Touch and Learn: A Gamified VR-Haptics Framework for Skillfull Palpation Training*

Baptiste Lesquerré-Caudebez[1,2] and Filippo Sanfilippo[1**][0000−0002−1437−8368]

[1] Department of Engineering Sciences, University of Agder, 4879 Grimstad, Norway
[2] Polytech Dijon, Bourgogne Franche Compté 21000, France

Abstract. Medical and nursing education plays a key role in preparing students for clinical challenges. To overcome equipment and resource limitations, researchers explore accessible methods like virtual reality (VR) and haptic feedback. This work presents a gamified palpation simulation—focused on deep and light palpation—integrated with a haptic glove (WEART G1) and an evaluation system. Built in Unity, the system enables users to feel virtual patient interactions while recording data for expert comparison. User testing and feedback support ongoing improvements to training effectiveness.

Keywords: Haptic feedback · Medical education · Virtual reality · Immersive education · Palpation.

1 Introduction

Training medical students in procedural techniques remains challenging due to limited access to equipment, simulators, and patients. While cadavers are standard in training, they involve preservation, cost, and availability issues [10]. These constraints highlight the need for accessible, realistic alternatives. Advances in virtual reality (VR) and haptics offer immersive simulation environments that address many traditional limitations.

Recent research explores VR with haptic feedback for replicating clinical tasks. This work focuses on palpation training using a WEART haptic glove, delivering force feedback to simulate varied resistance beneath a virtual abdomen. Users interact with multiple regions, and the system evaluates performance using finger position, orientation, and applied force compared to expert data, helping identify mistakes.

A core technical feature is the proxy-based haptic feedback model [1], where a constrained proxy point interacts with virtual surfaces. Force is computed from the proxy–user position gap, enabling realistic interaction with soft tissue. This method controls the glove's tactile output.

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[**] Corresponding author: Filippo Sanfilippo, filippo.sanfilippo@uia.no

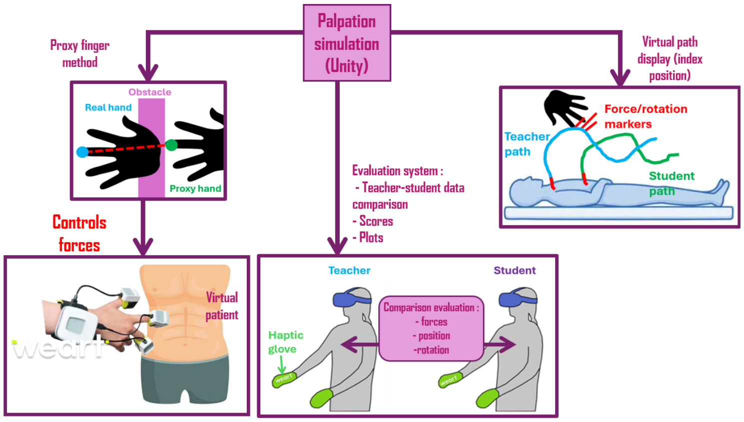


Fig. 1. The system combines a Unity-based simulation, WEART haptic glove, and performance evaluation. Users perform guided palpation tasks with force, position, and orientation data recorded for feedback.

Advances in haptic device design improve both force [11] and texture rendering [6]. For example, Gießer et al. [2] developed Skillslab+, an AR training tool using SenseGlove Nova for nursing education. It supports real-time hand tracking, task customisation, and feedback. The current system adopts a similar evaluation framework to guide user training.

Refining VR realism demands continuous improvement [9, 8]. Zhu et al. [12] developed a haptic interface combining soft materials, sensors, and AI for object recognition, enhancing tactile realism. Their insights inform future upgrades in personalised force rendering for palpation simulations.

Evaluating VR simulation quality requires standardised tools. Melo et al. [5] introduce a grading system for the IPQ to assess presence. Gao et al. [4] propose the CIQ for interaction quality, adaptable to specific use cases. Both are used in this study to assess realism, usability, and training effectiveness.

This work combines VR and haptics into a gamified palpation training system (overview in Figure 1), incorporating expert-aligned evaluation and validated user feedback tools.

The rest of this paper is structured as follows: Section 2 outlines the system architecture and haptic interaction method. Section 3 details the user study and analysis. Section 4 concludes the study.

2 Methodology

The present work builds upon a previously initiated prototype [7], extending and refining the system into a more comprehensive palpation simulation framework. This section details the methodologies employed for integrating haptic feedback, the design of the performance evaluation system, and the implementation of standardised questionnaires for user testing. The entire simulation was

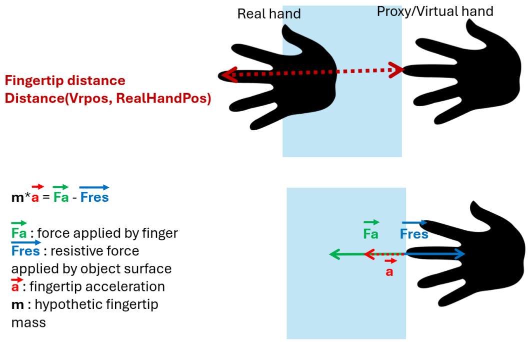


Fig. 2. Schematic representation of the second proxy finger method applied within the project, with velocity consideration.

developed using the Unity game engine, enabling seamless communication with the WEART G1 haptic glove and the Meta Quest 2 virtual reality headset. Integration of the Unity WEART SDK facilitated full utilisation and control of the haptic device's capabilities, supporting precise and programmable tactile feedback during the simulation.

2.1 Proxy-Based Haptic Feedback Integration

The proxy-based method proposed by Ruspini et al. [1] enables realistic haptic feedback by decoupling the user's real hand position from a virtual proxy that responds to collisions in the simulated environment. In this study, the approach is adapted for integration with the WEART glove in a virtual palpation training setup. Each hand has two representations: a **ghost** (real) hand that follows the user's physical motion and a **proxy** (virtual) hand that interacts with the environment. When the proxy touches a virtual object, it is constrained by the collider, while the ghost continues its motion. The proxy attempts to follow the ghost by sliding along the object's surface, simulating realistic contact behaviour.

The implementation uses the WEART Unity SDK, assigning both proxy and ghost components to each hand. On collision, the proxy stops while the ghost proceeds. The distance between corresponding fingertips is continuously measured, normalised between 0 and 1, and capped at 1 if it exceeds a defined threshold. These force values are then transmitted to the WEART glove to provide context-aware haptic feedback. All proxy and obstacle objects include colliders that trigger collision events and control the activation of the proxy mechanism, ensuring responsive and realistic tactile interaction in the simulation.

A modified proxy finger method integrates acceleration effects into the haptic force calculation, based on Newton's second law [1]. The finger's penetration velocity is used to scale the force feedback, increasing realism by reflecting motion dynamics—faster movements produce stronger forces, in line with $F = ma$.

Force components are computed separately for each axis (x, y, z) and combined into a single resultant force for rendering. Unlike the basic proxy method, this model accounts for both contact depth and movement speed, resulting in more physically accurate feedback. To avoid excessive force values, the virtual finger's mass is reduced during simulation.

Figure 2 illustrates this acceleration-based proxy model. The force from acceleration (F_a) still reflects the ghost–proxy distance, while the resistive force (F_{res}) incorporates acceleration using individual position components. For instance, the x-component is calculated as:

$$\begin{aligned}\text{XComponent} = {} & |\text{VRPos}_X - \text{RealHandPos}_X| \\ & + \text{MassFinger} \cdot \frac{|\text{RealHandPos}_X - \text{PreviousRealHandPos}_X|}{(\text{Time} - \text{PreviousTime})^2}\end{aligned} \tag{1}$$

The total force magnitude is then calculated by aggregating the x, y, and z components and normalising the result using a scaling factor:

$$\text{TotalForce} = \frac{\sqrt{\text{XComponent}^2 + \text{YComponent}^2 + \text{ZComponent}^2}}{\text{MaxScale}} \tag{2}$$

The variables are defined as follows:

- VRPos: Fingertip position vector (x, y, z) of the virtual (proxy) hand constrained by interactions with simulation objects.
- RealHandPos: Fingertip position vector (x, y, z) of the user's actual (ghost) hand, unaffected by virtual environment constraints.
- PreviousRealHandPos: Real hand position vector (x, y, z) from the previous time step.
- MassFinger: A constant approximating the mass of a human finger, used to calculate inertial force contributions.
- Time and PreviousTime: Time values at the current and previous simulation iterations, respectively.
- MaxScale: A normalisation factor representing the maximum tolerable force-producing distance between the proxy and real hands; used to bound the output force between 0 and 1.

2.2 Data Recording and Student Evaluation

To objectively assess student performance, the simulation compares recorded finger data—position, orientation, and force—with expert reference data from instructor sessions.

Building on a prior Unity-based project with a soft-body patient and UI, the system adds haptic feedback and defines nine abdominal *sub-interactions* for evaluation.

Interaction data are logged in `.txt` and `.json` formats, including *path data* and *sub-interaction data* based on collision events.

After each session, a validation script compares student and expert data using percentage-based scores. Metrics assess accuracy across position, orientation, and force, using configurable tolerances to adapt scoring sensitivity.

Position and Orientation Scoring For each sub-interaction, a percentage-based score is computed by comparing the student's finger positions (or orientations) to the instructor's reference position at maximum applied force. The scoring metric accounts for the Euclidean distance between the student and teacher values, normalised using a maximum allowable distance and adjusted by a tolerance offset:

$$\text{Pos\%} = \frac{1}{n}\sum_{i=0}^{n}\left(1 - \frac{\text{dist}(SPos_i, TMaxForcePos) - \text{TolOffset}}{\text{MaxDist}}\right) \tag{3}$$

To ensure the score remains bounded within the range $[0,1]$, the following constraints are applied:

$$\text{If} \quad 1 - \frac{\text{dist}(SPos_i, TMaxForcePos) - \text{TolOffset}}{\text{MaxDist}} < 0 \quad \Rightarrow \quad \text{Pos\%}_i = 0 \tag{4}$$

$$\text{If} \quad 1 - \frac{\text{dist}(SPos_i, TMaxForcePos) - \text{TolOffset}}{\text{MaxDist}} > 1 \quad \Rightarrow \quad \text{Pos\%}_i = 1 \tag{5}$$

Variable definitions:

- $TolOffset$: Tolerance offset constant used to increase scores and adjust difficulty.
- $MaxDist$: Maximum allowable distance (for position or rotation).
- n: Number of student positions or rotations recorded within the instructor's force range.
- $SPos_i$: i-th student position or rotation within the selected force range.
- $TMaxForcePos$: Instructor's reference position or rotation at maximum applied force.
- Pos%: Percentage score representing position or orientation accuracy for a sub-interaction.

Tolerances can be configured via a user interface prior to exam execution. Users may select predefined difficulty levels or manually adjust the tolerance values using interactive capsule toggles. These settings can also be modified directly within Unity's object inspector, providing instructors with full control over evaluation strictness.

Force Peak Scoring Force-based evaluation includes two scoring criteria. The first quantifies how closely the student replicates the instructor's peak force for each finger. The score is computed using the absolute difference between the two force values, adjusted by a force scaling offset to account for difficulty calibration:

$$\text{ForcePeak\%} = \text{FSOff} + 1 - |\text{TPeakForce} - \text{SPeakForce}| \tag{6}$$

Variable definitions:

- $TPeakForce$: Maximum force applied by the instructor.
- $SPeakForce$: Maximum force applied by the student.
- $FSOff$: Force scaling offset used to adjust score sensitivity.
- ForcePeak%: Percentage score representing the similarity in peak force application.

Force Timing Scoring The second force-related metric evaluates the duration for which the student maintained a force value within a specified offset of the instructor's peak force. This measure, applied only to the index finger, reflects the quality of sustained palpation and is defined as:

$$\text{ForceTime\%} = 1 - \frac{|\text{SCount} - \text{TCount}|}{\text{MaxCount}} \tag{7}$$

Variable definitions:

- $SCount$: Number of simulation iterations the student maintained a force near the instructor's peak.
- $TCount$: Corresponding iteration count for the instructor.
- $MaxCount$: Maximum number of iterations observed across both student and instructor datasets.
- ForceTime%: Score representing timing accuracy in force application.

In both peak force and force timing evaluations, offset and tolerance values are adjustable through the same interface used for position and rotation scoring. These parameters let instructors tailor scoring sensitivity to different training levels. The final score for each sub-interaction is the average of position, rotation, peak force, and force timing scores. This system enables finer performance differentiation and helps students identify specific errors and assess their proximity to expert criteria.

To support real-time feedback and post-exam review, new interface elements are added (Figure 3). A validation canvas presents sub-interaction scores in both percentage and graphical formats. Barometer-style visuals summarise spatial and force metrics. An interactive plotting canvas lets students compare their performance to expert data over time, with selectable options for focused self-assessment.

2.3 Paths and data display

An empirical validation method complements the scoring system by visually displaying the user's palpation path, including position, rotation, and force. This enables direct comparison with the instructor's reference, helping users understand technique discrepancies beyond numerical scores.

As shown in Fig. 4, paths are rendered in real time using Unity's `LineRenderer`, with force intensity visualised through a gradient texture—blue/green for low force, red for high. When hovering over a path segment, five cylindrical markers appear, showing orientation and force trends across nearby points. Marker height represents force; tilt shows rotation.

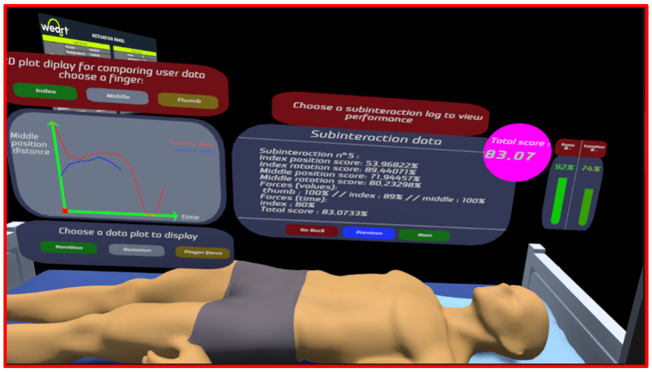
Supplementary thumb and middle finger paths appear during sub-interactions and are toggleable through a control panel. Users can show/hide paths or reset to the latest session.

This tool supports performance review by comparing user paths with expert references, providing a visual benchmark for improving palpation technique.

2.4 Questionnaire Methodology

To evaluate user feedback, two validated tools are used: the Igroup Presence Questionnaire (IPQ) for assessing presence [5], and a modified Customisable Interaction Questionnaire (CIQ) for interaction quality [4]. "Factors" and "subscales" refer to specific questionnaire components.

The IPQ measures perceived presence, while the CIQ assesses satisfaction with palpation, interaction quality, scoring logic, and interface usability. Each item uses a seven-point Likert scale, with subscale scores computed as group means.



Subinteraction n°5 :
Index position score: 53.96822%
Index rotation score: 89.44071%
Middle position score: 71.94457%
Middle rotation score: 80.23298%
Forces (values):
thumb : 100% // index : 89% // middle : 100%
Forces (time):
index : 80%
Total score : 83.0733%

Fig. 3. In-game user interface for displaying evaluation data of a single sub-interaction. The interface includes performance plots (left) comparing student and teacher metrics, detailed score breakdowns (center), and barometer visualisations of mean scores for spatial (position and rotation) and force-based metrics (right).

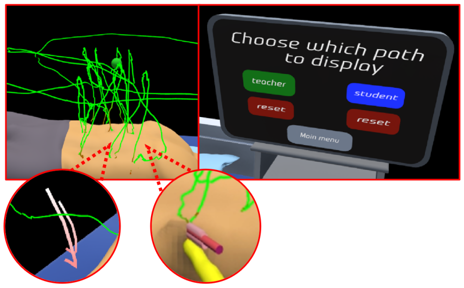


Fig. 4. In-game user interface for displaying the user's index finger path with embedded force information.

Participants complete the questionnaires via a custom HTML/JavaScript interface [3], with responses saved in `.csv` format. A Python script processes the data and computes subscale averages. IPQ scores are converted into percentile grades (A–F) following [5].

Visual plots display individual and average scores, with IPQ results shown alongside letter grades. These tools support structured feedback analysis and guide improvements in simulation presence and interaction quality.

3 Experiments

This section outlines the user testing procedure and presents key findings that inform future development. The testing approach is loosely based on the methodology in [2].

A total of 13 participants, including students and instructors, took part in the study. Feedback from these sessions, along with data from standardised questionnaires, provided valuable insights into current system limitations.

Each 35-minute session began with a structured introduction covering simulation goals, instructions, and questionnaire methods. Participants then used the hardware and explored the simulation's core features. Facilitators offered real-time guidance to address individual learning needs and ensure engagement.

All participants completed the student examination module, while one physician contributed "teacher data" for reference evaluation.

3.1 User Testing Results

Following user testing, questionnaire data are analysed to evaluate the simulation's effectiveness in delivering presence and interaction quality. This section presents quantitative results from the IPQ and CIQ, along with qualitative user feedback. Scores are reported on a 7-point Likert scale (0–6).

The IPQ results (Tables 1 and 2) show limited effectiveness in creating a strong sense of presence. While the General Presence subscale scores well with an average of 4.85 (Grade A), other subscales—Spatial Presence, Involvement, and

Table 1. IPQ user testing average subscale scores with qualitative grade rankings according to percentile thresholds defined in [5] (scores out of 6).

Subscales	**Grade**	**Average Score**
General Presence	A	4.85
Spatial Presence	F	4.02
Involvement	F	2.81
Experienced Realism	F	2.62

Table 2. Distribution of IPQ subscale grade counts across all user responses (13 participants).

Subscales	A grade count	B grade count	C grade count	D grade count	E grade count	F grade count
General Presence	11	0	1	0	0	1
Spatial Presence	0	2	1	0	3	7
Involvement	0	1	0	0	1	11
Experienced Realism	1	0	0	3	2	7

Table 3. CIQ user testing average subscale scores (out of 6).

Subscales	**Average Score**
Quality of Interaction	4.53
Comfort	3.90
Assessment of Task Performance	4.08
Consistency with Expectations	4.06
Quality of Sensory Enhancements	4.50

Experienced Realism—score below 4.0 (Grade F). Involvement and Experienced Realism are particularly low, averaging 2.81 and 2.62, with most users receiving F-grades.

The CIQ results in Table 3 show generally positive perceptions of interaction quality, with all subscales scoring above 3.0. “Quality of Interaction” and “Quality of Sensory Enhancements” score highest (4.53 and 4.50), reflecting user appreciation for interactivity and haptic feedback. Lower scores in “Comfort”, “Task Performance Assessment”, and “Consistency with Expectations” highlight issues with ergonomics, clarity, and system behaviour alignment.

4 Conclusions

This work presented a VR simulation for palpation training, combining a Unity-based environment with WEART glove haptic feedback. A modified proxy finger method delivers localised force to enhance tactile realism. Interfaces support performance evaluation by comparing student and expert data, while visual tools enabled real-time feedback and error analysis.

User testing revealed limitations in comfort, immersion, and fidelity, yet participants responded positively to the concept, highlighting the potential of haptics-enabled training in medical education.

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