Augment, Instruct, Execute, and Verify: Augmented Reality Wound Care Training with 3D Printed Props

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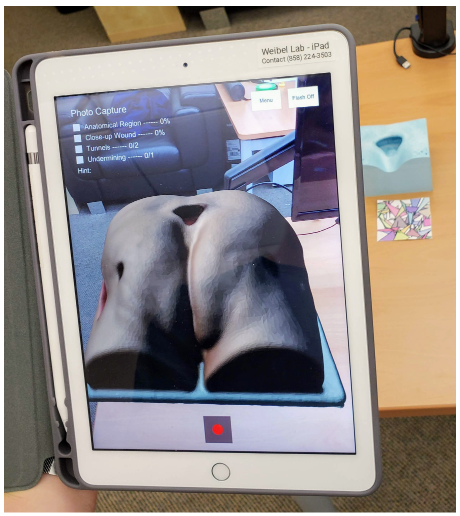

Figure 1: *Augment*: AR provides additional visual information to the 3D printed block on the table, showing the rest of the body that is not physically available

KEYWORDS
Augmented Reality, 3D Printing, Wound Care, Clinical Training, Augment Instruct Execute and Verify

ABSTRACT
Chronic Wounds do not heal in a predictable amount of time the way most wounds do. The healing process may require elaborate interventions as well as an understanding of the different factors preventing recovery. Nurses, the ones at the front-line of care, are however not always equipped with the resources to properly handle these complex types of wounds, and while specializations exist, most

WISH'19 Original Research Paper, CHI 2019 Conference on Human Factors in Computing Systems May 4–9, 2019, Glasgow, Scotland UK,

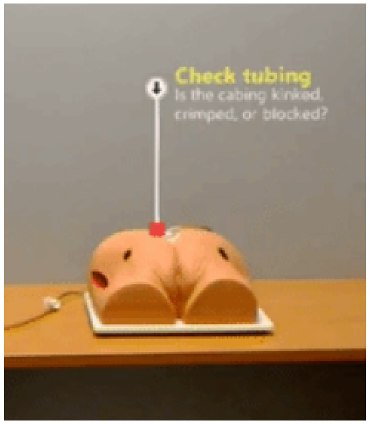

Figure 2: *Instruct*: Example of the Instruct step: guiding the user to check a specific part of the plastic model for blockages.

Figure 3: *Execute*: Example of the Execute step: here, the user puts the tablet on the side and *executes* the instructions given in the previous step (e.g., gathering material to apply to the wound)

nurses only have basic wound care training. Continuing Medical Education programs are structured to serve these nurses, but current approaches for hands-on teaching of wound care are limited to a few scenarios and static plastic models. In this paper, we explore a combination of Augmented Reality (AR) and 3D printing to enrich hands-on training. Through interviews with experts and nurses as well as prototyping sessions, we propose *Augment, Instruct, Execute, and Verify*, a workflow for interactive training through AR, and show its applications with two prototypes.

INTRODUCTION AND BACKGROUND

Treating patients with chronic wounds such as pressure ulcers, diabetic ulcers, and arterial and venous ulcers is an important part of inpatient, outpatient and home care. Wound care practice encompasses several responsibilities such as staging, dressings, infection control, promotion of therapeutic nutrition, mobility, hygiene, and comfort [1]. Healthcare costs for wound care are considerable and amount to an estimated £3 billion per year in the UK [9] and ranges from $28.1 to $96.8 billion in the US [8].

Nurses are at the forefront of wound care, and while they all receive basic wound care training during nursing school, wound care patients can require more elaborate interventions such as negative pressure therapy, oxygen therapy, and specialized dressings, all procedures that might not be part of standard nursing training. While specialized certifications exist, and show promising results in postgraduate training [10], these specialists represent a small portion of the professionals in a hospital. Typical Registered Nurses (RN) are not certified, and rely on continuing medical education events to improve their skills.

Continuing Medical Education (CME) activities are an alternative to specializations, accounting for several educational actvities that seek to bring clinicias up to date. Rounds, educational meetings, conferences, refresher courses, programs, seminars, lectures, workshops, and symposia are examples of the different formats available for CME [2] . While there is some evidence that interactive CMEs have a positive impact on a clinician's work [2], there are still gaps in how wound care training happens during CME events.

In this paper we approach the problem of wound care training from a human-centered perspective. We report on interviews with wound clinicians to understand the gaps in wound care training. We outline possible areas of improvement and address existing limitations through simulated scenarios that combine Augmented Reality (AR) and 3D Printing. Finally, we propose *Augment, Instruct, Execute, and Verify* as a viable workflow for training and testing nurses through AR.

RELATED WORK

Previous investigations on methods to promote learning chronic wound assessment found that AR not only improves student interest but also leads to greater performance in diagnosing parameters [5, 6]. Through the display of different wound parameters (e.g., depth, edges, necrotic tissue, infection, etc.)

Figure 4: Design workshop with wound specialist exposed to AR and 3D printed technology.

[1]http://gwep.cloud.ucsd.edu

on training models during simulated clinical cases, students using AR were able to diagnose cases more accurately than students looking at photos. These findings corroborate our hands-on workflow that leverages Augmented Reality to increase the visual fidelity of a case with the extended benefit of using it to instruct and check a student's progress on applying a treatment to a 3D printed model.

HUMAN-CENTERED DESIGN OF WOUND CARE TRAINING

In order to better understand current limitations and opportunities to improve wound care training, we engaged clinicians and experts in wound care in a range human-centered design activities [7] spanning expert interviews and technology probes. We then extracted what we learned into a new workflow dubbed *Augment, Instruct, Execute, Verify*, and we evaluated this workflow by implementing two prototypes that embody our proposed workflow.

In this section we report on the result of our interviews and technology probes (see Fig. 4), while the next section introduces our workflow and its initial implementation.

Expert Interviews

During the 2018 Geriatrics Workforce Enhancement Program[1] Annual Wound Care Workshop, we interviewed 9 clinicians who volunteered 15 to 30 minutes of their time: one plastic surgeon specialized in wound care (Expert), two primary care physicians (PCP), one Registered Nurse with Wound Care Certification (RN 1), four RN without Wound Care Certification (RN 2-5), and one Physician Assistant (PA) with a Master degree in geriatrics. While our work is informed also by the PA and PCPs views, in this paper we focus mostly on outlining nurses' needs and requirements. PCPs and PAs are not directly involved in the day-to-day wound healing process, but they have an important role on educating the patients and their family members.

Interviews Results — In general, nurses reported that they do not feel prepared for many aspects of wound care when in the field; they reported training in nursing school to be "rudimentary" and with "very minimal exposure to actual wounds"(RN 2). They also mentioned that education at work is limited, and sub-optimal, with instructions often delivered by more senior nurses who however do not always have a wound care specialization. When specialists are available, they usually do not have a lot of time to go into details with all nurses. In addition, nurses reported how "there is no rotation for wound care"(RN 3), so learning proper wound care during rotations is constrained to specific opportunities while shadowing a more experienced nurse who happen to be treating a wound patient. The inadequate training is compounded by the introduction of new therapies, that often add complexity to care, with new equipment usually requiring additional training that unfortunately does not usually get fulfilled. Finally, when standardized training models are available, they are limited to very basic scenarios without important details: nurses reported how these training are based on "Plastic type models (...) not live/detailed wound" (RN 4). In general, it seems that most of the wound

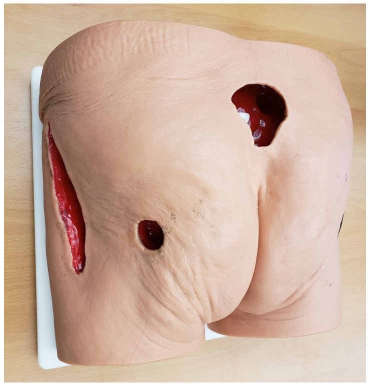

Figure 5: VATA's Seymour Wound Care Model™. Notice the three types of wounds available on the model.

Figure 6: 3D Printed Model reproducing a sacral wound

care work "is pushed off to the front-line staff, but they don't have the right training" (PA), with most of the learning happening on the spot, in other words: "Learn to swim or drawn" (PA).

Addressing current limitations with CME through novel technologies

As pointed out by nurses during interviews, current training models can only represent a limited type of wounds during very specific stages (Fig. 5). Chronic wounds are complex and slowly but always changing. They may present cellulitis, exudate, necrosis, rashes, bleeding, and internal structures such as bone and fat. These features can potentially lead to different treatments that are either impossible to cover with current models, or would require a large set of plastic models. Finally, the shape of a wound changes over time, thereby changing the way one would apply a dressing to it.

To understand how to potentially close this training gap, we engaged in year-long iterative brainstorming sessions with the domain experts described above, similarly as done in [4]. Specifically, we looked into the possible benefits of using novel technologies such as Augmented Reality (AR) and 3D printing as a way of creating interactive training programs that capture this inherent complexity to wound care training.

On the one hand, AR has been widely researched in medical education and simulation, and given that it is a technology that allows us to superimpose information on the world, it can be used to present virtual artifacts and simulate bleeding as well as show guidance to instruct someone on how to perform a task.

On the other hand, 3D Printing technology is an affordable and relatively fast way of producing customizable plastic models. It enables everyday people to turn digital 3D models into 3D physical objects. Combined with technologies such as 3D scanning, it allows fast and accurate reproduction of wounds at various stages (Fig. 6).

During our iterative brainstorming sessions with the domain experts we eventually reached the conclusion that by combining both technologies, we can represent dynamic and static features of a wound. AR affords a level of flexibility not present in current training models (e.g.: simulating spontaneous conditions such as bleeding or infection within the same model), while 3D printed models provide the haptics for preparing a dressing and can represent different shapes of a wound.

AUGMENT, INSTRUCT, EXECUTE, AND VERIFY

Building on the combination of 3D printing and AR, we developed a small number of prototypes with our experts, which allowed us to isolate a workflow that combines the use of plastic models for haptics and interaction with realistic augmentations as viewed through a tablet or a cellphone. In this section we describe and then implement our training workflow based on four components. The four components of our workflow are repeated for every sequence of instructions (i.e. when users need to go through a multi-step checklist).

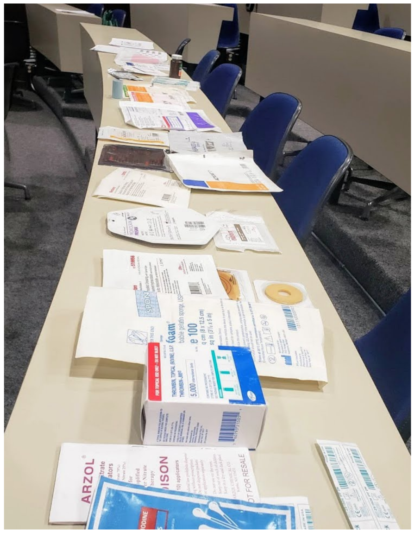

Figure 7: Display of a range of different dressings that can be applied during wound care and need specific instructions

(1) **Augment:** This is a critical part of the workflow. In this step, Augmented Reality visualizations achieved using a see-through interaction with a tablet or a cellphone (see Fig. 1) add context and animate a static 3D printed model, contextualizing the 3D-printed model within the current training scenario. AR affords more immersive and dynamic training situations, demonstrating time progression of wounds as well as wounds under different conditions (necrotic, tissue, inflammations, different types of bleeding, exudate, etc.).

(2) **Instruct:** Instructions are overlaid on the screen to guide the user to perform a specific task or action, or how to apply a specific dressing. The action does not need to be confined to interaction in AR with the tablet, and may include activities such as the gathering of specific dressings and equipment. Instructions can vary from visual augmentations showing the user where to go or look at [3], to text on the screen.

(3) **Execute:** This is the moment the user may have to put the tablet on the side to execute any instructions given in the previous component (Fig. 3).

(4) **Verify:** After executing any required steps, the user gets the tablet back and uses AR as a way of checking the work. The application may use marker tracking as well as more elaborate computer vision techniques to validate what the user did. For instance, if the task was to gather specific types of dressings (Fig. 7), the Verify step would locate them through the camera before completing the overall task or proceeding to the next step.

Workflow's Implementation

To demonstrate our workflow, we developed two prototypes that trains and tests users on two scenarios. The first prototype focuses on the ability to document a wound through pictures that capture important contextual information as well as fine detail. The second one focuses on the ability to recognize the presence of bleeding, necrosis, or exudate.

To build our prototypes, we used Unity3D[2] with ARKit[3], an Augmented Reality technology available on most iOS devices. While ARKit supports object tracking, it was not reliable enough to align virtual visualizations on wound blocks; thus, we resorted to Image Tracking to track markers placed near the wound block (Fig. 1).

Prototype 1: Training on how to properly document wounds— When photographing a wound, different pictures should capture the location of the wound (i.e., where does it stand with respect to the patient's body) as well as unique features of the wound, such as tunnels and undermining. By using Augmented Reality, our prototype is able to show these features with great detail through the tablet screen, and we can also use the tablet's position in space to infer the content of the pictures. Table 1 shows how this prototype's implementation fits with our Augment, Instruct, Execute, Verify workflow.

[2]https://unity3d.com

[3]https://developer.apple.com/arkit/

	Prototype 1 Workflow
Augment	Our prototype overlays a mesh that replicates a wound texture onto a 3D printed wound model. This allows for a highly realistic wound for the trainee to operate on
Instruct	Our prototype then guides the trainee on how to operate on said wound, in this case, to take photos of the wound from different angles
Execute	The trainee will be able to take pictures of the wound model with our prototype as part of the training
Verify	Our prototype will evaluate the results of the training process and provide the trainee with a rate that indicates the accuracy of their execution (taking pictures of the wound)

Table 1: Workflow for the 1st prototype

	Prototype 2 Workflow
Augment	Our prototype overlays a mesh that replicates a wound texture onto a 3D printed wound model. The texture varies for the same 3D printed model, showing a visual simulation of necrotic tissue, bleeding, or representing some exudate.
Instruct	Our prototype then guides the trainee on how to operate on said wound, in this case, to take photos of the wound from different angles
Execute	The trainee will be presented with multiple-choice style questions where they can identify the wound.
Verify	Our system acknowledges

Table 2: Workflow for the 2nd prototype

Prototype 2: Training on how to identify different artifacts on a wound— Part of the initial assessment of a wound is looking for bleeding, rashes, redness, exudate, foreign bodies, and other features. Through Augmented Reality, our second prototype can simulate some of these features by changing the texture used in the 3D visualization. This prototype focuses on showing a wound with signs of bleeding, necrosis, or exudate. Similar as with the previous prototype, Table 2 illustrates how our proposed workflow has been used to guide the design of this second prototype.

CONCLUSION AND FUTURE WORK

In this short paper, we introduce Augment, Instruct, Execute, and Verify: a workflow focused on using 3D printed props and Augmented Reality to enhance wound care training during Continuing Medical Education activities. The two prototypes show how the workflow adapts to scenarios where a student interacts with both the augmented reality content as well as the physical prop to develop a better understanding of the chronic wound model at hand.

We are working closely with medical experts and hospitals to generate content ranging from the application of basic wound dressing to more complex and challenging therapies such as Vacuum-Assisted Closure of a Wound. Finally, we plan on validating our efforts through deployments at wound training workshops.

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