FROM VIRTUAL TO TANGIBLE: GESTURAL EXPERIENCE IN COMPUTER NETWORK EDUCATION

DO VIRTUAL AO TANGÍVEL: A EXPERIÊNCIA GESTUAL NA EDUCAÇÃO DE REDES DE COMPUTADORES

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Abstract. While network simulators are commonplace in IT education, many fail to progress beyond basic skill replication within a synthetic environment. This article presents a study on the user acceptance of an innovative pedagogical simulator for computer network assembly that utilizes natural gestural interaction. Our investigation, focused on ergonomics, usability, and learner engagement, involved a cohort of student volunteers. Analysis of user perceptions reveals that system aesthetics, ease of use, and perceived utility are significant predictors of both satisfaction and overall usefulness. The findings demonstrate that bilateral (two-handed) gestural interaction enhances user immersion and satisfaction. The study also identifies current limitations, including insufficient auditory feedback and a lack of accessibility features for students with special needs. We propose future developments centered on interface personalization and ongoing research to validate the simulator's efficacy in long-term skill retention and educational outcomes.

Keywords: Gestural Interaction; Technology Acceptance; Educational Simulation; Computer Network Training

Abstract. Embora os simuladores de rede sejam comuns no ensino de TI, muitos não conseguem ir além da replicação de habilidades básicas em um ambiente sintético. Este artigo apresenta um estudo sobre a aceitação dos usuários de um simulador pedagógico inovador para montagem de redes de computadores que utiliza interação gestual natural. Nossa investigação, focada em ergonomia, usabilidade e envolvimento do aluno, envolveu um grupo de estudantes voluntários. A análise das percepções dos usuários revela que a estética do sistema, a facilidade de uso e a utilidade percebida são preditores significativos tanto da satisfação quanto da utilidade geral. Os resultados demonstram que a interação gestual bilateral (com as duas mãos) aumenta a imersão e a satisfação do usuário. O estudo também identifica limitações atuais, incluindo feedback auditivo insuficiente e falta de recursos de acessibilidade para alunos com necessidades especiais. Propomos desenvolvimentos futuros centrados na personalização da interface e pesquisas contínuas para validar a eficácia do simulador na retenção de habilidades a longo prazo e nos resultados educacionais.

Keywords: Processo educacional; Perspectivas da sala de aula; Equipamentos para educação; Treinamento em laboratório.

1. INTRODUCTION

The integration of gesture and motion capture technologies has substantially influenced teaching and learning environments, particularly in domains that rely on hands-on, experiential learning mechanisms (Orlandini et al., 2024). And numerous tools developed in recent years offer valuable opportunities to demonstrate, simulate, and, in most cases, foster genuine engagement within educational settings(Damasceno, 2023). Their role in education is consequently poised for significant expansion, with the potential to transform traditional teaching methodologies (Fan et al., 2023).

Gesture-based interactions have been implemented through various mechanisms, including wearable sensors and vision-based systems, to enhance educational experiences (Shanthakumar et al., 2020). Adopting these technologies has introduced new paradigms, techniques, and methodologies into the educational process, facilitating activities that would be difficult or impossible to conduct in a real-world environment (Vieira et al., 2025). Virtual Reality (VR) technology has enabled specialized and simulated training across various industrial sectors (Damasceno et al. 2017).

Gesture recognition technologies exhibit substantial variations in precision and user adaptability, both critical characteristics for educational applications (Fernandes et al., 2023). In recent years, significant scholarly debate has focused on aspects such as system accuracy and precision (Tölgyessy et al., 2021), gesture capture methodologies(Juan, 2021), the capacity for adaptation to user-specific needs (Sheu & Chen, 2014) the underlying technological implications (Aly, 2024), and the operational costs associated with the requisite devices (Rengganis et al., 2018).

Selecting a gesture recognition technology for education often involves a trade-off between precision and user adaptation. Systems offering high precision with moderate user adaptability are suitable for educational content requiring accurate gesture interpretation. Conversely, technologies that may sacrifice a degree of precision but are highly adaptable to different users offer greater flexibility, making them more versatile in dynamic classroom environments.

Within the domain of computing education, particularly in vocational training for computer networks—where a fundamental objective is the operational deployment of network infrastructure—instruction typically begins with theoretical classroom lessons before progressing to specialized laboratory practice (Fuxiang et al. 2009). Consequently, teaching often incorporates tangible didactic materials, physical connection equipment, and simulation software(Siraj et al. 2012).

However, the pedagogical presentation of these artifacts is frequently limited to identifying network instruments and equipment and simulating basic data transmission (Janitor et al. 2010). It is well-established that a significant portion of procedural knowledge can be effectively transferred through virtual instrumentation, which enables a wide range of experiments that are otherwise difficult to conduct due to high operational costs or equipment acquisition limitations (Sukirman et al. 2021).

This potential is further amplified by the increasing popularity of VR visualization devices, such as 3D glasses, also known as Head-Mounted Displays (HMDs), which have been widely disseminated in schools through low-cost models like Cardboard (Baran 2019).

Nevertheless, to effectively leverage the technical features of virtual maintenance, the tutorial or instructional process for students using visualization and interaction devices must be meticulously designed (Bachmann et al. 2018). This addresses the aspect of visualization. When considering interaction, a spectrum of input devices exists to bridge the conceptual gap between the user and the virtual environment.

As hand gestures constitute one of the most fundamental communication modalities in daily life, the capacity to recognize these movements should be integral to digital interfaces, especially those aiming to create simulators that closely mimic users' real-world actions (Vosinakis and Koutsabasis 2018).

One of the most prevalent devices for hand gesture recognition applications is the Leap Motion™ controller (Sharma et al. 2015), This technology narrows the gap between the

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physical manipulation of tools and their simulated virtual counterparts. However, there is a distinct lack of applied research on the benefits and limitations of integrating gestural interaction technology within an immersive virtual environment to support instruction in a discipline where hands-on operational practice is as crucial as logical reasoning and conceptual knowledge of computer networks (Janitor et al. 2010; Prvan and OžEGOVIć 2020) .

Therefore, this research investigates identifying interaction elements and evaluating users' perceptions trained by a computer network assembly simulator utilizing gestural interaction. The study analyzes the usability, ergonomics, and engagement that a low-cost simulation tool can offer to traditional computer networking classes.

2. EXPERIMENTAL DESIGN AND METHODOLOGY

This study employed an experimental approach centered on a custom computational artifact, the SimNet3D software, a 3D virtual reality simulator for computer network installation (Orlandini et al., 2024). The primary objective of the research was to evaluate whether the simulator's implemented functionalities align with the didactic requirements of technological undergraduate programs. (Computer Science or Software Engineering courses).

The virtual environment features digitally modeled representations of essential networking equipment, including a wireless router, a desktop computer, an RJ45 network cable, two male RJ45 connectors, and a cable crimping tool. The simulator trains users in proper procedures for assembling network cables and establishing connections between network devices. The application supports both immersive and semi-immersive visualization modes, with the semi-immersive mode allowing users to exit virtual experience by redirecting their gaze. In contrast, the fully immersive mode requires a head-mounted display (HMD).

Interaction within the virtual environment was implemented through a Natural User Interface (NUI) approach using the Leap Motion™ controller for hand tracking. This design is grounded in the premise that hand gestures provide an intuitive method for manipulating digital interfaces, particularly valuable for simulating hands-on tasks with tools that are typically costly or difficult to access. The interaction schema was informed by established taxonomies of natural gesture-based interaction, including pointing, pantomimic, and direct manipulation paradigms.

Four core gestures were implemented to enable all in-simulator actions: hovering to select objects, pinching to grasp and move items, pointing to activate functions, and rotating to adjust object orientation. These gestures were mapped to essential network cable maintenance procedures, including crimping tool manipulation, RJ45 connector handling, wire preparation according to T568A/B standards, and device connection. Each action was associated with specific gesture requirements and quality standards, allowing tasks to be performed sequentially or as independent modules.

The gesture-based interface aims to create a synesthetic user experience that emulates physical manipulation of objects, prioritizing intuitive interaction over traditional input devices to enhance realism and user engagement. The design seeks to provide an authentic simulation experience that supports the development of practical skills in network installation and maintenance.

This research protocol was reviewed and approved by the Institutional Ethics Committee of the Federal University of Technology – Paraná (UTFPR) in accordance with national ethical guidelines.

2.1.Experimental Procedure

The experimental evaluation of the SimNet3D simulator was designed to assess its usability and interface ergonomics. A cohort of participants ($N \geq 20$) will be recruited from the university population through institutional announcements. Volunteers will provide demographic information and complete an Informed Consent Form (ICF) before engagement. Each participant will interact individually with the simulator under controlled conditions.

To account for potential novelty effects, the experimental design incorporates three testing sessions per participant, scheduled on non-consecutive days. Each session will have a maximum duration of ten minutes. All interactions will be video recorded to enable subsequent analysis of user behavior and ergonomic factors.

Data collection will be performed through a multi-method approach. After each session, participants will complete a validated questionnaire based on the Technology Acceptance Model (TAM) framework (Ibrahim et al., 2018), which has been widely adopted in educational technology research. This instrument will capture metrics across several dimensions: perceived ergonomics of task performance, overall system usability, user engagement levels, emotional responses, and perceived usefulness and ease of use.

The analysis strategy involves a stratified examination of the collected data. Video recordings will be systematically coded to quantify ergonomic metrics such as movement efficiency, gesture accuracy, and error rates. Questionnaire responses will undergo statistical analysis to evaluate usability indicators and user perceptions. A subsequent cross-analysis integrating behavioral data with subjective measures will be conducted to generate comprehensive insights regarding user engagement and the overall pedagogical effectiveness of the gesture-based simulation approach for vocational training in network installation.

2.2.Survey Instrument Development

A structured survey instrument was developed based on established theoretical frameworks to address the research objectives. As detailed in Table 1, the questionnaire is organized into four thematic sections: Course Design (perceptions of structure and resources of instructions), Perceived Usefulness, Perceived Ease of Use, and Intention to Use. Items were adapted from validated instruments to ensure reliability, and responses were collected using a five-point Likert scale (1 = strongly disagree, 5 = strongly agree).

Table 1. Survey items used in the study

Course Design (CD)	
CD1	Course materials (readings, guides, etc.) were well-organized and accessible.
CD2	Learning resources were released in a timely manner, supporting my progress through the course.
CD3	The overall design of the course components effectively supported the learning objectives.
CD4	I perceive the design of the course components to be good.

Perceived Usefulness (USE)	
USE1	Using this simulator helped me complete learning tasks more efficiently.
USE2	The simulator enabled me to better acquire the knowledge and skills intended in this course.
USE3	Using this simulator improved the quality of my learning.
USE4	This simulator enhanced my overall learning performance.

Perceived Ease of Use (PEU)	
PEU1	Interacting with the simulator felt intuitive and required minimal mental effort.
PEU2	I found the simulator's controls and interface easy to use.
PEU3	It was easy for me to become proficient at using the simulator.
PEU4	I could easily find the information and functions I needed within the simulator.

Intention to Use (IU)	
IU1	I would choose to use this simulator over traditional learning methods for this subject.

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IU2	I believe simulators like this should be implemented in other courses.
IU3	I would recommend this simulator to other students.
IU4	I intend to use this simulator frequently for my coursework.

3. RESULTS

Incorporating gestural interfaces into virtual reality (VR) environments remains a complex endeavor, despite its surface-level appearance of simplicity. Empirical data from our evaluation underscores persistent usability challenges, particularly within action-specific interactions.

These observations highlight a critical disconnect between theoretical potential and practical implementation, necessitating a deeper examination of how such limitations impact functional and educational outcomes.

To navigate these complexities, we applied the TAM (Ibrahim et al., 2018) to systematically evaluate perceived usability and functional utility. This framework provides a structured lens through which to analyze how gesture-specific flaws, as quantitatively captured in the perceived difficulty metrics, influence broader engagement and adoption patterns. By situating our findings within this established model, we move beyond isolated observations toward a nuanced understanding of how interaction design shapes educational efficacy in immersive environments.

Figure 1 details the perceived difficulty of simulator tasks, these challenges are not uniformly distributed across all actions.

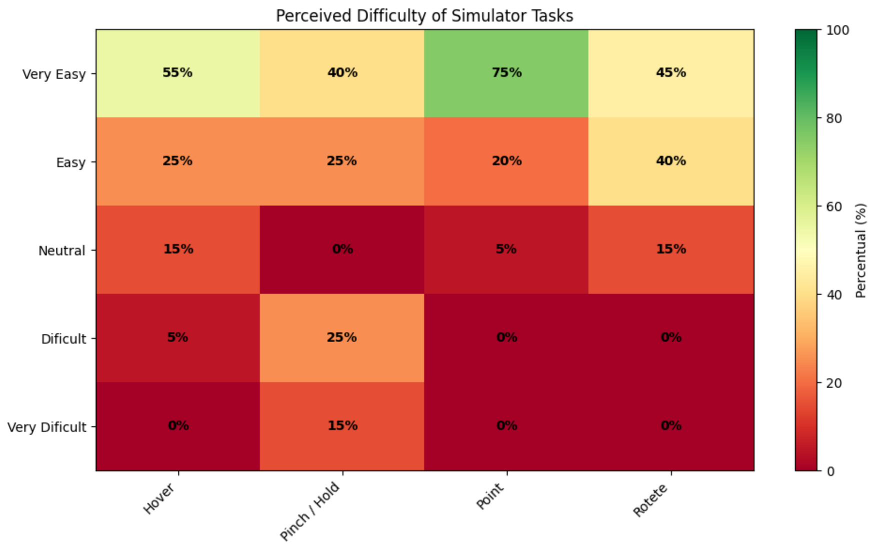

Figure 1. Perceived Difficulty of Simulator Tasks
Source: Authors (2025)

The data reveals a stark contrast between highly intuitive gestures, such as 'Pointing' (rated as 'Very Easy' by 75% of users), and more complex motor actions like 'Pinch/Hold', which presented significant hurdles—40% of users found it 'Very Easy', but a combined 40% rated it as 'Difficult' or 'Very Difficult'.

Our analysis identifies the 'pinch/hold' gesture as a significant pain point, revealing inconsistencies that undermine user proficiency and task execution. This finding is not merely technical but pedagogical: when users struggle with foundational interactions, their cognitive load increases, diverting attention from learning objectives to interface mechanics. Such friction compromises the simulator's educational value, suggesting that usability and

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instructional design must be addressed as interdependent yet distinct dimensions of development.

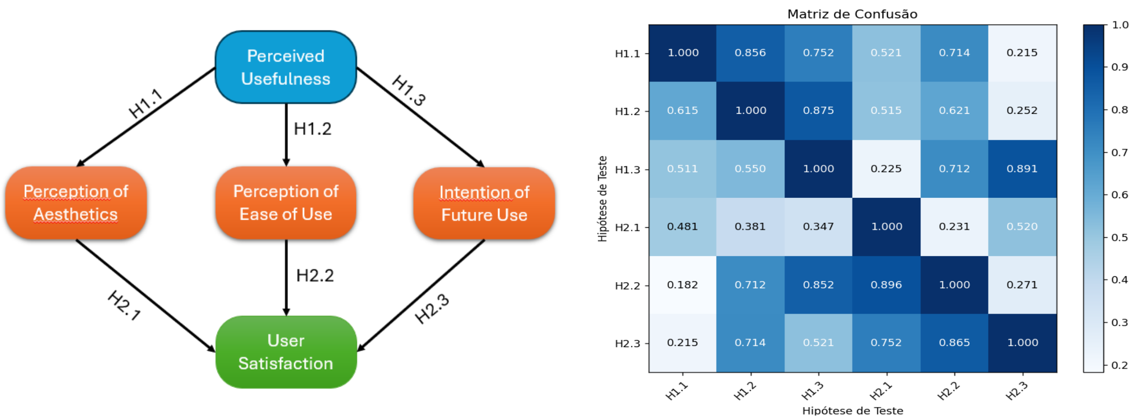
This study also proposes a theoretical model based on two primary constructs: Perceived Usefulness by the user and User Satisfaction with using the simulator. The subsequent analysis seeks to measure the level of agreement in participants' responses to a specific item in the survey. Thus, greater uniformity in the group's responses to a given question manifests as an approximation of the corresponding value in the confusion matrix to 1. So, the hypotheses described in Table 2 were operationalized, instrumentalized by the TAM evaluation form, and used to construct the analyses presented in Figure 2.

Table 2. Technology Acceptance Hypotheses

$H_{1.1}$ – Does the user perceive the usefulness of the Tool based on its aesthetics?
$H_{1.2}$ – Does the user perceive the usefulness of the tool based on its ease of use?
$H_{1.3}$ – Did the user perceive the usefulness of the Tool due to the need for its use?
$H_{2.1}$ – Is the user satisfied with the tool because of its aesthetics?
$H_{2.2}$ – Is the user satisfied with the use of the tool because of its ease of use?
$H_{2.3}$ – Is the user satisfied with the tool because of the need to use it?

Adopting new technologies in educational settings is highly context-dependent, as perceptions of usability and utility vary widely across learning environments and user demographics. To explore these dynamics, a series of hypotheses was developed to measure technology acceptance (Table 1), with Figure 2 visually representing these constructs.

In this Figure, in contrast, depicts the relationships identified through an analysis of responses from 20 participants after three interaction sessions with the tool, emphasizing emergent patterns and points of conceptual ambiguity observed among users.



a) Relationship between Hypotheses of Use   b) Confusion Matrix

Figure 2. Hypotheses of Use
Source: Authors (2025)

Hypotheses H1.1 and H2.1 examine whether the tool's aesthetic qualities influence perceived usefulness and user satisfaction. The model implies that aesthetic perception may exert a direct effect, though the strength of this relationship likely depends on how users value design within an educational setting. Similarly, H1.2 and H2.2 focus on perceived ease of use, investigating its effect on both Usefulness and Satisfaction relationship central to technology acceptance models such as TAM, where ease of use is theorized to precede and positively affect both constructs. Finally, H1.3 and H2.3 explore the role of perceived need for use in shaping usefulness and satisfaction, acknowledging that contextual relevance may significantly impact acceptance.

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The hypothesis correlation matrix reveals substantial overlap between specific constructs—notably between H1.1 and H1.2, which exhibited 85.6% conceptual confusion among respondents. This overlap raises questions about the discriminant validity of these variables within the participant group. Specifically, respondents appeared to conflate aesthetic perception with perceived usefulness, suggesting that, within this sample, visual design was implicitly associated with functional utility. However, this observed association should not be interpreted as a generalizable causal relationship but as a context-specific perception.

Furthermore, the matrix indicates that perceived need for use (H1.3 and H2.3) was consistently distinguished as an independent factor positively affecting usefulness and satisfaction. It reinforces the importance of contextual relevance—such as alignment with learning objectives and practical applicability—in educational technology acceptance.

These findings are consistent with broader scholarly discourse, which emphasizes the importance of adapting technology acceptance models to accommodate the specific demands and unique particularities of educational environments.

The perception of the research participants regarding course design was evaluated. The results presented in the stacked bar chart, shown in Figure 3, detail the distribution of responses on a satisfaction scale, where 5 (green) indicates "very satisfied" and 1 (red) "very dissatisfied".

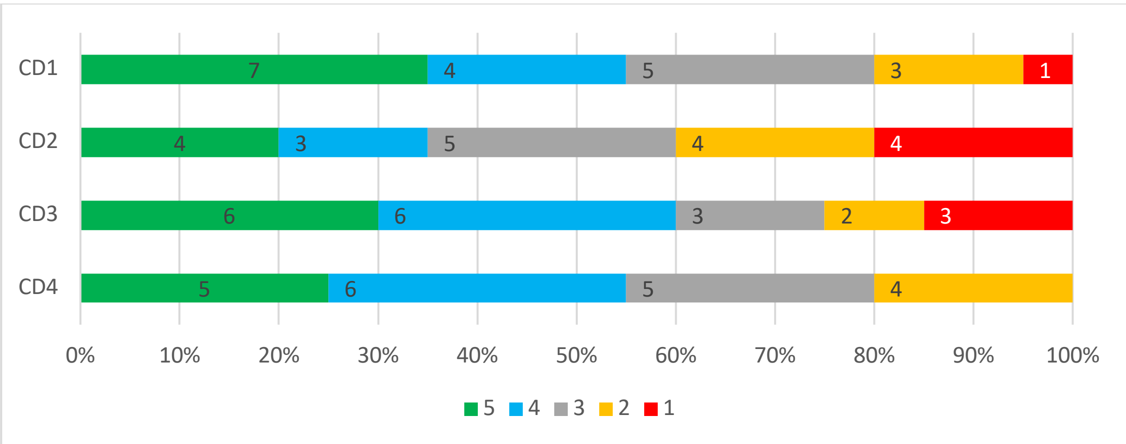

Figure 3. Perceived Difficulty of Simulator Tasks
Source: Authors (2025)

The analysis revealed strong indications of overall satisfaction with the organization of teaching materials (CD1) and the overall course design (CD4). In both categories, the sum of the responses "very satisfied" (5) and "satisfied" (4) exceeded 10, suggesting high approval. Specifically, 11 students rated the organization of materials as satisfactory or very satisfactory, and another 11 gave the same rating for the overall design of the course.

The highest approval rate was observed in the category "The overall design of the course components effectively supported the learning objectives" (CD3), with 12 of the responses indicating satisfaction or very satisfied. This data suggests that the course structure was perceived as highly effective in supporting learning objectives.

In contrast, the category "Learning resources were released promptly, supporting my progress through the course" (CD2) presented the most heterogeneous distribution of responses. Although seven students reported satisfaction, many participants expressed neutrality or dissatisfaction (13), pointing to this category as a potential area for optimization.

The survey data indicate that the course design and organization successfully supported learning objectives. The discrepancy between high satisfaction rates with the design and organization and divided perceptions about the timeliness or flow of activities in the simulator suggests that even if the material is high quality and well structured, perceived effectiveness

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may be compromised if the flow of activities in the simulator is not aligned with the pace of the students.

4. CONCLUSION

This study investigated the acceptance of educational software with a gesture interface, supported by a motion capture device, in a training context using virtual reality simulators. The analyses, represented in the theoretical model and confusion matrix figures, provided valuable insights into users' perceptions of the tool's usefulness and satisfaction.

Based on the data analyzed, it was found that users' perceptions of usefulness and satisfaction are strongly influenced by aesthetics, ease of use, and the need to use the system. However, the confusion matrix revealed some confusion between these variables, suggesting the need for a better conceptual distinction between the evaluated factors. This points to the need for refinement in the theoretical model and adjustments to the hypotheses, especially in the clear differentiation between aesthetics and ease of use.

In addition, the results suggest that using Leap Motion, especially in interactions involving two hands, can increase users' sense of immersion and satisfaction, a positive point for technology. However, the research revealed important limitations, such as the lack of integration of sound features and the impact of gestural interactions on students with special needs or coordination difficulties.

These findings indicate that improvements in the interface and adaptations for different user profiles are essential to make the system more inclusive and effective. It should be noted that when Leap Motion captures both hands simultaneously, the user's sense of manipulation is greater, providing greater immersion and satisfaction with the system. It was not the focus of this research to report on using more than one hand in the interaction, leaving this for a future experiment.

The results also showed that the interaction technique tested may not be ideal for all types of students, particularly those with special educational needs or those whose hand-eye coordination is not as good.

In summary, this study contributes to advancing knowledge on gestural interfaces in the context of virtual reality simulators but also points to critical areas for future research. Future research is recommended to explore the integration of multimodal feedback, the customization of the interface for different types of users, and the impact of using both hands in interactions, broadening the scope of the experiments and enhancing the results obtained so far.

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