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A Professional Development Program using a Low-Cost Exoskeleton Kit to Support Trainers in Translating Technical Research to Implementable Recommendations

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1. Introduction

People with limb disabilities resulting from neurological and musculoskeletal disorders represent a minority that has been excluded from educational and social opportunities [1]. Such individuals additionally face barriers to participation in the workforce, especially in the agriculture and manufacturing sectors [2], where many job tasks rely on manual dexterity [3]. This exclusion and underrepresentation have adversely affected the economic wellbeing and living conditions of people with limb disabilities and, in many cases, led them to experience health deterioration and poverty [2]. The promotion of full and equal access for this group of people to their human rights and their integration into community life is known to be positively influenced by the development, access, and adoption of assistive technology [4]. In fact, exoskeletons, a type of assistive technology that can be worn and directly controlled by people with limb disabilities, are considered as a promising solution to restore motor functions for them [5] and to help them regain their autonomy in the performance of activities of daily living (ADL) [6]. Even as the cost of implementation of exoskeleton solutions remains a concern [7], the accelerating development of mechatronics and robotics research in the last decades [6] forecasts a narrowing in the access gap for these solutions, thus increasing the likelihood of their adoption to address the restoration of human motor capacities.

To promote the adaptation of wearable robot technology research output for addressing practice-based issues, the concept of "knowledge translation and exchange" (KTE), or two-way communication between researchers and practitioners, is deemed effective [8]. In a case where technology is developed with the intention of restoring manipulation or other functionalities (e.g., for people with limb disabilities), the role of occupational therapists (OTs) is of paramount importance since they serve as communication links during the KTE between the technology developers and the end-users. In general, the goal of OTs is to facilitate an exercise regimen that can "enable engagement in occupations" [9] by supporting the enhancement of a person's skills and abilities in the performance of ADL, domestic activities, and leisure activities [10]. However, with the introduction of new engineering and robotics-based interventions in therapy programs, OTs often find it challenging to independently bridge the gap in knowledge from research to practice. In fact, clinicians and therapists are concerned about the lag in the successful translation of new knowledge into evidence-based healthcare practices [11], [12]. In response, the field of healthcare has witnessed a proliferation of diverse KTE strategies, e.g., regular or facilitated researcher-practitioner meetings, education workshops by researchers, educational outreach visits, etc., [8], [13].

The key outcomes of a successful KTE process include a change in the awareness and attitudes of practitioners as well as the integration of the proposed intervention in practice. An essential ingredient of effective KTE strategies is the relationships built between the researchers and stakeholders (clients, service providers, and policy/decision-makers) [8]. Face-to-face interactions are deemed more effective than the use of printed materials [8]. While online KTE strategies can increase stakeholders' access to healthcare data, the associated information overload is deemed a drawback [14]. Practitioners are more likely to incorporate robotic technology in therapy programs if the KTE process clearly specifies its outcomes and benefits [7].

This paper proposes a training program to promote communication and information exchange in the above spirit. Specifically, it seeks to support robotics researchers, who are developing exoskeleton technologies, in translating technical research to implementable recommendations for the OTs while obviating the information overload. We envision a KTE process that will utilize social capital theory [15] and cultural-history activity theory (CHAT) [16] as its theoretical frameworks. Informed by the social capital theory, this effort will prepare robotics researchers to cultivate and leverage ties with healthcare professionals [17] for facilitating effective knowledge exchanges and communication. The proposed KTE process will support the development of mentor-protégé relationships among the researchers, OTs, and end-users, hence creating a social network. Successful KTE will create channels for support, communication, trust-building, mutual recognition, and acknowledgment [15]. This is further supported by the ideas from CHAT, which considers the mentor-protégé relationship as critical for KTE [18]. It suggests that for experts from different contexts to productively engage in KTE, they must create shared mental models and engage in collaborative problem solving [19]. Evidence-based practices, e.g., project-based learning (PBL) [20] and the 5E instructional model [21], will facilitate the synthesis, dissemination, and exchange of actionable knowledge between researchers and stakeholders.

For this work, we propose a weeklong workshop, where engineering education researchers will introduce to exoskeleton developers the aforementioned social and educational theories, along with a review of the cultural and historical context of occupational therapy as a health profession. The exoskeleton developers will participate in an example hands-on lesson formulated under the frameworks supported by the social and educational theories to complement their understanding. Then, they will collaborate in small groups to create instructional materials to train OTs on translating the technical aspects of a newly developed exoskeleton product, with the guidance of the educational researchers. The exoskeleton developers will revise and refine the created training materials based on the feedback from the educational researchers and from their own peers. Finally, they will generate improved and revised versions of the instructional material, which will support them to train OTs on the developed exoskeleton product effectively.

2. Theoretical Framework

2.1. Occupational Therapy Context

Occupational therapy is a health profession whose practitioners promote the health of clients through their successful integration in occupations [22]. The primary goal of occupational therapy is to enable people so that they can participate in their communities. Thus, OTs apply systematic interventions that can reduce the effect of one's disabilities on their ADL [23]. By promoting the engagement of their clients in meaningful occupations, OTs aim to empower them to be self-reliant in supporting their families and to construct their identities through what they do [23], [24]. To join the occupational therapy profession at the entry level as an OT in the United States, a graduate degree in the discipline is the minimal requirement. Alternatively, one can serve in the role of an assistant to an OT by acquiring an associate or baccalaureate degree [23]. According to the World Federation of Occupational Therapists, in 2020, the United States had four occupational therapists per 10,000 people [25] and most of the OT practitioners in the United States are women (92% in 2010) [23]. In the context of this work, when designing lessons, instruction, and supporting materials based on social theories, it is crucial to understand the historical origins of the occupational therapy profession, its cultural relevance, and the principles in which the profession is grounded. This knowledge may allow the enrichment of social relationships, which in turn can increase access to the social capital available in the network and identify all the factors embedded in the OT practice that may influence planning an educational activity lesson.

2.2. Social Capital Theory

Social capital refers to the resources, tangible or potential, generated in a social network to which its members may have access [26]. These available resources support the individuals and benefit them with information, trust, and reciprocity, which eventually can increase their ability to solve individual or collective problems [27]. However, access to these resources is not assured to all social network members. Instead, the quality of the relations between the individuals, which are founded upon trust-building, mutual recognition, and acknowledgment, determines the access to the available social capital [27].

The concept of social capital has been used in education to increase its relevance and quality. Argyris and Schön have proposed in [28] a reflective practitioner model that is a professional protocol to support the development of mentor-protégé relationships. This model assumes that both the learners and the instructors have essential knowledge of the problem and it seeks out the connection of thoughts and feelings among the created social networks [29]. In this manner, the planning of the instruction becomes an exercise of mutual learning-in-action [30], [31], and the collaborative exploration of trust-building between the instructor and the learners empowers them both [32].

In the context of this project, the social capital theory is particularly beneficial in creating and sustaining a social network consisting of robotics researchers and OTs. During the professional training proposed under this effort, building quality relations between the network members will create bridges of access to resources that may complement the KTE process. These resources may be critical in creating intellectual capital and cross-functional team effectiveness and may facilitate the dissemination and acquisition of specialized knowledge.

2.3. Cultural-Historical Activity Theory

While designing a learning activity, it is essential to identify and consider the various elements that influence what the learners may think, observe, analyze, and do in carrying out that activity. To do so, the cultural-historical activity theory (CHAT) provides a framework (see the top triangular structure and its nodes in Figure 1) that focuses on the actors (i.e., the subjects) involved in the activity, including their socioeconomic relations; their actions (i.e., the object); the tools to facilitate (i.e., the mediating tools) these actions; and their psychological motives (i.e., the outcomes) [33]. This framework encapsulates the activity as a systemic whole, allowing the analysis of dynamics of economics, culture, and history embedded in the system, at a particular point or over time [33], [34].

The CHAT activity system, proposed by Engeström in [16], is represented through an interconnected structure composed of six elements that interact to produce a desired outcome (see Figure 1). The upper triangular structure represents the actions taken by the actors involved in the activity. In the case when the activity is concerned with a training or classroom environment, the actions taken by the trainees (subjects) are motivated towards a particular purpose (what is to be accomplished) by utilizing mediating artifacts (resources available or practices) [34], [35]. The base of the structure in Figure 1 illustrates how the collective activity is shaped by the cultural and sociohistorical factors, in the form of policies and conventions (i.e., the rules), the designation of authority (i.e., the division of labor), and the community (e.g., a classroom) where the activity takes place [35]. The activity system's outcome (what the trainees learn) is dictated by the dynamics between the elements that are part of the activity.

The interconnectedness of the structure of the CHAT framework in Figure 1 is helpful for the mediating tools involved in teaching and learning, unpacking the multiple layers that might be present while pursuing the construction of the object activity [36]. By uncovering these structures, processes, relations, and configurations present in the activity system, the design of the activity can be improved and it can empower the learning outcomes [34], [36].

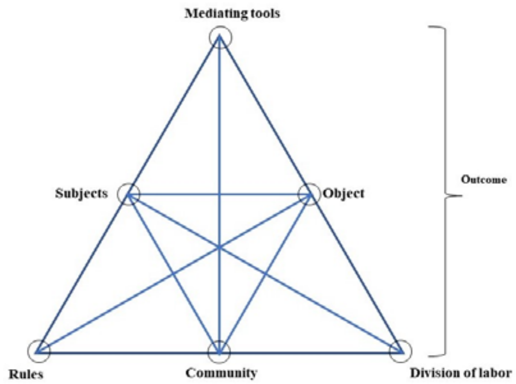


Figure 1: CHAT Activity System of [16]

2.4. Project-Based Learning

Project-based Learning (PBL) is a method of education that uses authentic and engaging real-world questions and problems related to the context of the learning process [37] to make the learners perceive the learning experience as meaningful and beneficial for the educational purpose [38], [39]. Moreover, the impact of PBL in occupational therapy education has been studied, researched, and implemented extensively [40], [41] as a proven and effective method of teaching. This student-centered teaching approach is typically implemented within small groups [39], where students are encouraged to cooperate and identify the outcomes that correspond to the objectives of the learning experience [39], [41].

To implement PBL, Larmer proposed in [42] a comprehensive, research-based framework called the "Gold Standard PBL" to help instructors to measure, calibrate, and improve their practice. To effectively design a project, it establishes a set of seven essential project design elements (see Figure 2) and the corresponding teaching practices to facilitate student learning, engagement, and skill development, which are the main goals of any well-designed project [34].

2.5. 5E Instructional Model

The 5E instructional model is a widely used inquiry-based learning model, commonly prescribed for professional development (PD) [43]. As seen in Figure 3, it consists of five stages, each beginning with an 'E', through which learners experience a learning progression that helps them understand the concepts through engagement in hands-on activities. Specifically, beginning with tasks and questions that **engage** learners, the instruction transitions such that learners **explore** creative and alternative solution strategies. Next, participation in hands-on learning activities allows learners to **explain** concepts and then they are prompted to **elaborate** their understanding by considering novel situations. Finally, to **evaluate** learners' performance and progress, assessments are performed.

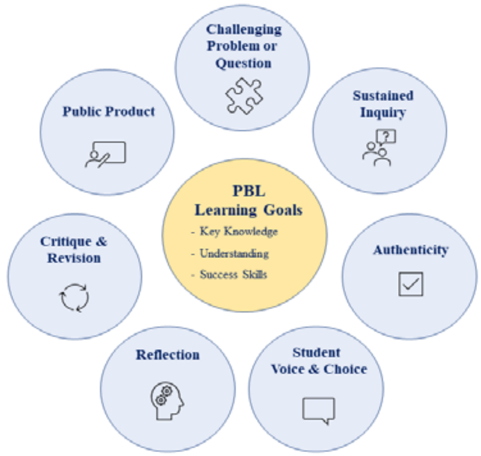


Figure 2: The Gold Standard PBL with Seven Essential Elements [42]

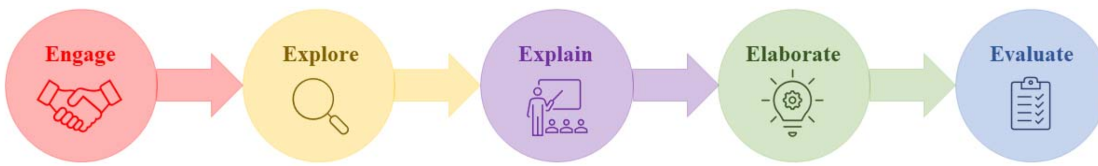


Figure 3: The 5E Instructional Model of [43]

3. Workshop Description

In the workshop that is being developed, engineering education researchers (i.e., the *education researchers*) with PD expertise will conduct a hands-on, collaborative, weeklong training program focused on various pedagogical strategies and the development of effective curriculum materials. The workshop participants will comprise *exoskeleton developers* who are engineering researchers developing a wearable robotic product. On the first day of the workshop, the education researchers will introduce important concepts about occupational therapy, including its definition, historical origins, cultural relevance, and the context of the profession in the United States. Later, the exoskeleton developers will be introduced to the concepts of social capital theory, CHAT, PBL, and the 5E instructional model. For the next two days, they will work in groups, with support from the education researchers, to create the instructional materials for a summer workshop, wherein they will train OTs about the intended use of the developed exoskeleton product. The instructional materials will include presentations, handouts, activity sheets, and other documents. The exoskeleton developers will present their work to the education researchers and other participating peers for feedback on the fourth day. On the last day, they will improve and modify their work before presenting it to all workshop participants, their research faculty supervisors, and educational researchers.

3.1. Activity models

3.1.1. Activity 1: An Introduction to Theoretical Concepts

During the first day of the workshop, the education researchers will introduce important concepts about occupational therapy as a profession, along with social and educational frameworks for designing an effective lesson. For the first activity, the *community* will consist of the educational researchers who will deliver information and the exoskeleton developers who also constitute the *subjects* participating as individuals [35]. The exoskeleton developers as workshop participants will be expected to individually take notes, follow directions, make contributions, and participate when prompted by the educational researchers.

The *object* of this activity will be to introduce educational and social theories and frameworks to the exoskeleton developers so that they can identify factors that influence the development and quality of a lesson and how these factors can meaningfully be incorporated to enhance the learning experience. For this purpose, the education researchers will start with the introduction of the fundamental concepts by following an initiation-reply-evaluation sequence [44], asking probing questions to the class, and gathering ideas from respondents. These ideas will be evaluated in a whole-class setting. Later these ideas will be connected to the formal definitions of social concepts (social capital theory and CHAT) and educational concepts (PBL and 5E instructional model).

For the *division of labor* of the activity, the education researchers will hold the pedagogical responsibility since they possess the expertise on the relevant theories that are to be introduced to the exoskeleton developers and enacted by them. This role will be reflected during the decision-making on the logistics as the instruction develops and in actions like probing the participants, evaluating their responses, and then introducing the formal definitions to them.

The *mediating tools* to achieve the object of the activity will consist of (1) the class discussion generated from participants' inquiries and reflections; (2) the education researchers' instructional material; and (3) the education researchers' evaluation critique. The education researchers will have control of all these mediating artifacts, although these are shared with the exoskeleton developers. The *outcome* sought by this activity will be for all participants to fully understand the theoretical concepts behind the social and educational frameworks, which will serve as tools to design training lessons effectively.

Under the lens of CHAT, identifying the model elements provides a detailed representation of the activity and what to expect from its development (see Figure 4). The exoskeleton developers are expected to develop individual understanding by participating in the activity and paying attention to the education researchers' explanations. However, for this activity, the participants are not expected to interact with one another or help their peers understand the concepts being explained.

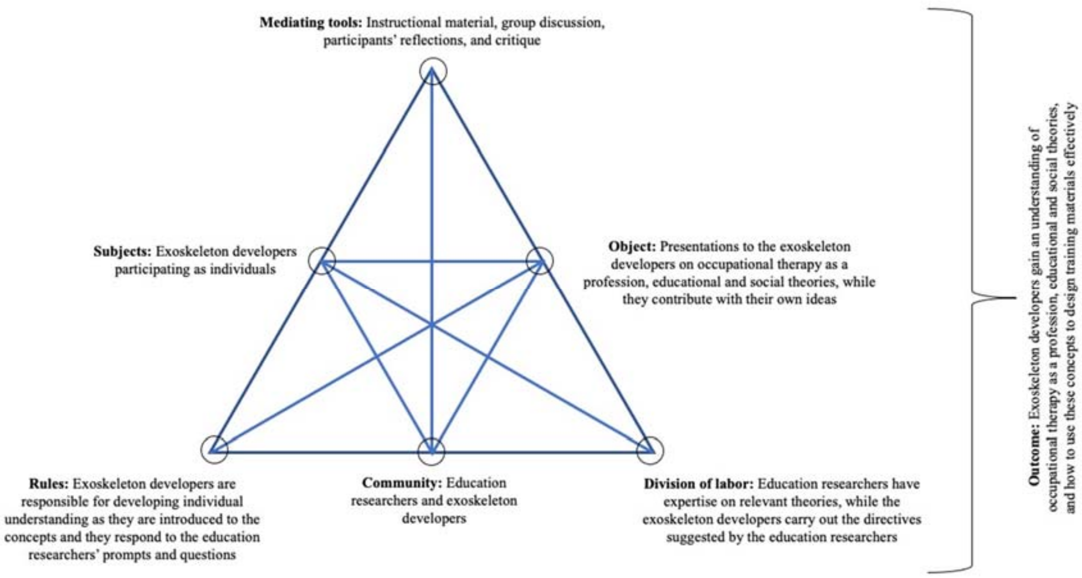


Figure 4: CHAT Activity Framework for an Introduction to the Theoretical Concepts

These *rules* are the product of the workshop structure for this activity, where the education researchers are solely responsible to determine how the mediating artifacts are used during the activity.

To complement the understanding of the educational and social theories, an example lesson using the frameworks supported by these theories will be provided. This lesson will be based on a hypothetical case where a group of exoskeleton developers is supposed to train OTs about the operational modes of an exoskeleton device. In delivering this exercise, the role of the trainers will be performed by the education researchers, while the exoskeleton researchers will carry out the role of OTs. This example lesson will include using a ready-to-assemble, low-cost, 3D-printed exoskeleton kit. Details about this example lesson are presented in Section 4.

3.1.2. Activity 2: Creation of Instructional Materials

On the second and third days of the workshop, the education researchers will instruct the exoskeleton developers to create instructional materials for training OTs about the use of wearable robots without overloading them with technical information (*object*). During this activity, the *community* will consist of the educational researchers and exoskeleton developers who will also constitute the *subjects*. Now, the educational researchers will interact intermittently with the exoskeleton developers who will participate as groups [35] of two to three people.

This activity considers the educational researchers as experts on the relevant educational and social theories and the exoskeleton developers as experts on exoskeletons who now additionally possess

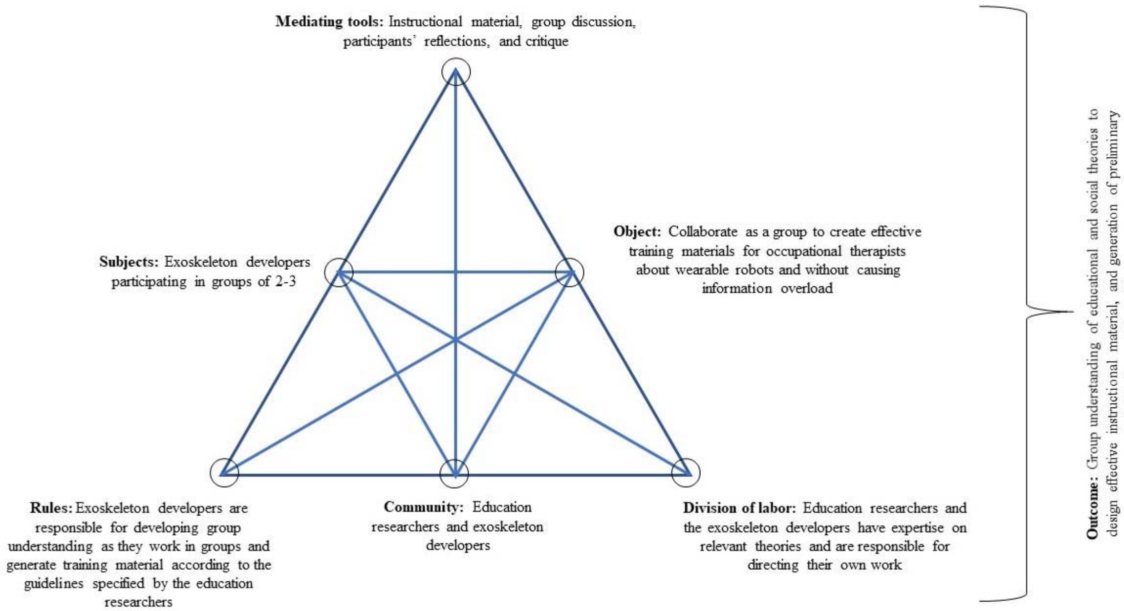


Figure 5: CHAT Activity Framework for Creation of Instructional Materials

an understanding of the educational and social theories covered in the first activity. This will be used in the *division of labor* for the sharing of expertise and authority between them.

The exoskeleton developers collaborating in small groups will be responsible for creating the instructional materials, while the education researchers will provide guidance to each individual group. Thus, the *rules* for this activity will require the participants to interact with one another in their own group to generate the training materials for OTs, following the guidelines specified by the education researchers. To do so, the exoskeleton developers will have access to *mediating tools* such as the instructional materials provided by the educational researchers, group discussions, reflections, and critiques from the educational researchers and their peers in their own team.

For the *outcome* of the activity, the participants will be expected to develop a group understanding and collaborate to generate preliminary training material for OTs, using the previously learned educational and social frameworks. See Figure 5 that represents the structure of this activity concisely.

3.1.3. Activity 3: Presentation and Improvement of Training Materials

On the fourth day of the workshop, the exoskeleton developers (*subjects*) will continue to participate in the same groups formed during the second activity. Each group will present their training materials generated in the previous activity to the education researchers and their peer participants from the other groups (*community*). Then, each group will receive feedback from the education researchers and their peers, use the feedback to make refinements, and present the revised training materials during the fifth day of the workshop where the audience will additionally include exoskeleton researchers' faculty mentors.

The *division of labor* for the activity will evolve as the activity develops. During the presentations on the fourth and fifth days, each group will exercise their expertise developed through engagement in producing their own training materials. They will additionally hold the logistical authority for sequencing and presenting their work under the overall authority held by the education researchers for organizing the logistics of the group presentations. Following the conclusion of each group's presentation, the lead education researcher will organize a class discussion, coordinate the questions from various education researchers and peers of workshop participants, and provide feedback to the presenting group to allow them to work on improving their work product.

The *mediating tools* to fulfill the *object* of generating revised and improved training materials will be the instructional material provided by the education researchers and the whole-class discussion, which will include participants' reflections and their critique, generated at the end of the presentation of each group. For the *rules* of this activity, the groups of participants will present the generated training material, one at a time, following the guidelines specified by the education researchers. Each team of participants and the educational researchers will make inquiries and provide feedback following each presentation.

At the end of this activity, the expected *outcome* will be to achieve a group understanding of educational and social theories to design instructional material effectively and to generate revised and improved materials that can be used to train OTs. See Figure 6 for a concise encapsulation of this activity.

4. Lesson Example

4.1. Case Description

The example case will involve a group of exoskeleton developers, who will train OTs about a newly developed exoskeleton robot's operation principles and operation modes, without overloading them with technical information. The lesson designed for this example case utilizes the social and educational theories introduced during the first day of the workshop. The lesson will include a project designed using the PBL and 5E instructional model frameworks that will involve the use of ready-to-assemble, low-cost 3D-printed exoskeleton kits.

For this exercise, the education researchers will perform the role of the exoskeleton developers of a new wearable robot product. Because these engineering education researchers have the content knowledge of robotics, it will be assumed that in preparing for the workshop they have acquired

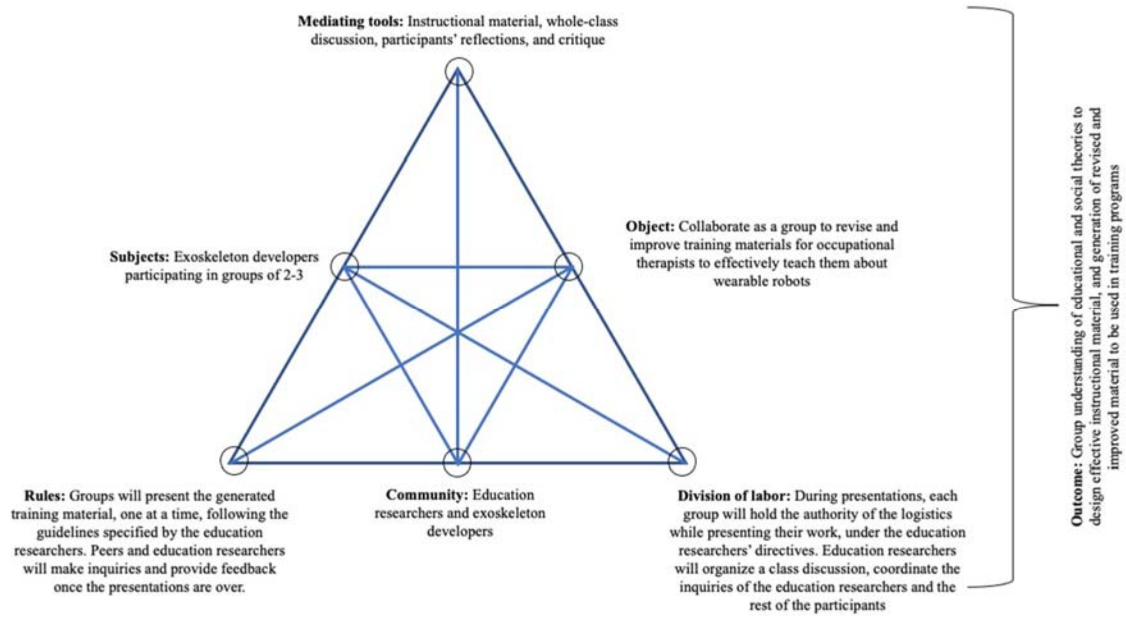


Figure 6: CHAT Activity Framework for Presentation and Improvement of Training Materials

sufficient expertise about the wearable robot's operation principles and operation modes. In contrast, the participants (the original exoskeleton developers) will carry out the role of the OTs, who are expected to learn about the product to further translate this knowledge into implementable recommendations for the final users of the exoskeleton.

4.2. CHAT Analysis

The *community* of this activity will consist of the *pretend* exoskeleton developers and the *pretend* OTs (*subjects*). The exoskeleton developers will interact intermittently with the OTs, who will participate as groups of two to three people.

The *division of labor* and *rules* will change according to the state of the activity. First, the exoskeleton developers will hold the logistical authority to organize the groups of participants and provide the directives to complete the project proposed for this exercise. Then, the exoskeleton developers will share the logistical authority with the OTs, who will collaborate in small groups and follow the guidelines provided for the project. During the group work, the participants will interact with one another only in their own groups. After the groups finish the assigned task, they will present their results to the *community* of this activity, one group at a time. Here, the exoskeleton developers will regain their logistical authority by organizing a class discussion, coordinating the questions of the rest of the OTs and the exoskeleton researchers, and providing feedback to each of the presenting groups.

The *object* of the activity will be for the groups of OTs to investigate and explore the principles of operation and operation modes of a low-cost 3D printed exoskeleton prototype. The groups will be required to assemble the exoskeleton and configure its parameters for pre-programmed operation modes, seeking the proper functioning of the prototype while it is worn by a person.

To fulfill this *object*, the OTs will have access to *mediating tools* such as the project guidelines, project material provided by the exoskeleton developers, group discussions, reflection, and critiques from the exoskeleton developers. The expected *outcome* of this activity will be to achieve a group understanding of the principles of operation of exoskeleton technologies, their benefits, and their intended use for people with upper-limb disabilities. The structure of this activity under the CHAT lens is represented in Figure 7.

4.3. Project-Based Learning

The lesson of this example case will include a project designed using the PBL method to encourage the OTs to cooperate and identify the expected learning outcomes. Following the "Gold Standard PBL" framework, the project design has established the learning goals and considered the seven essential project design elements that a well-designed project should have to maximize student learning and engagement.

The *key knowledge* and *understanding* that the project will seek as the learning goals for the OTs are to understand the principles of operation of exoskeleton technologies, their benefits, and how these can help people with upper-limb disabilities. The connection of this learning goal with real-

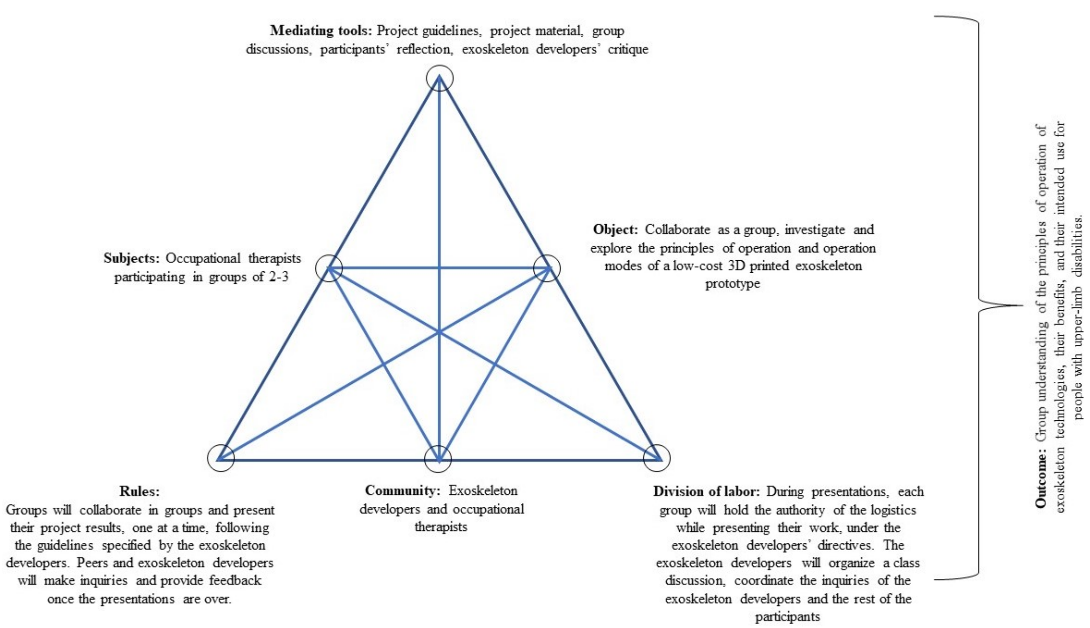


Figure 7: CHAT Activity Framework for Lesson Example

world applications is critical to engage the participants and awaken their interest in the learning process. Since OTs are likely to work directly with clients with limb disabilities, the opportunity of working among peers to complete a project related to their field of work will encourage the development of *success skills*. Specifically, the lesson will encourage the OTs to match the project's learning outcomes to real-world applications in their field through collaboration, critical thinking, and effective project management.

The *challenging question* that will drive this project is: How can technology improve the quality of life of people with upper-limb disabilities to perform ADL? The question will remain open-ended and, initially, it will not be narrowed to a specific kind of technology. This way, it will connect with the prior knowledge of OTs about upper-limb disabilities and encourage them to generate answers using their current knowledge and perception of the role of technology in this context. Moreover, this question will generate a *sustained inquiry* process during the enactment of the lesson that will drive the OTs to ask questions, generate group discussions, and find resources to refine their ideas and translate them into possible answers to the driving question.

In education, the *authenticity* of a project refers to how close the concepts being discussed during the project's development are to applications in the real world [45]. To make this project lesson authentic, the driving question will connect to a real-world problem that is relevant to the practice of occupational therapy. Moreover, the lesson will employ a low-cost 3D-printed exoskeleton kit to illustrate the principles that exoskeletons are used to assist people with upper-limb disabilities. Even though the low-cost exoskeleton design is merely didactical and not intended for medical applications, it will help the OTs understand the limitations and design challenges that exoskeleton developers face while developing a product for real-world applications.

The OTs will be instructed to collaborate in their respective groups and choose one of their team members to serve in the role of a user to wear the exoskeleton. The rest of the team members will assemble the exoskeleton kit and configure the operating parameters to ensure that the user can wear the prototype properly and feels comfortable with the system's overall performance in each of the operation modes available. This way, the lesson will make the OTs' *voices and choices* heard during teamwork and create a sense of ownership for the project and its outcomes. Moreover, the OTs will have opportunities to *reflect* on how the parameter tuning affects the performance of each of the available operating modes and how these would affect the user with an upper-limb disability using it. The group discussion and the feedback from the exoskeleton user will promote a *revision and critique* process on the exoskeleton's final assembly and programmed parameters. This way, the overall quality of the project outcomes will improve and the learning experience will be enhanced.

In the end, each group will present, one at a time, the results of the project lesson to their peers and the exoskeleton developers. This *public product* presentation will motivate and encourage high-quality work since project outcomes will become tangible instead of a private reasoning exchange between the group members. The expected outcomes to be presented will include their answers to the driving question and a description of the overall process of reflection carried out to assist the member of the group designated to use the exoskeleton.

4.4. 5E Instructional Model

This lesson example will be organized using the five cognitive stages that the 5E instructional model suggests. The goal will be for the OTs to understand the concepts through a learning cycle to keep them engaged during the hands-on activity [46]. Details of the 5E instructional model implementation are provided in Table 1.

To ***engage*** the OTs, the exoskeleton developers will show videos about the challenges people with upper-limb disabilities face when performing ADL and some of the current technological solutions available. Then, the exoskeleton developers will set up a discussion exercise, laying out a scenario where the OTs are part of a technology development team, trying to develop the best technological solution to help people with upper-limb disabilities perform ADL. The OTs will discuss in small groups and use their current knowledge of technology to describe the solution they envision, including its principles of operation, the sensors and mechanisms it uses, and its main features.

Later, each group of OTs will be given a low-cost exoskeleton kit to allow them to ***explore*** some of the basic principles of operation of the exoskeleton technology. They will designate a group member as the *client* to use the low-cost exoskeleton and then assemble and customize it for the client's use. The OTs will have the opportunity to investigate the mechanism and explain how it works and how it is controlled for each of its operation modes. Then, based on their intuition about how the exoskeleton should work, they will modify the programs' parameters to achieve the best performance for the exoskeleton.

Next, for the ***explain*** stage, the exoskeleton developers will lead a discussion, where each group of OTs will share their observations and strategies to determine the optimal parameter values for each operation mode. Then, the exoskeleton developers will explicitly introduce the relevant concepts about exoskeleton technologies, explaining their principles of operation, main components, and main characteristics. This stage will conclude with OTs explaining how the low-cost exoskeleton works and the purpose of each operation mode.

The ***elaborate*** stage will allow the OTs to revise the solutions they proposed in the engage stage, considering the newly acquired knowledge. They will also revise their results and observations made while working with the low-cost exoskeleton in the explore stage and will be required to come up with suggestions to improve the low-cost exoskeleton kit.

In the last stage, the OTs will present their revised results and suggestions to improve the low-cost exoskeleton and share their thoughts on how the best technological solution should help people with upper-limb disabilities perform ADL. This will provide the exoskeleton developers an opportunity to ***evaluate*** the learning and designs of the OTs.

Table 1: The 5E Instructional Model for the Lesson Example

<table>
<tr><th>Stages</th><th>Descriptions</th></tr>
<tr><td>Engage</td><td>
The exoskeleton developers will show videos about people with limb disabilities, describing the difficulties they face performing ADL and some of the existing solutions to overcome these difficulties.
The exoskeleton developers will ask the OTs to suppose that they are invited to a panel to discuss the creation of the best technological solution to help people with upper-limb disabilities.
How will this device improve the quality of life of people with upper-limb disabilities to perform ADL?
The OTs will discuss and share observations about the technologies that they are familiar with, including their advantages and current limitations.
The OTs will suggest new solutions or ways to improve existing technologies.
What are the main factors an ideal solution should consider?
How should it work to help patients with upper limb disabilities?
What sensor should it have? What should it sense?
What should be the main features?
Each group of OTs will provide a one-paragraph description of their solution, describing how the solution works, its most important characteristics and how it will help people with upper-limb disabilities to perform ADL.
</td></tr>
<tr><td>Explore</td><td>
The exoskeleton developers will distribute a low-cost 3D printed exoskeleton kit to each group.
Each group will designate a member as the client who will wear the exoskeleton.
The OTs will assemble and customize the exoskeleton kit for the designated client.
The OTs will investigate the pre-programmed operation modes of the exoskeleton. They will modify the programs' parameters and record their observations on how the exoskeleton system performs.
</td></tr>
<tr><td>Explain</td><td>
The groups will share their observations and strategies on determining the optimal parameter values for each operation mode.
The exoskeleton developers will lead a discussion about the principles of operation of exoskeleton technologies, their main components, and characteristics.
</td></tr>
</table>

	▪ The exoskeleton developers will then focus on the low-cost exoskeleton kit, inviting OTs to explain how this exoskeleton works and the purpose of each operation mode.
Elaborate	▪ The OTs will revise the solution they proposed in the engage stage, and improve it based on their current understanding of exoskeleton technologies. ▪ The OTs will revise their results and observations based on their current understanding of exoskeleton technologies and suggest improvements to the design of the low-cost exoskeleton. o What sensors should be added or changed? o What operation modes should be added or changed? o What design changes should be considered? o How could these improvements help people with upper limb disabilities to perform ADL?
Evaluate	▪ The OTs will share their revised results and suggestions for improvements to all their peers and the exoskeleton developers. ▪ The exoskeleton developers will coordinate a final discussion. The OTs and the exoskeleton developers will share their thoughts on the groups' presentations and ideas.

4.5. Hardware

For this example lesson, the low-cost exoskeleton kit [47] consists of a FEETECH high-torque servo motor FS5115M-FB with position feedback, a TAL220 straight bar load cell with a capacity of 10 kg with a HX711 load cell amplifier, and several 3D-printed parts (upper and lower arm cuffs, connecting links) (see Figures 8 and 9). This exoskeleton robotic device is assembled using screws and nuts, and its design adjusts around the user's elbow joint, allowing its only degree of freedom to guide the elbow flexion-extension movement. The 3D-printed upper arm cuff can be adjusted at different positions with various screws and nuts to fit the user's arm size. Additionally, both upper and lower cuffs include hook-and-loop fasteners to firmly accommodate the user arm for the exoskeleton.

The motor and the force sensor are interfaced to an Arduino UNO microcontroller to monitor and control the exoskeleton system. A set of pre-programmed operation modes is to be offered through a program designed to execute on the microcontroller. These operation modes will be made accessible to the users through a graphical user interface (GUI) that will communicate with the microcontroller through a Bluetooth or Wi-Fi module. The GUI will allow the users to modify the tunable parameters of the exoskeleton safely and without compromising the overall system functionalities.

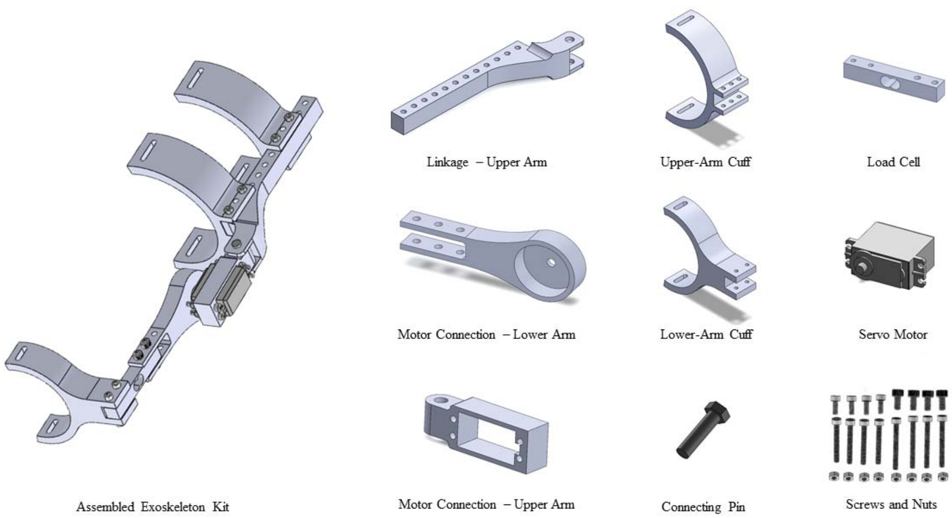


Figure 8: Exoskeleton Kit Hardware – 3D Models

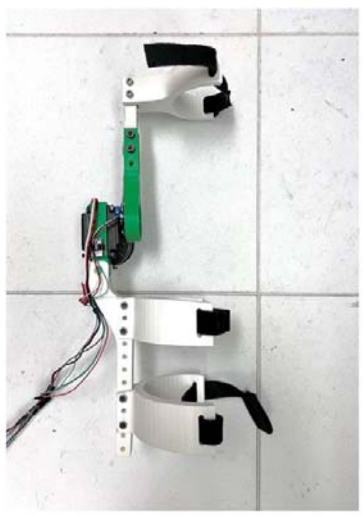
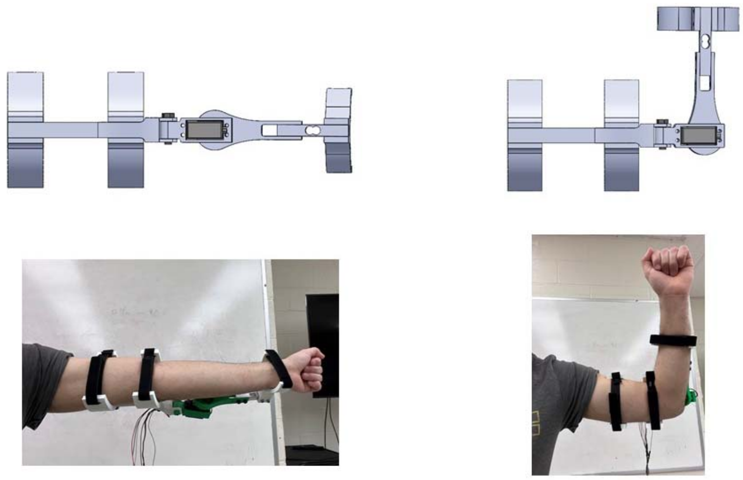


Figure 9: Assembled Exoskeleton Kit

4.6. Control Modes

The exoskeleton system will have four different operation modes: (1) point-to-point movement, (2) record-and-play trajectory, (3) basic admittance, and (4) virtual wall. Each mode will illustrate the different functionalities that the exoskeleton prototype offers and allow the modification of specific parameters that will modify its angular position based on the mode selected, the parameter values set by the user, and the sensor readings. The system will have an angular range of operation between 0˚ and 90˚. Specifically, it will consider the minimum angular position (0˚) as the position when the elbow is fully extended and the maximum angular position (90˚) as the position when the elbow is flexed forming a right angle with respect to the upper arm (see Figure 10).



Position a 0° Position a 90°

Figure 10: Exoskeleton Positions

Point-to-point movement: The point-to-point movement mode will implement a back-and-forth movement between two commanded angular positions for a determined number of times. The user will set the number of repetitions and the angle values for the initial and final position of the back-and-forth movement. To control the angular position, the controller will read the values of the angle sensor and change the angular position of the exoskeleton according to the commanded angle values provided by the user.

Record-and-play a trajectory: The record-and-play trajectory mode will start with a recording phase, allowing the exoskeleton's free movement for a specific time. During this time, for the trajectory of the movements performed by the user, this mode will obtain the corresponding measurements using the angle sensor readings and store the same in the controller memory. Then, after waiting for a short period, this mode will reproduce the trajectory stored in the memory by changing the angular position of the exoskeleton accordingly. The user will be able to set the number of seconds for the recording period, whose range will be restricted by the controller's available memory, and the waiting period before reproducing the trajectory.

Basic admittance: In the basic admittance mode, the controller will measure the interaction force readings from the force sensor and will move the angular position of the exoskeleton by an angle that will be proportional to the sensed force. In this mode, the user will have access to modify the controller gain, which determines the controller's responsiveness to the applied force. With an increasing value of the control gain, a smaller applied force will cause a change in the angular position of the exoskeleton. On the other hand, if this gain value decreases, the user will need to apply a greater force before the exoskeleton angular position starts to vary.

Virtual wall: In the virtual wall mode, the controller will behave the same way as in the basic admittance mode. However, it will only allow the exoskeleton to move in a certain range and prevent it from moving beyond the defined range of motion. The user will be able to modify the minimum and maximum angle values of the range of motion, and the controller gain to determine the controller's responsiveness to the force applied.

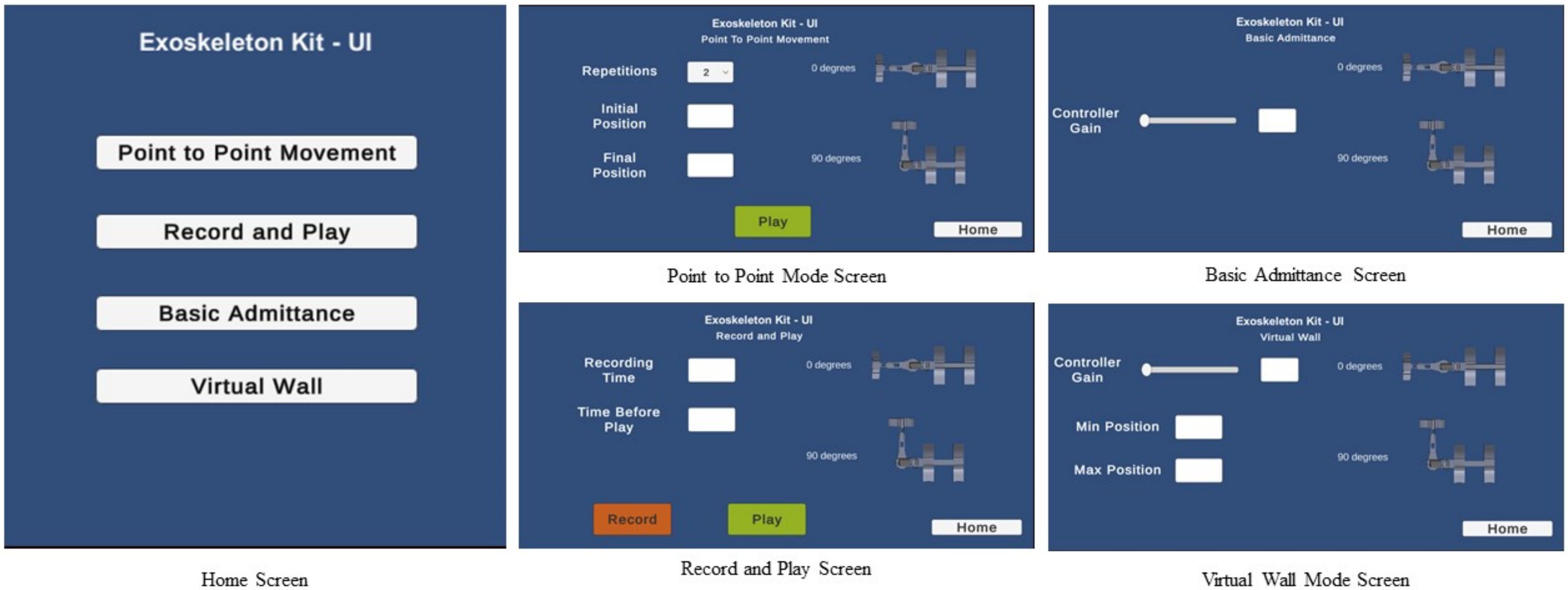
4.7. Graphical User Interface

The designed system will include a GUI to help guide the users when they work with the exoskeleton kit. The GUI will communicate with the microcontroller using a Bluetooth or Wi-Fi module. The GUI will consist of an application developed using the Unity Game Engine, that will be available as a web application and a mobile application. Through different programmed screens, the users will be able to select among the available modes and modify the parameters of each mode safely and without compromising the system's overall functioning (see Figure 11).

5. Discussion and Future Work

The workshop plan considers starting by introducing the exoskeleton developers to a cultural and historical review of occupational therapy as a profession and to relevant social and educational theories, to provide them with the tools and background necessary to design effective training material and structures that will translate their technical research into implementable recommendations for OTs. The targeted social theories will allow the exoskeleton developers to recognize the social capital and use it in favor of the KTE. Moreover, it will engage them in designing lessons effectively by identifying and managing the elements of an activity (see the CHAT framework) that affect the outcomes of a learning process. Alternatively, the educational theories will provide the exoskeleton developers with the design and planning frameworks that will take into account essential pedagogical factors that affect the learning process and organize them in a learning cycle to keep the learners engaged during a lesson (see the PBL and 5E frameworks). Next, the exoskeleton developers will generate training materials to train the OTs. These materials will be presented to all the workshop participants, with the goal of generating a process of revision and improvement where exoskeleton developers and education researchers participate. Such a process will allow the exoskeleton developers to create effective training material to train OTs without overloading them with technical information.

The social capital in a social network formed by the OTs and engineering researchers developing exoskeleton technologies can significantly benefit the learning process. To access this capital, special attention needs to be given to promote social relationships through trust, acknowledgment, and mutual recognition among the network members. In the context of this work, the social network formed solely by the exoskeleton developers from diverse engineering backgrounds already engenders access to essential resources that may favor the design of effective lessons.



Point to Point Mode Screen

Basic Admittance Screen

Home Screen

Record and Play Screen

Virtual Wall Mode Screen

Figure 11: GUI screens

These resources, embedded in the social relationships of the network, may be available in any form (e.g., objects, services, influences, knowledge) and can be explored to design lessons that can facilitate the process of translating technical research into implementable practices for people without an engineering background. By adding to this network the expertise of OT about clients with upper-limb disabilities, who are the intended final users of the exoskeleton product, the available resources in the network will increase significantly. By considering the perspectives from OTs about the potential users of exoskeleton technologies, the instruction planning can become an exercise of mutual learning that can provide the network members the means to complement the lesson planning and the overall KTE significantly. Because of this, the introduction to the concept of social capital will emphasize the importance of building social relationships to maximize access to social capital and enhance the quality and relevance of a lesson.

To plan a learning lesson, the CHAT framework will provide the exoskeleton developers the means to identify the elements involved in the activity development and recognize how their possible interactions may affect the learning experience. While developing training material, the exoskeleton developers expect that at the end of the activity, the OTs (subjects) accomplish an understanding of the essential technical aspects of the exoskeleton product developed. The exoskeleton developers will determine the actions that the OTs need to take to reach the outcome (object) and the mediating tools (e.g., training material, interactions between OTs and exoskeleton developers) that will assist them in performing those actions. Furthermore, the CHAT framework considers how these elements are shaped by policies and conventions (rules) followed by the individuals involved in the development of the activity (community) exercising specific roles (division of labor). These rules and division of labor are established by the lesson's design and are also influenced and determined by cultural and historical factors that evolve over time. In the case of an activity where exoskeleton developers and OTs constitute the community of the activity, their distinct education backgrounds and areas of expertise, and even the time and place where the lesson is being held, can inform how the lesson should be delivered to accomplish an enhanced learning experience.

To design lessons and generate training materials, the exoskeleton developers will also be introduced to the PBL method and the Gold Standard PBL as a framework to implement this method. These will serve as tools during the training material design to ensure that the exoskeleton developers take into account the essential elements specified in the Gold Standard PBL that can facilitate the student learning experience and the achievement of the lesson's learning goals. In the context of this workshop, the aim will be for the exoskeleton developers to include in their lessons' training materials hands-on activities that illustrate the characteristics of the exoskeleton product, to encourage the OTs to cooperate and intuitively identify the exoskeleton product's operation principles, modes of operation, and essential technical aspects. This way, the OTs will feel engaged in the learning process and perceive the learning experience as meaningful and beneficial for their PD.

Finally, the 5E instructional model will provide exoskeleton developers with a framework to organize the lessons and structure the generated training material in the five stages proposed by the model to ensure that the OTs experience a learning progression that will keep them engaged during the enactment of lesson and its hands-on activities. Consequently, the lessons and training material generated by the exoskeleton developers at the end of the workshop are expected to first engage through tasks, questions, or demonstrations about exoskeleton technology. Then, the OTs will be encouraged to explore solution strategies to the situations presented in the previous stage, and then the OTs will perform hands-on activities that illustrate the working principles of the exoskeleton product, that will help them to identify the concepts through which they can explain their reasoning. In the following stage, they will elaborate their understanding by considering different circumstances regarding the benefits and challenges of using exoskeleton technologies, and, in particular, the developed exoskeleton product. At the end of the learning cycle, the exoskeleton developers will evaluate the OTs' understanding through public presentations and individual assessments.

The lessons designed in this workshop will be implemented in a two-day session that will be conducted by the exoskeleton developers after being trained in the development of effective training materials. Further research will explore and evaluate the learning outcomes of the OTs and analyze the effects of considering the educational and social theories adopted in this work in the design of educational material for occupational therapy. The structure considered in this workshop will be studied to explore its various elements that have the potential to render a replicable methodology beyond OT training. For developers of engineering products, such a study will produce guidelines to identify appropriate theoretical constructs and instructional tools for designing effective training materials that can translate technical research into implementable recommendations for users who may not require in-depth technical expertise. This replicable methodology will begin with an exploration of the cultural and historical background of the targeted users' profession and then integrate strategies adapted from the social capital theory and the CHAT framework. Following such a preparation, engineering professionals will become capable of identifying the available resources in a social network and designing the training activities by accounting for the economic, cultural, and historical dynamics embedded in the training activities. Finally, the consideration of PBL and 5E frameworks will provide the engineering professionals with the instructional planning and design tools to enhance the learning process and organize it in a learning cycle to keep the learners engaged during the training activity.

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