure, a simple design that substantially reduces the manufacturing cost.

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Thus, corroborating with this study, an Irish research study showed similar results. After the creation of a child mannequin for BLS training, the researchers noticed a significant improvement in the initial care for the victim, correct proportion of chest compressions and depth, adequate respiratory rate, and prompt medical support. This low-cost intervention has the potential for wide application in developed and developing countries[16-18].

Electronic devices were not used in the development process because of its low-cost concept, so there were limitations in this regard. A Brazilian study aimed at creating a digital educational instruction application for advanced cardiovascular life support corroborates this perspective by demonstrating that diverse forms of technologies can contribute to improving teaching/learning, helping to fill gaps in the assessment and management of cardiac arrest and strokes. The use of technology would certainly be another alternative and would increase the cost of the prototype; for this reason, the researchers understand that technological tools can be used later, but would require new partnerships[19].

The CPR intervention was possible thanks to the low cost of the mannequin and the availability of a small amount of time from the instructors in the validation process; thus, it is possible to infer that the efficient use of the teaching staff is especially important in educational environments, even if the training opportunities are limited in time. In addition, the students' learning needs, such as communication skills and error correction, can be addressed individually with immediate feedback on their performance[17,19-21]. For regular training at universities, often seen as prohibitively expensive due to the use of high-fidelity simulators, the intervention described can be conducted by educators motivated to improve the quality of teaching.

The results of the validation were positive and the evaluators' suggestions added greater quality to the low-cost prototype, strengthening its importance and providing more specific information related to CPR, a relevant topic, in which it is sought to improve the quality of care for patients in cardiopulmonary arrest. The relevance of the evaluation by the target audience about the quality and sufficiency of the content of the educational technologies in health is fundamental[22] since, regardless of the tool to be used, validation allows verifying the relevance and effectiveness of the technology.

Understanding the limitations and potential of the prototype is of paramount importance for nurses who are designers, entrepreneurs and educators. Alternatives for education in health will always be necessary, given the dynamism of the updates in the protocols and recommendations.

CONCLUSION

The study addresses the development and validation of a low-cost prototype for cardiopulmonary resuscitation in adults, including the initial stages of ideation, development and validation of the product, with an emphasis on arterial and venous flows for educational purposes.

It is considered that the prototype worked as planned, allowing to visualize the importance of the perfusion pressure, the appropriate depth, and the effectiveness of chest compressions. It was positively evaluated as a teaching tool, favoring the understanding of the importance of performing effective compressions, minimizing interruptions and flushing after the administration of each medication. It is believed that, based on this low-cost prototype, this concept can be expanded to other training sites, such as health services and technical and higher education institutions, due to its low-cost approach.

The fact that there are no feedback devices for the student, requiring teacher supervision to guide and provide instructions, is pointed out as a limitation of the study. In addition, the product allows for the visualization of the relationship between depth and compression, but does not allow for massive training of compressions. It is hoped that the product developed can be replicated with the aid of the method used and that it will be an important tool for training and qualification not only for students and professionals, but also for the community, expanding the knowledge acquired from the prototype. A comparative study with a standard training mannequin is suggested, observing the application of depth and compression.

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