# AI in the Shell: Towards an Understanding of Integrated Embodiment

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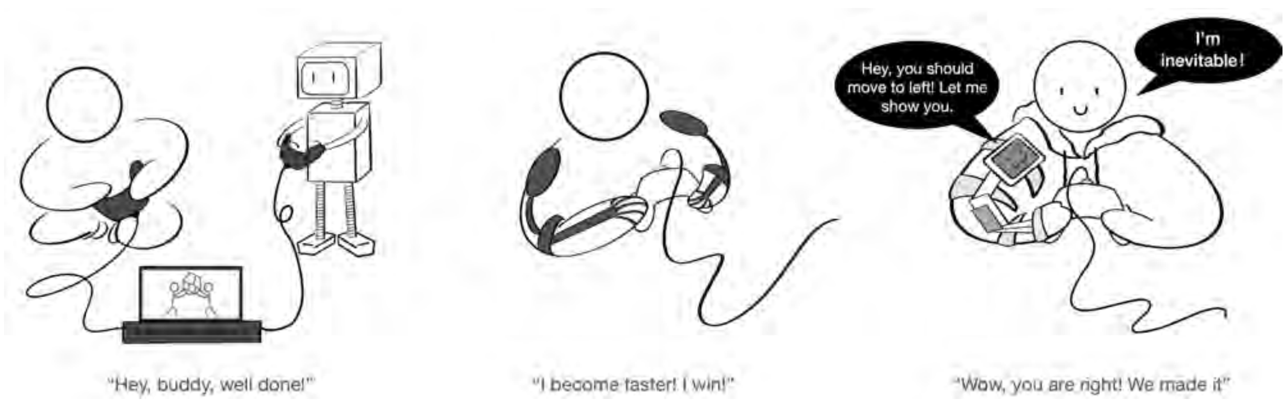


**Figure 1: Human-Computer Integration highlights a partnership between computers and human, while overlooking how users' embodiment relates to technologies. Meanwhile, in recent years, technologies are becoming increasingly closer and even interwoven with the human body to enhance their bodily capabilities, mediating their embodiment and making them feel augmented. In this work, we explore whether computers can incorporate into one's embodiment and form a partnership with the user.**

## ABSTRACT

With technologies becoming increasingly intelligent, the interaction paradigm of Human-Computer Integration where computers and human form a partnership emerged. Most of these works considered computers as separate from users' embodiment. However, in recent years, technologies are becoming increasingly closer and even interwoven with the human body. Our work asks whether computers can incorporate into one's embodiment and form a partnership. We call this ***integrated embodiment***. Such a paradigm might facilitate a more direct and intimate partnership between humans and computers. To exemplify the paradigm, we present *AI-in-the-Shell*, an exoskeleton-based system that enables users to experience having an AI residing in their body. The AI-powered system can make independent decisions and actuate the user's body to better support their daily tasks and experiences, e.g., to enhance their game performance. We hope this work can extend the current understanding of Human-Computer Integration, and step towards a more complete understanding of integrated embodiment.

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## CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; **Interaction paradigms**; *Interaction design.*

## KEYWORDS

Integrated embodiment, human-computer integration, augmented human, exoskeleton

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## 1 INTRODUCTION

With the recent development of autonomous and intelligent technology, human-computer interaction is gradually transiting from the traditional 'stimulus-response' schema to *Human-Computer Integration (HInt)* where computers and humans form a partnership [12]. Such a partnership indicates that technologies usually obtain a higher level of autonomy compared to traditional interactions. A typical example is a smart alarm that can determine when to wake the user up based on the weather and traffic of the day. With HInt, human and technologies are codependent, drawing meaning from each other's presence.

Most of the current HInt systems consider computers as separate from the user's embodiment, showing limited influence on how we experience our body and how we use our body to interact with our surroundings. However, in recent years, technologies are becoming increasingly closer and even interwoven with the human body, which might mediate our embodiment [22]. The rubber hand illusion is a typical example as the experiment lets one experience a rubber hand as one's own and hence influences one's way of reacting to external stimuli [5]. As recent phenomenological research suggested, our body and its actions become technologically embodied when embodiment incorporates technology [22].

The trend of technological embodiment and HInt inspired us to consider: can we design technologies that incorporate into our embodiment and form a partnership? We call this paradigm ***Integrated Embodiment***, which highlights a tight intertwinement between intelligent technologies and our lived body. To exemplify the paradigm of *integrated embodiment*, we present *AI-in-the-Shell*, an interactive system that enables users to experience an AI-powered arm-worn exoskeleton as an intelligent partner for supporting daily tasks and experiences. The exoskeleton is powered by AI to actuate the user's limbs for certain tasks. As such, the exoskeleton actuation is controlled by an intelligent AI while being experienced by the users in an embodied manner. In other words, with *Integrated Embodiment*, AI shares a certain level of bodily autonomy with the user. At this stage, we chose to experiment the system in games and play scenarios. We trained an AI to play Pong via reinforcement learning techniques. With such a system, AI can serve as a partner to support either collaborative play or competitive play. For example, the player can be actuated by the exoskeleton to achieve better game performance; while can also use one arm to play against another 'player' controlled by the other AI-actuated arm.

Our work makes the following contributions.

- Presenting the paradigm of *integrated embodiment* where intelligent technologies incorporate into one's embodiment and form a partnership.
- Presenting an interactive system *AI-in-the-Shell* that allows users to experience *integrated embodiment.* The AI actuates the user's body via an arm-worn exoskeleton to better support their daily activities. The system can serve as a vehicle to help us understand the design and user experience of *integrated embodiment.*

Ultimately, with our work, we hope to open up a design space of *integrated embodiment* to extend the relationship of embodiment between human and computers, and also enrich the current understanding of Human-Computer Integration.

## 2 RELATED WORK

In this section, we present interaction theories and practices that are closely related to *integrated embodiment*, i.e., Human-Computer Integration, technological embodiment, and shared agency.

### 2.1 Human-Computer Integration

Human-Computer Integration (HInt) refers to a 'partnership or symbiotic relationship in which humans and software act with autonomy' [12]. One example is the semi-autonomous vehicle, where users and computers work together to drive. We can also see concepts from other disciplines that share similar understandings with HInt. For example, the notion of *human-AI collaboration* refers to the paradigm where humans and intelligent technologies work for a shared goal [37]. Another example is *human-centered AI* which highlights that AI is to enhance human capabilities rather than replace them [38]. Similarly, Ren et al. [30] presented *human-engaged computing* which refers to synergized interactions between humans and computers for high-level wisdom that enhances human's survival probability and full potential. Mueller et al. [27] elaborated on the concept of HInt, highlighting the close interwoven between human and computational systems.

These theoretical theories have motivated the emergence of numerous design knowledge in the field. For example, Andres et al. [2] presented *integrated exertion* where technologies can extend the user's physical abilities by performing contextually-aware actuation and control negotiations in the context of exertion interactions. On a practical level, the authors presented augmented eBikes that can actuate based on the user's body postures [1]. As the user leans forward to invest more physical efforts during cycling, the electrical assistant module is activated and hence the eBike goes faster. There are other practical works around Human-Computer Integration. Some of them explored the design of intelligent agents and IoT devices as smart companions or collaborative partners [9, 31]. For example, Khot et al. [17] designed a robotic dining companion that acts like a human co-diner to enrich the social experiences during solo dining.

These works suggested a trend where the relationship between humans and computers is transiting from the 'master-slave' mode to a partnership with a relatively equal relationship. Our work also contributes to the HInt paradigm as we hope to support a partnership between computers and users. Meanwhile, we argue that current works around HInt mainly focused on the partnership facilitation while overlooking how these technologies might influence the users' embodiment. Our work investigates whether we can experience an integrated embodiment with technologies where technologies are incorporated into our embodiment to form a partnership. With *integrated embodiment*, we can experience the intelligent technology through our lived body.

### 2.2 Technological Embodiment

Our embodiment is not static but can be mediated via technologies, mostly when the technology becomes integrated into our body [13]. As Ihde suggested, technologies can form an *Embodiment* relation with users when users embody the technology [15]. In this condition, the technology becomes an extension of the human body, and users experience and interact with the world via this extended body [36]. Prosthetics that can let people experience as part of their body is a typical example of technological embodiment. Another example was given by phenomenologist Merleau-Ponty, presenting that a blind man can incorporate his cane into his embodiment and hence can experience the surrounding world via the tip of the cane [11].

Inspired by the malleable nature of one's embodiment, HCI researchers have explored how technologies can be designed to mediate one's embodiment, either for functional goals like augmenting one's bodily capabilities or for experiential goals like facilitating engaging bodily experiences. Leigh et al. [20] presented the concept of *Symbiotic Human-Machine Interfaces* which refers to interfaces where technologies offer extended functions of existing parts of the human body, while establishing low-burden communication with human sensorimotor or somatosensory systems. Danry et al. [10] further presented the paradigm *Experiential Integration* where users experience technologies as part of 'themselves' rather than 'others'. With technologies that support *experiential integration* performing certain functions, one experiences 'I did that!' rather than 'The machine did that' or 'I made the machine do that'. Rapp [29] made theoretical contributions from a postphenomenological perspective, arguing how wearable technologies can form an extension relationship with users and influence how users relate to the world.

We can also see a number of practical works in the field that aimed to design technologies to mediate one's embodiment. Saraiji et al. [32] presented MetaArms, a pair of wearable robotic arms that are operated by the user's legs and feet. Such a system could give users an extra pair of limbs to achieve tasks that are hard to be completed with two hands. The associated user study demonstrated that MetaArms could extend the user's embodiment as users suggested that they felt like the robotics arms were part of their own body. Misawa and Rekimoto [23] presented ChameleonMask, a telepresence system that displays a remote user's face on a real human's face, making the surrogate be regarded as the actual remote person. Tajima et al. [33] investigated the use of electrical muscle stimulation (EMS) to assist users' touch and let users experience as if they have pressed a button rather than being forced by technologies to press. Apart from utilizing bodily-integrated technologies, researchers found that sensory experiences can also be designed to mediate one's embodiment. For example, auditory, haptic and olfactory stimuli can influence one's body images and hence shape their sense of embodiment in daily life, which might further influence how they interact with the world [6].

The above works around technological embodiment have shown the malleability of one's embodiment and provided practical guidance on how we can design technologies to mediate one's embodiment. These works have huge potential in fields like human augmentation and rehabilitation. However, they mainly placed the human body at the center stage, exploring how technologies can be incorporated into one's lived body to extend their embodiment. In this condition, the technology is experienced as part of the user's body and therefore remains 'transparent' to the user. On the contrary, our work presents *integrated embodiment* where users do not necessarily experience integrated technologies as part of themselves. Instead, the users embody the technology and experience it as an intelligent partner.

### 2.3 Shared Agency

Shared agency is an emerging interaction paradigm where computers own a certain level of agency over the user's body. Systems that support shared agency are often designed to actuate the user's body for communications or facilitating intriguing bodily experiences.

A representative work that designed shared agency for information communication is PossessedHand, an electrical muscle stimulation (EMS)-based system that can control the user's hand dynamically and mechanically [34]. Such a system can be used, for example, for assisting musical instrumental learning or supporting navigation by actuating the user's hand to point to a certain direction. Later, Lopes et al. presented that one's proprioceptive sense, i.e., feeling the pose of one's own body, can be used as a design material for interactions [21], and developed Pose-IO, a wearable device that provides interaction input and output based on proprioception. The system senses the user's wrist movement via accelerometers as input and provides output information by actuating the user's muscles via EMS. These works that utilized body agency for digital communication mainly considered the human body as design material, without much discussion on the user's embodiment.

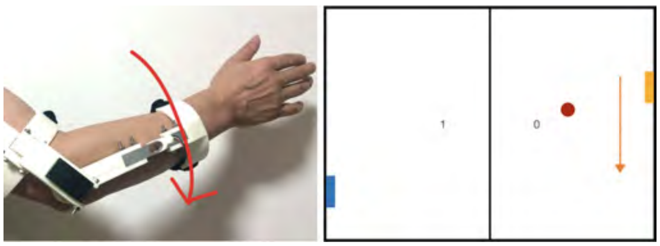
There are other works that considered how shared agency might facilitate intriguing bodily experiences. Byrne et al. [7] used Galvanic Vestibular Stimulation (GVS) technology to induce vertigo experiences and hence reduce the player's agency in a two-player balance game. Patibanda et al. [28] discussed shared agency in bodily play, and presented a design concept of *body-actuated play*, which refers to digital play that leverages body-actuating technologies such as EMS to facilitate game input and output. Mueller et al. [26] presented a design framework based on a set of design exemplars to highlight how limited control over the human body can be used to facilitate playful experiences. Similarly, Benford et al. [4] introduced a conceptual framework of *contesting control* in bodily interactions and unpacked key dimensions of associated user experiences, i.e., the surrender of control, self-awareness of control, and looseness of control. These works indicated the potential of shared agency in designing playful and engaging bodily experiences.

However, most of these systems around shared agency did not support a sense of integrated embodiment as most of them were 'smart' technology rather than 'intelligent' technology. In these works, bodily actuation was pre-determined by programming, e.g., via decision trees. Meanwhile, in our work, we aim to design intelligent devices that can make decisions without being pre-programmed, but improve themselves based on past learning. As such, instead of following well-defined rules to solve a specific task, intelligent devices can automatically extract knowledge based on prior data and adapt them to daily tasks. Also, intelligent devices are easier to be modified and improved by adding new data for learning. By doing so, with *integrated embodiment*, the user can experience the intelligence technology as a 'partner' incorporated into their embodiment rather than a smart tool that extends their body.

## 3 DESIGN EXEMPLAR: AI-IN-THE-SHELL

*AI-in-the-Shell* is a design exemplar of *integrated embodiment.* It is an AI-powered wearable exoskeleton where computers can make

(a)



(b)

**Figure 2: These two figures illustrate how the AI-powered exoskeleton actuates the human player's limb to play Pong. The game interface consists of two paddles and a ball. With *AI-in-the-shell*, the exoskeleton takes over the player's arm to move an in-game paddle to hit a ball back to the other side based on the instructions given by AI. The goal of the AI is to hit the ball and make the opponent miss the ball when it is passed to the opponent's side. (a) The exoskeleton actuates the player's arm to flex for moving the yellow paddle up. (b) The exoskeleton actuates the player's arm to extend for moving the yellow paddle down.**

decisions independently and actuate the human body for performing daily tasks. The system also supports low-burden communications between the exoskeleton and users via bodily actuation. As such, users can experience an AI as a partner 'residing' in their body. To demo the system, we trained an AI to play the game Pong via reinforcement learning techniques. With our system, the player's arm can be actuated by the exoskeleton to achieve better game performance (see Figure 2). Next, we will elaborate on the system details and preliminary user experiences.

## 3.1 System Design

In our work, we designed the exoskeleton to serve as the user's playmate for playing Pong, a two-player computer game where the player controls an in-game paddle to hit the ball back and forth. The player earns a point when the opponent fails to return the ball. The game ends when a player wins by getting 11 points. With *AI-in-the-shell*, the exoskeleton supports both bodily input and output when playing Pong. When AI is not activated, the exoskeleton can be used to measure the player's arm movement, i.e., the player can use the exoskeleton as a 'game controller' to sense their bodily inputs for the paddle control. The exoskeleton can also be used for actuating the player's arm, i.e., taking over the player's arm to control the paddle for better game performance. Next, we introduce our interaction design with *AI-in-the-shell*.

Pong usually supports two modes:

- Player vs. Player: Both the paddles are controlled by human players via input devices.
- Player vs. Computer: One paddle is controlled by a human player while the other paddle is controlled by the computer.

Based on this, our work envisions the following interaction scenarios with *AI-in-the-shell*:

- Player vs. AI: The player controls one paddle with a free arm. The other arm is actuated by the AI-powered exoskeleton to control the other paddle.
- Player(+AI) vs. Computer: The human player initiates the game and battles against the computer. When AI finds that the player falls behind the computer, it communicates with the player via bodily actuation to apply for joining the game. Once the player agrees AI to involve, AI will take over the player's limb and battle with the computer.
- AI(+player) vs. Computer: In the player's daily life, when the AI detects that the player is not using their limbs for daily tasks, the AI might ask the player whether it can play games as it is boring. Once the player agrees, AI will actuate the player's arm to battle with the computer. The human player can join the game at any time, turning the mode into the Player vs. AI mode.

With the three interaction scenarios, AI acts like our partner who can play with us, help us when we have difficulties in play, and even express its willingness to play during leisure time. We note that the possible interactions with *AI-in-the-shell* are not limited to these scenarios. In the future, we can explore more interaction possibilities. For example, we can deploy the system for playing strategic games and support real-time human-AI negotiations via bodily actuation, letting AI better play to its strengths with decision-making. Here in this work, we designed these three game scenarios to demo a future where we experience a partnership between human and technology through integrated embodiment.

## 3.2 System Implementation and Pilot Deployment

*3.2.1 Hardware.* Our system was developed based on the EduExo robotic exoskeleton kit 1.0 version[1], an exoskeleton for supporting users' elbow movements execution. The device includes an angle sensor and a force sensor to read the elbow angle and the interaction force between the exoskeleton and the user. The actuation is powered by a motor situated at the user's elbow joint. The exoskeleton kit also includes an Arduino Uno R3 as the control module to read signals from the position and force sensors, and to control the movements of the motor. In the AI mode of our work, we use Arduino Uno R3 to receive signals from our AI algorithm and further control the actuators to determine the player's arm movement.

*3.2.2 Software.* The first step of software implementation is game development. We developed the Pong interface with 640 x 480 pixels based on [16]. The game difficulty can be adjusted via the speed of the moving ball. The game becomes more difficult as the ball

[1]The EduExo Robotics Kit, a do-it-yourself robotic exoskeleton kit launched by Auxivo AG. https://www.eduexo.com/eduexo-kit/

moves faster. In our game, the speed of the ball ranges from 0 to 2,100 pixels per second.

Then we developed the Computer player by programming the paddle to move up and down to the vertical coordinate of the moving ball. To evaluate the game performance of the Computer player, We did a pilot study with four human participants. We set the ball speed as 2,100 pixels/second and asked each participant to play against the Computer player for five rounds. Players wore the exoskeleton to measure their arm movements for controlling the in-game paddle. The average score was 11 (Computer) : 0 (Human). This result showed that with the game's maximum difficulty, a human player was nearly unable to win the Computer player.

The next step was to train an AI player to achieve a better game performance than the Computer player. We used reinforcement learning (RL) techniques to train the AI. The principle of RL is to let an AI agent try to take actions that maximize its rewards in its environment. In our work, we utilized DQN algorithm to train the AI. DQN is a common-used RL algorithm that combines Q-Learning, a model-free RL algorithm, with deep neural networks to let RL work for complex environments like video games [25]. Prior research has demonstrated the efficiency of DQN for training an AI to surpass a professional human Pong player [24]. In the training process, we sent the game screenshot of each frame to the AI agent as input, and let it decide the in-game actions, i.e., moving the paddle up or down. After the training, the AI reached a robust level and could beat the computer by 11:0 on average when the ball speed was set as 2,100 pixels/second.

*3.2.3 Deployment and Preliminary User Experience.* We deployed the trained AI to the exoskeleton, and recruited another four participants to experience our system. Each participant was first invited to battle against the Computer player without AI-powered actuation. We hoped this could help players become familiar with the game and also experience the difficulty of playing against the computer. With the ball's moving speed increasing, all the participants found the game became more difficult. The average score was 11 (Computer) : 2 (Player) when the ball's moving speed was 1,000 pixels/second. When the speed reached 2,100 pixels/second, the average score was 11 (Computer) : 0 (Player). Then we activated the AI, letting the exoskeleton take over the player's limb to battle against the Computer for another five rounds when the ball speed was set as 2,100 pixels/second. The average score was 11 (AI) : 2 (Computer). After this, we asked players about their game experiences. All the players considered the experience intriguing and playful. One participant said: "This was fantastic. It was like having a professional gamer holding my arm to play!"

Next, we set the game to the player vs AI mode. All four participants were right-handers so we asked them to wear the exoskeleton with the left arm. During the study, participants used their right arm to control one paddle and the other paddle was controlled by their left arm actuated by the exoskeleton. All the participants found that AI was inevitable and they could not win the game, which made them feel a bit frustrated.

After the study, our participants reported their reflections on AI's game strategy. Players mentioned that during the first round of play, without the AI actuation, they kept stretching and bending their arms to move the paddle, aiming to catch the ball. However, when being actuated by the exoskeleton, they found that sometimes the device stopped for a second and then started to move to the right place to catch the ball. They thought it was because the AI stopped to predict the ball's path after it hit the boundary and then controlled the paddle to wait at the right place in advance rather than chasing the ball in a hurry. Our participants believed that this strategy could be used to improve their game performance. Therefore we finally set the system to player vs computer mode again, letting players try out this strategy without the AI-powered actuation. The results showed that the players' game performance was greatly improved. When the ball's moving speed was set as 1,000 pixels/second, the average score raise to 11 (Computer) : 5 (Player) from 11 (Computer) : 2 (Player). This finding showed the benefits of having an intelligent AI compared to programming with well-defined rules. With well-defined rules, computers would actuate the human body following the developers' pre-setting. Meanwhile, with *integrated embodiment*, the AI automatically learn from the prior data and generate their game skills and strategies which might not be expected by designers. As such, the player might learn new strategies from AI. In other words, with prior works that used pre-defined rules to actuate the player's body, one can only overcome their limited human reaction time to achieve tasks that cannot be completed in the past; while with *integrated embodiment*, one can also overcome the human's limited strategic understanding of certain tasks. This is similar to prior research around RL. For example, AlphaGo, the RL model for playing the game Go, can be used to help discover novel game strategies. By embedding RL techniques, AlphaGo is able to perform counter-intuitive yet powerful moves with a spirit of flexibility and open-mindedness [3].

Overall, our preliminary user study gave us a first insight into the potential user experience of *integrated embodiment*. It demonstrated that with our system *AI-in-the-Shell*, players could experience having an AI embodying in their body and serving as a partner. Meanwhile, the study also indicated how the system could be further iterated before the formal user study. For example, in the future design of Player vs. AI mode, we can design the AI player to dynamically adjust its game skill to keep the human player within a state of flow [8]. Also, the study demonstrated the potential of using AI-powered exoskeletons to teach players motor skills and game strategies. In the future, we might consider other types of games that require a higher level of motor or strategic skills in our system to investigate how players can learn from AI through their embodiment.

## 4 LIMITATIONS

This work has limitations. First, we explored the paradigm of *integrated embodiment* in the context of games and play as a starting point. We believe games and play is an area suitable for open explorations. In future work, we will explore the paradigm in other daily scenarios. For example, we can apply the paradigm in digital health to design an AI-powered wearable for intervening in one's inappropriate health behaviors. We might also investigate *integrated embodiment* the paradigm in scenarios that require certain skills. For example, for people who are learning how to cook, we can design the exoskeleton to borrow the user's arms to cook better. Second, in this work, we only explored using an arm-worn exoskeleton to demo the idea of integrated embodiment. We chose this device in our design as it can take over one's body and execute certain fine motor movements, which can let players experience an AI embodying in their body and sharing a certain level of autonomy when performing certain tasks. In the future, we can also explore other forms of bodily-actuated technologies such as leg-worn exoskeletons and EMS. Third, we did not investigate the AI(+player) vs. Computer scenario in this preliminary study, as we think a field study would be more appropriate for testing this scenario. We will explore the player experience with AI(+player) vs. Computer scenario in future field studies.

## 5 FUTURE WORK

We are interested in understanding the user experiences of *integrated embodiment* in the field. In future work, we will design a questionnaire based on the Sense of Embodiment (SoE) questionnaire [18] and the Sense of Agency Scale (SoAS) [35], and add more items that relate to *integrated embodiment*. For example, we will ask whether the player experiences a co-embodiment with the AI, whether they experience a partnership with the AI, and how much they trust the AI. We will conduct a pilot study to evaluate the understandability and efficacy of the questionnaire and iterate its design [19].

To conduct the user study, we will invite 15 participants to experience the system in the field for two weeks. On the day of the study, we will invite the participant to our research lab and help them wear the exoskeleton, set up the system, and also educate them on how they can deploy the system by themselves. Then the participant will leave our lab and experience the system for two weeks. After the experience, we will ask the participant to fill out the questionnaire and conduct a semi-structured interview. The aim of the interview is to further unpack the user experience and the paradigm of *integrated embodiment*. The quantitative data will be analyzed via statistical methods and the interview data will be analyzed via inductive thematic analysis approach [14]. Based on the results, we will articulate the user experience of *AI-in-the-Shell* and discussed the key design themes of *integrated embodiment*.

In the long term, we will further explore the paradigm of *integrated embodiment* via designing and studying more design exemplars. For example, in this work, we only explore Through analyzing the design and user experience of these exemplars, we will generate a design framework of *integrated embodiment* and evaluate the framework via a focus group.

## 6 CONCLUSION

In this work, we present ***integrated embodiment***, an interaction paradigm where the computer incorporates into the user's embodiment and acts like a partner. To exemplify this idea, we designed and developed *AI-in-the-Shell*, an AI-powered arm-worn interactive exoskeleton that can play the game Pong. With *AI-in-the-Shell*, the player can experience playing with AI through their own body or improving their game skills with the bodily support provided by the AI. We hope this work can help us step towards an understanding of designing *integrated embodiment*. Ultimately, we hope to open up a design space of *integrated embodiment* to extend the current understanding of Human-Computer Integration.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