Migration Between Two Embodiments of an Artificial Pet

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Abstract

Characters that cross dimensions have elicited an avid interest in literature and cinema. In analogy to these characters, we explore the concept of migration: process by which an agent moves between embodiments, being active in only one at a time. We developed an autonomous artificial pet with two embodiments: a virtual within a smartphone and a physical robotic embodiment. Considering that owners' interactions with real pets lead to emotional attachment and potentially related health benefits, we conducted a user study with elementary school students to assess their attachment to the prototype and how natural they felt the interaction was. By the end of the experiment children felt closer to the artificial pet and 43.3% considered the two embodiments to correspond to the same entity, although migration was never explained to them. As a result, this paper presents a novel generic methodology that allows the evaluation of other implemented prototypes that support migration. Furthermore, we created a set of design guidelines for migrating agents.

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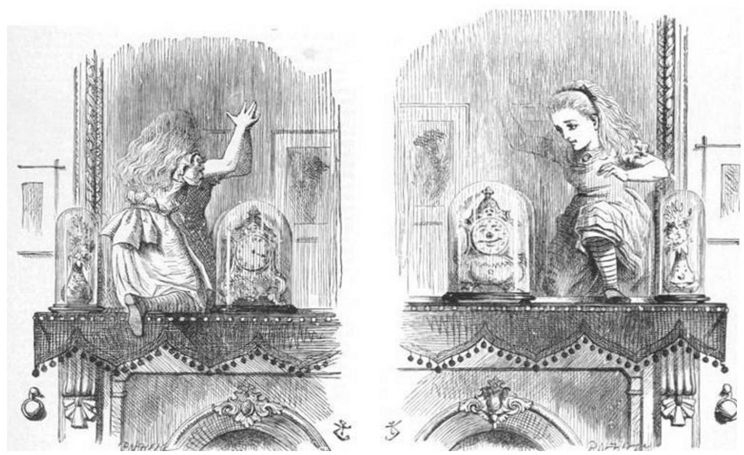

Figure 1: Alice entering the Looking Glass. Illustration by Sir John Tenniel.

1 Introduction

Story characters that cross dimensions have a peculiar way of tickling our imagination. *Alice* going *Through the Looking-Glass*(Figure 1[2]), *Neo* diving in and out of *The Matrix*, or even *Frodo* sliding into a shadow dimension in *Lord of the Rings*, are all story elements that echo in our collective consciousness. Perhaps they appeal to an inherit desire to transcend our human limitations, go beyond what meets the eye, and see a new truth through the foggy reality of our everyday lives. Whatever the reason, characters that *migrate* between dimensions have elicited an avid interest in literature and cinema, among other art forms.

In analogy to these dimension crossing characters, one can imagine an agent that inhabits the real world with a physical body, but whose essence can be transported to a virtual world. For example, an agent could have both a robotic embodiment and a virtual representation in a hand-held device. Would such an agent have the same appeal as cinema characters that hop dimensions? Would people see the agent as one entity or simply understand the embodiments as different characters? What metaphors or symbolic representations should be used for the dimension crossing process? How can one take advantage of the unique characteristics of each dimension? Researchers working in *embodied agents* are trying to answer these and other questions.

Such cross-embodiment process will be here named *agent migration*, or simply *migration*, according to the following definition:

> *"Process by which an agent moves between embodiments, being active in only one at a time"*

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The fact that the embodiments work as shells to the agent entity is inspired in the Soul-Shell methodology presented by Arent *et al.*[1]. However in our definition the term agent is not restricted to characters with graphics embodiments as in the work by Arent *et al.*[1] (the term companion is used instead of agent to denote generic entity).

Another related concept is mobile agent[2]. According to Wooldridge, a mobile agent can transmit itself across a computer network, recommencing execution remotely. This definition de-emphasizes the importance of the agent's embodiment. Additionally, it pushes for communication across a network when there might be only two devices interacting in agent migration.

Mixed reality[3] and blended reality[4] are two other related concepts to agent migration. The term mixed reality is more commonly used to refer to artifacts in the middle of Milgram's Reality-Virtuality Continuum[5] for which the same embodiment enables interaction at the physical and virtual level while in agent migration the entity might move from opposite sides of this scale (robot to graphical agent in the screen). The blended reality concept focuses on the transition between fully physical and fully virtual environments, as agent migration, but does not require the entity to have its own agency, to be autonomous.

Having analyzed related concepts, we will look closer into agent migration in the context of artificial pets, trying to understand how the previously questions can be answered in this specific context. Artifical pets have become very popular since Tamagotchi's success in 1997. These pets generally evoke caring actions from owners, such as feeding, cleaning and playing. This in turn can lead to emotional attachment between users and pets[6], thus creating engagement, companionship and enjoyment. Other successful cases that have created technological substitutes for pets are Nintendogs, with 7 million games sold worldwide, and the on-line pet nurturing website called Neopets. More recently the video game Kinectimals goes as far simulating petting a virtual character with gestures, and even their developers recognize the importance to analyze players' interactions with such systems[7].

There is a large body of work that has investigated the benefits of *real* pets on owners. For instance, Pattnaik[8] argues that animals can serve as teachers, healers and companions to humans, and Adkins and Rajecki[9] present a study that shows how pets can help in the grief resolution process. Johnson *et al.*[10] mention that visits from a trained visitor dog and its handler can have a positive impact on the therapy of cancer patients.

Inspired by the benefits of *real* pets, researchers are starting to conduct empirical studies to investigate whether artificial pets can truly deliver some of the benefits of the *real* ones. For instance, Wada and Shibata[11] show that seal robots can increase the social interaction of elderly people due to the interaction with the robots. The work in Lawson and Chesney[6] investigates whether younger owners have the same emotional experience as older owners. These artificial pets can generally be developed in two different embodiments: a screen based pet, such as Nintendogs, or a robot based pet, such as the Sony Aibo.

In the work here presented, we use a robotic pet called Pleo from Innvo Labs

Corporation; Pleo is a robotic dinosaur with touch sensors, several motion motors, speaker capabilities, and some limited object recognition attributes. The study conducted by Fernaeus *et al.*[12] show that Pleo has several limitations with respect to user engagement over a long period of time. For instance, here are some of the limitations that have been reported in the study:

- *Short battery life*: Pleo's battery life lasted for about an hour and fully charging it could take four hours. Hence, children would easily get upset with this issue;
- *Playing interrupted*: The dinosaur robot would sometimes freeze due to the battery draining out completely. This would interrupt the child's playing activity, and an adult would have to change the battery in order to resume the activity.
- *Maintenance and caring not integrated with interaction and play*: While some artificial pets, like Tamagotchi, have maintenance and caring actions that blend with play patterns, the maintenance of Pleo is not integrated with any playing activity. In addition, Pleo requires a significant amount of effort to prepare, update and recharge, which is normally performed by an adult and not the child.
- *Unfulfilled expectations*: Participants had very high expectations with regard to the robot's intelligence and computational features, such as response to voice commands, its ability to be trained and its mobility. This could be partly explained by the marketing information that generated these high expectations on the participants.

Such issues can also be found in other robot pets, with possibly similar consequences on engagement. Despite the issues above, the Pleo robot has the potential to evoke an affective connection with its owner. Jacobsson[13] presents a study that analyzes posts from Pleo user forums and shows that Pleo owners were afraid of losing their artificial pet in case they had to send it to support due to malfunctioning. Hence, the owners would prefer to void their warranties and fix the artificial pet themselves.

Both robotic artificial pets (e.g. Pleo robot) and screen based artificial pets (e.g. Nintendo Dogz) have shown potential; in other words, having limitations as well as unique attributes. For instance, robotic pets enable a unique tactile experience, while screen based pets allow a longer continuous interaction by the fact that children can carry the pet with them all the day. With positive features on both sides, it is reasonable to reiterate the previously posed question "How can we take advantage of the unique characteristics of each dimension?".

With this motivation, we decided to develop an artificial pet based on the Pleo with two embodiments: a virtual embodiment within a mobile phone and a physical robot embodiment (the robotic Pleo). The migration between virtual and physical embodiments should extend the interaction flow[14] and possibly address the first two issues mentioned above. For instance, whenever the physical embodiment is running low on battery charge, the artificial pet could migrate to the virtual embodiment.

In order to assess the hypothesis that migration between embodiments can enhance a user's experience, we first needed to analyze whether the migration between embodiments can be naturally understood. Hence, we conducted a user study with elementary school children that interacted with an artificial pet that can migrate from two different embodiments, namely PhyPleo (the robot pet) and ViPleo (the virtual pet on a mobile phone). This allowed us to investigate the perceived relationship between owners and a virtual pet with the capability of migrating between a physical and virtual embodiment.

An initial version of the prototype was originally presented by Gomes *et al.*[15] and some preliminary results have been reported in the work by Segura *et al.*[16]. However, this work goes further by detailing the complete experiment preparation process and presenting novel results from relevant new data, thus leading to new guidelines for agent migration.

Hence, the first key contribution is the description of the complete experiment preparation process. The second key contribution is a novel generic methodology that can help the scientific community to develop a standard for evaluating companion agents migration. Finally, the third key contribution is the creation of design guidelines for companion agents migration, which is derived from the findings of the user study.

This paper is organized as follows. Section 2 presents the related work on artificial pets, agent migration and mixed reality environments. Section 3 describes the architecture of the two embodiments of the artificial pet, namely ViPleo and PhyPleo. Section 4 presents the user study and describes the results. Finally, Section 5 presents our concluding remarks and future work.

2 Related Work

There is a large set of topics related to the work presented in this paper. We broadly group these into three main categories: work related to human-robot interaction, work related to artificial pets, and work related to agent migration.

2.1 Human-Robot Interaction

Human-Robot Interaction is a new and exciting research field focused on investigating, designing and evaluating the interaction between robots and humans[17]. In this area, many researchers are addressing the interaction between children and robots. One particular study conducted by Okita *et al.*[18] investigated whether 3-5 year old children apply animistic intuitions (i.e., intelligence, realistic behavior, and agency) to artificial pets. The results indicate that younger children are more likely to attribute the concepts of alive and animate to all the artificial pets, regardless of the pet's look and behavior, while the older ones start to have a more meaningful distinction between the concepts of alive and not alive in artificial pets. Although this study presents some very interesting results, our work is focused on a different research problem, since we are investigating whether the migration process between a virtual and a physical artificial pet affects the interaction with the children and how they perceive the migration process.

Another interesting approach applied to child-robot interaction was proposed by Castellano *et al.*[19], in which a methodology is used to collect and model affective expressions of children playing chess with a robot. The collected data was then used to train a context-sensitive affect recognition system for the robotic game companion, with the aim of making the interaction more engaging. Although this paper is also concerned with the engagement between the children and the robot, there is no migration process between embodiments in the system.

There are also many other papers focused on child-robot interaction. For instance, within the ALIZ-E project[20], Baxter *et al.*[21] present an approach for implementing a companion robot in a pediatric ward, while Ros *et al.*[22] propose experimental designs and share lessons learned in social human robot interaction within a hospital pediatric department. In addition, Vircikova and Sincak[23] present an experience with a humanoid robot that is aimed at raising the interest of children in physical exercise within a therapy program. However, none of these works are focused on the migration process between a virtual and a physical agent and the effects on the interaction.

2.2 Artificial Pets

Artificial pets are physical or virtual agents that mimic *real pets* and have been widely used to entertain users (i.e., owners). For instance, the Sony Aibo is a robotic dog that can find a ball and approach it, can hear its name and react enthusiastically, among other features. In the virtual environment, Nintendogs is an example of artificial pets whereby users can play, speak to the dog, and take care of it. In addition, artificial pets are also been used as social companion for elderly populations[11] and for learning purposes.

Regarding educational goals, several academic works have utilized artificial pets within a virtual environment (i.e., pets in virtual embodiments). For instance, Virtual Polar Bear[24] is an educational environment, which tries to create an attachment between owners and their polar bears, in order to teach environmentally responsible behaviors towards energy conservation. The owners of the polar bear are challenged with several environmental decisions that can impact the living conditions of a polar bear (i.e., the size of the ice floe in which the bear lives), and thus motivate users to change their behavior towards energy conservation. The My-Mini-Pet[25] and My-Pet[26] are also learning environments in which the game's progress and pet's growth depends on learning activities (e.g. solving simple arithmetic expressions). These environments are examples of how the bonding effect between artificial pets and owners can lead to learning. However, these applications have a limited set of actions in order to fulfill the virtual pet's needs. Additionally, none of the applications have been tested with physical embodiments.

The work presented by Dimas *et al.*[27] has similar motivations to ours and even tests a similar prototype: an artificial pet with a physical embodiment (modified Pleo robot) and a virtual embodiment. However, it does not present a migration between the two embodiments.

2.3 Agent Migration

Recall that agent migration is concerned with the process by which an agent moves between embodiments, being active in only one at a time. Within a purely virtual environment, McIntyre *et al.*[28] presents an experiment where cognitive agents can migrate between many different sites equipped with cameras. These agents inspect the world through these various cameras and build a collective representation of what they see.

In the work by Koay *et al.*[29], the migration takes place between two physical embodiments instead. These robots were equipped with LED panels to display three different visual cues in order to indicate the migration process. The participants of the described study were primary school students and the visual cues were shown to be helpful to highlight the migration process of the agent's identity. Nevertheless, none of these works have investigated the agent migration between a physical and virtual embodiment.

The work from Roberts *et al.*[30] steps in this direction by presenting a game in which a ball moves between a physical and virtual environment. In the physical environment the ball is projected on the floor. The player can interact with the ball by controlling a robot that is able to push the projected object. In the virtual environment the ball is displayed as a three-dimensional object on a screen. There are also characters with similar physiognomy and animation to the controlled robot, and these are responsible for pushing the ball back to the physical environment in order to maintain a Pong like game. The aim is to maintain continuity of movement when the ball passes between the two environments, so that a user's perceptual continuity is maintained throughout the game's duration. However, this work does not consider the migration of an actual agent between the two environments.

In follow up research presented by Robert and Breazeal[4] and Robert[31], a character (alphabot) transitions between the real world as a robot, to a virtual world as an animated character. Alphabot is an educational toy for children inspired by the alphabet block. Alphabot is similar in appearance to the mentioned traditional toy, but instead of static letters, it allows for interactively adding and removing symbols from it, giving visual (led based) and auditory feedback regarding these events. The transition between worlds is performed through a husk, with the alphabot being in only one world at a time, thus in line with a soul-shell approach[32]. In spite of the similarities with our work, alphabot is remotely controlled, so it might be too strong a statement to call it agent migration.

Hence, despite the existence of numerous related approaches on human robot interaction, artificial pets, and agent migration, the combination of these elements in a unified autonomous prototype of an artificial pet has not been investigated in other works. Moreover, the analysis of the migration process is a fresh perspective in the field of computer entertainment.

3 ViPleo and PhyPleo: Architecture and Migration Process

This work utilizes two embodiments of the artificial pet Pleo. ViPleo is a virtual pet that is designed to run on a mobile phone, while PhyPleo is the robotic pet. Figures 2 and 3 depict the two embodiments of our artificial pet.

(a) Petting (b) Feeding

Figure 2: PhyPleo Behaviors

Figure 3: ViPleo

While designing the migration process between the two embodiments, we followed the guidelines in the soul-shell approach[32], in which the *personality* of the artificial pet is preserved regardless of the pet's embodiment. The *personality* of the artificial pet is defined as "the persistent features which make it unique and recognizable from the owner's perspective". Hence, the *personality* should be reflected in both embodiments in a consistent way, with only one embodiment active at a time.

In order to design the two embodiments, we started analyzing interesting aspects of commercial virtual pets that could serve as requirements for our artificial pet. In the work by Kaplan[33], we identified two key aspects that could help the development of the *personality* of the two embodiments. First, successful commercial virtual pets generate a sense of guilt when owners do not take care of the pet. This *affective blackmail* makes owners feed, clean, nurse and play with the pet, in order to avoid situations such as the pet dying or running away. Second, virtual pets should create a need for interaction, but also maintain some freedom. Hence, the pet should present some exploratory behavior, but seek the owner's attention from time to time.

Following Kaplan's guidelines for designing an artificial pet and taking into account the required *personality* consistency between the two embodiments, we selected the following needs for our pet (organized into the categories from the PSI-Theory[34]):

- *Preserving needs*: energy, water (thirst) and cleanliness;
- *Affiliation need*: petting (need for affection);
- *Competence need*: skill.

The needs above are represented by a numeric value that ranges from 0% (unfulfilled need) to 100% (fulfilled need). Hence, a water need with a value of 5% means that the pet is thirsty and would like to receive some water from its owner.

Our current implementation of the artificial pet has a virtual embodiment (ViPleo) on a mobile phone and a robot embodiment (PhyPleo). The pet has the ability to migrate between the two embodiments, but only one can be active at each time. For instance, when ViPleo is activated, PhyPleo freezes. The following list presents the user actions and how they affect the needs of our pet :

- Feeding (Implemented in PhyPleo e ViPleo) increases energy;
- Petting (Implemented in PhyPleo e ViPleo) increases petting;
- Wash (Implemented in ViPleo) increases cleanliness;
- Water (Implemented in ViPleo) increases water;
- Training (Implemented in ViPleo) increases skill;

Additionally, ViPleo has bowel movements after the feeding action in order to decrease the cleanliness value. There is also a decaying effect on the values of energy, water, cleanliness and petting on both embodiments, regardless of the users actions. PhyPleo and ViPleo present exactly the same decay on the values of the aforementioned needs. Training does not decay for either of them. In order to give some visual and sound cues to the users when some need values are low, the following list presents the pet's behavior in response to the needs:

- Energy low in PhyPleo: sniffs the ground, bites downward and slowly moves forward;
- Energy low in ViPleo: sits down and cries;
- Petting low (energy not low) in PhyPleo: gives discontent growls;
- Neither of the above in PhyPleo: waggles its tail and gives high pitch barks;
- Neither of the above in ViPleo: walks around the playground

Lastly, the need values in ViPleo can be visualized through a graph bar as shown in Figure 4.

Figure 4: Need Values in ViPleo

3.1 Architecture

The architecture of the two embodiments is depicted in Figure 5. PhyPleo's behavior is implemented with Pawn scripts that run on virtual machines (VM) on top of the robot's operating system (LifeOS). We had to use the example

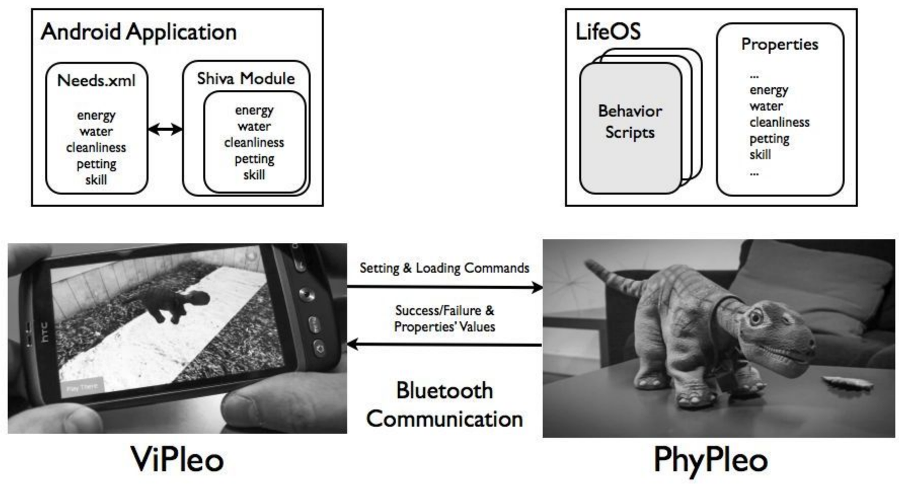

Figure 5: Architecture Overview and Migration

behaviors in the Pleo's SDK, because we did not have the original code or the possibility of linking a compiled version of it to our code. Hence, we could not extend the robot's original behavior with additional functionality.

The need values are stored in the property section of the memory that can be accessed by any Pawn script that is running on one of the VMs. In addition, the memory can be accessed through a monitor interface; the monitor interface is used to set and load properties via Bluetooth. The robot has a serial connection (UART) that we use to connect a bluetooth dongle, which enables a wireless communication with the robot.

ViPleo was developed as an Android application that runs on a mobile phone. The Android application was written in Java with a module that uses a Shiva3d graphical engine. In fact, this module is the interactive part of the application and is internally scripted in Lua. In addition, the Android application is responsible for the following tasks: (i) the communication with PhyPleo, (ii) loading the needs from an XML file, and (iii) for starting the Shiva module.

After the Shiva module starts, local variables in the application are updated with the need values from the XML file. While the application is running, the variables are updated in response to the user's interaction and the decaying effect on the need values. The XML file is only updated with the local variables when the Shiva module exits.

The migration process between ViPleo and PhyPleo involves sending the need values through Bluetooth. However, the need values are only transferred, when one embodiment is activated and the other one deactivated. The migration process is always triggered by the Android application; hence, the migration process only happens when the robot is turned on and the Android application is running. The steps of the migration process between PhyPleo and ViPleo are presented in Figures 6 and 7.

Migration: PhyPleo → ViPleo

1. *Need values in LifeOS properties are requested via Bluetooth by the Android application;*
2. *The need values are sent to the Android application via Bluetooth;*
3. *In ViPleo, the values in needs.xml are overwritten by the received values;*
4. *The Android application sends a command to PhyPleo so that an "empty behavior script" is loaded, so that the Pleo robot stands still;*
5. *The Shiva module is started;*
6. *Need values are loaded from the needs.xml to the Shiva module;*

Figure 6: The steps of the migration process from PhyPleo to ViPleo

Migration: ViPleo → PhyPleo

1. *Need values in the Shiva module are stored in the needs.xml;*
2. *The Shiva module exits;*
3. *The Android application loads the need values from needs.xml;*
4. *Setting commands for the need properties are sent via Bluetooth to PhyPleo;*
5. *The Android application sends a command to PhyPleo so that the "empty behavior script" is unloaded and the normal behavior of the pet is resumed;*

Figure 7: The steps of the migration process from ViPleo to PhyPleo

4 Case Studies

4.1 Online Study

In a preliminary study[3], we evaluated how adult users of the robotic pet Pleo perceived the possibility of being able to interact with a second embodiment of their own pet. The 26 participants were recruited from the on-line forum, bobthepleo[4]. They answered a set of questions concerning how they rated their current experience with the Pleo robot, interacted with ViPleo (37 minutes on average) and finally were asked to answer a larger set of 'as if' questions about the possibility of having the artificial pet in two different embodiments.

The results suggest that the addition of a second embodiment would promote the enjoyment of interaction with the artificial pet. Participants also envisioned that they would better understand the pet's behavior and would be less reluctant to carry it around. Finally, 84% agreed that ViPleo was similar to the Pleo robot, and 73% would value interacting with ViPleo when the robot's battery level would be low. In conclusion, the results appear to indicate that Pleo robot adult users would value having a second embodiment for their artificial pet. However, they did not interact with the whole prototype, which may affect the validity of these results.

4.2 Pilot Study

We performed a pilot study with children in which they interacted with the complete prototype. The procedure was similar to the one we are about to describe in the next subsection, with children interacting with the prototype in groups of three. The insights we took from this pilot study were the following:

- Children commented that they perceived ViPleo as more obedient than PhyPleo.
- Having groups of children interact with the prototype together, instead of just one at a time, led them to talk to each other. This allowed experimenters to gather informative comments that children would make on their own actions but also on their interpretations of the artificial pet's behavior.
- Only two children would be actively engaged with the experience at a time. This led us to believe two children per group would be a better fit to the experiment than three.

4.3 Elementary School Children Study

Following up the pilot study, we performed an evaluation in which our aim was threefold: i) exploring the way children understood the companion and the

[3]Detailed description in the work by Gomes *et al.*[15]
[4]http://bobthepleo.com/forums/ (last accessed September 2011)

process of migration ii) their assessment of the game experience, and iii) their perceived relationship with the pet.

A key question that we wanted the children to answer was the number of entities perceived during the interaction; hence, they were asked how many dinosaurs they interacted with. We considered that if a child answered “one” than that same child thought that the prototype represented only one entity. Under the same principle, in the study described by Robert[31], children were asked “How many alphabots were there?”. Additionally, while testing the evaluation structure in the pilot study, we had comments indicating that ViPleo was perceived as more obedient and PhyPleo as more independent. Therefore, the two hypothesis we considered in this study were the following:

- Children would indicate they interacted with only one dinosaur after being exposed to the whole prototype;
- Children would rate ViPleo embodiment as more obedient than the PhyPleo embodiment;

The second hypothesis was directly derived from the pilot study conclusions.

4.3.1 Procedure

The evaluation was performed with elementary school children from the 5th grade (10 and 11 years old), 51 in total, 53% of which were male. Figure 8 presents a photograph of the interaction between PhyPleo and a child. We were aiming at children that were old enough to understand the questionnaire, and that could answer the more abstract open ended questions. Conversely, we wanted to avoid older boys and girls as we suspected they might find playing with a toy dinosaur childish, thus being less motivated for the experience.

Figure 8: Interaction between PhyPleo and a Child

Drawing upon the insights gathered in the pilot study we grouped children in pairs for each session, except for one session in which there were three due to the uneven number of children. Grouping children for the evaluation of a migration character was an approach suggested by Robert[31](page 113), where the author claims that it reduces the need for adult assistance.

The sessions were video recorded with two cameras positioned orthogonally. There were two experimenters: a guide, which directly interacted with the children and guided them through the session; and a second experimenter, which stayed in the background, prepared the questionnaires, and occasionally checked if the cameras were capturing the children's behaviors.

The complete structure of each session is presented in Figure 9. In the introduction, children were told a storyline to motivate their interaction with the companion. They had to imagine that a neighbor had left them responsible for taking care of an artificial pet. From the start, and even in the experiment's consent form, we used the term "Dino" to refer to the prototype. This alternative name was used in order to avoid children from being influenced by online marketing of the Pleo robot. Marketing can influence particular users expectations regarding the robot's behavior evolution[12]. The sessions had two main parts. During the first one, children would interact with one of the embodiments during approximately 5 minutes. Then, they had to answer a closed questionnaire regarding only the interaction with the first embodiment (*Questionnaire Set I* in Figure 9).

The questionnaire was designed mostly using 5 point Likert scales (Table 1). Among other aspects, the questionnaire required participants to rate how difficult was the interaction experience (Question 2), and how obedient/independent was the artificial pet (Question 3). Moreover, they were asked to rate their relationship with the artificial pet: how easy it was to understand him (question 4), a question inspired by an adult attachment questionnaire[35]; and how emotionally close they felt towards it (not present in Table 1), which was adapted from a relationship evaluation scale[36]. Furthermore, questions 1, 6 and 7, are similar to the ones used in the alphabot study[31] ("How much fun did you have?" and "How much fun do you think Alphabot had?"). There was an effort to present a pictorial representation of certain ratings in order to help children undertand the questions, as suggested in the work by Henerson *et al.*[37]. For the original questionnaire with the visual representations consult Appendix A.

In the second part of the evaluation, after children answered the questionnaire, they would continue to interact with the same embodiment as before. After 1 minute the migration would take place automatically, the first embodiment would become inactive and the second embodiment active. Children could continue to play with the artificial pet in the second embodiment for 6 minutes. Finally, they answered the same set of questions as before (*questionnaire set II*) and there was a semi-structured interview. In this interview, they were asked about the number of dinosaurs they interacted with, and also what they thought happened when there was a switch between embodiments. Regarding this last question, a similar one was analyzed by Robert[31]: "What happens when Alphabot goes from here to there? (pointing at the diagram indicating physical and digital spaces)".

The order by which the two embodiments were presented was changed every

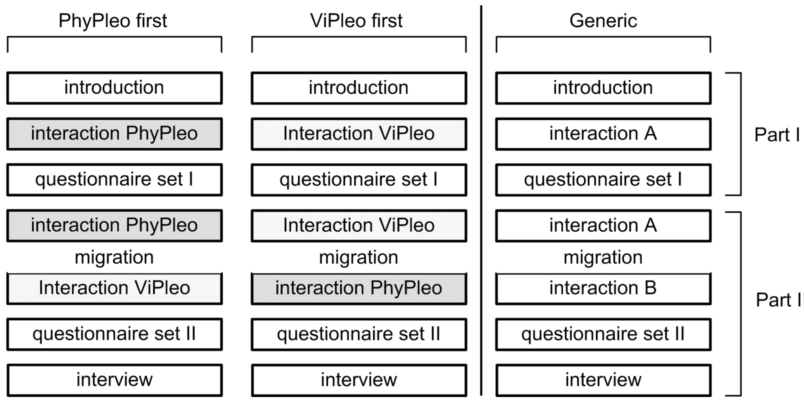

Figure 9: School children session structure

Table 1: Questionnaire - Likert scales (translated from Portuguese)

	Label	**Value 1 label**	**Value 5 label**
1	Fun	Not fun at all	Super Fun
2	Difficulty	Very easy	Very difficult
3	Dino Attitude	Independent	Obedient
4	(I) understood what Dino was thinking	Very badly	Very well
5	Dino understood my actions	Very badly	Very well
6	How was taking care of Dino (?)	Didn't like at all	Liked (very) much
7	What do you think Dino though of you taking care of him (?)	Didn't like at all	Liked (very) much
8	What would you think of having Dino at home (?)	Wouldn't like at all	Would like (very) much

other session so it would be possible to compare the two in isolation. We will refer to the group of children that interacted first with PhyPleo and secondly with ViPleo as *PhyPleo first*. The group of children that started with ViPleo and saw the migration to PhyPleo will be refered to as *ViPleo first*.

Demand Characteristics and Evaluation Apprehension: We wanted to avoid *demand characteristics* of the experiment[38], more specifically, that children answered questions according to what they felt the experimenters were expecting, rather than what they thought. Elementary school children are asked to write down answers by adults in the context of tests, so children might be inclined to perform 'well' according to their own interpretation of the experiment. Furthermore, there was also the possibility of children showing *evaluation apprehension*[39], that is, becoming anxious about being tested, which would unavoidably affect the results' validity. To address these issues there was a concrete effort to maintain an informal environment so that children would interact and answer questions freely. We present some of the steps taken:

- Before answering the first questionnaire, the guide would say that "there was no right or wrong answers", that "It was up to them to evaluate Dino, and not the other way around", that they could ask questions regarding the questionnaire (even if they thought they were silly), and they were free not to answer a question if they felt unconfortable with it.

- Before the second questionnaire, the guide would tell the children they could still ask questions regarding the questionnaire, regardless of the fact they had already answered such a questionnaire.

- In the beginning of the interview, the guide would ask children to say the first thing that popped into their head when prompted with a question.

- During the periods in which children were interacting with the prototype, the guide would distance himself a few meters from them. Moving towards the second experimenter, the two would then quietly chat with each other in english, paying limited visual attention to the children. Note that the chat was not on the children's native language and at their grade being able to follow such a conversation would be extremely uncommon. In spite of the distance, the guide would respond to children's requests if addressed.

- In interview question regarding the number of dinosaurs we tried to introduce a range of possibilities to avoid biasing the responses. We would say: "How many dinosaurs have you played with? One dinosaur, two dinosaurs, three dinosaurs, ten dinosaurs, a hundred...".

The interview could have been used to detect demand characteristics' effects. Nevertheless, users were not intensively prompted about what they thought the experiment was about. Thus, it does not exactly match the use of post-experimental inquiries as *quasi-controls* proposed by Orne[38]. Children were only asked what they thought the experiment was about when they were being accompanied to the experiment room, but even then in a non-systematic fashion. All these efforts were made so that the results gathered would be more accurate.

Limitations and Subsamples: There were technical and logistic issues that in some cases led to the procedure just described not being strictly followed. As previously mentioned, one of the sessions (session 19) had three children instead of two. Although we followed the procedure in session 10, one of the two children was mentally impaired. Drawing conclusions regarding mentally impaired children would require doing an experiment for that specific purpose, consequently we will not consider the data from this session.

In session number 20, the migration occurred two minutes after part II started, instead of one. However, it should be pointed out that part I of the experiment did follow the procedure. Similarly, in session 21, the procedure was also followed in part I, yet in the second part children were able to access the migration hidden option on the prototype and activate migration themselves. In session 17 children were able to activate migration twice.

Furthermore, in sessions 13, 16 and 22, there were technical problems with the migration [5]. These ranged from PhyPleo running out of battery to the wireless communication not working correctly. Finally, the video recordings for sessions 3 and 4 are missing, hence we can not assure that migration occurred according to the procedure.

All these issues, can add undesired noise to the data and compromise the results. We consequently decided that in this article we would not consider all the data from the mentioned sessions in the numerical analysis. We still mention these sessions in the discussion.

We will name the subsample without any of the mentioned problematic sessions as *conservative subsample*. It includes 15 sessions: 1, 2, 5 through 9, 11, 12, 14, 15, 18, 23, 24 and 25. The subsample has a total of 30 children, 12 of which are male. There are 7 PhyPleo first sessions and 8 ViPleo first sessions. This conservative subsample will typically be used when data from questionnaire set II is needed.

In some analysis we will only compare data from the first part of the experiment. Sessions 3, 4, 13, 16, 17, 20, 21 and 22 follow procedure in part I, thus questionnaire set I data can be used in such cases. In contrast, the issues of sessions 19 and 10 are transversal to the experiment. In the results' analysis we will refer to the subsample without sessions 19 and 10 as *first part conservative subsample*. It includes a total of 46 children, 22 of which are male. There are 13 PhyPleo first sessions and the remaining 10 are ViPleo first.

[5] The set of sessions labeled as having a technical problem is different from the work by Segura *et al.*[16]. In this other article, sessions 10 and 17 are also labeled as technical problems. Here we discard session 10 for other reasons and consider session 17 separately.

Table 2: Between Groups (PhyPleo first and ViPleo first) comparison *questionnaire set I*

	variable	***Mdn*** PhyFirst	***Mdn*** ViFirst	***U***	***z***	***sig*** $\alpha = .05$	***r***
1	Fun	5.0	5.0	199.0	-1.73	*ns*	-.26
2	Difficulty	3.0	2.0	254.5	-.13	*ns*	-.02
3	Obedience	4.0	4.5	157.0	-2.41	$p < .05$	-.36
4	Understand	3.5	4.0	184.0	-1.81	*ns*	-.27
5	Be understood	4.0	4.0	180.5	-1.92	$p < .05$	-.28
6	Like	5.0	5.0	233.0	-1.11	*ns*	-.16
7	Be liked	4.0	4.0	200.0	-1.47	*ns*	-.22
8	Take home	5.0	5.0	203.0	-1.92	*ns*	-.28
9	Closeness	6.0	6.5	246.5	-.30	*ns*	-.04

4.3.2 Results

Taking into account the described subsamples, we will now present the results from the questionnaire's data and from a quantitative analysis of the interviews [6]. We begin with a comparison between the ViPleo and PhyPleo embodiments.

Comparison between embodiments: Since by the end of *Part I* (see Figure 9), the participants had only interacted with one embodiment, either PhyPleo or ViPleo, we will look deeper into the *questionnaire set I*. As only data from part I is used, we consider the *first part conservative subsample*. We want to compare differences between two independent groups (*PhyPleo first* and *ViPleo first*), and each question corresponds to an ordinal variable (values are ordered but there is no guarantee in regard to scale), consequently we perform a Mann-Whitney test[40] for each of the nine questions. Our hypothesis, in what concerns the embodiments, was that ViPleo was going to be considered more obedient than PhyPleo. Hence we consider 1-tailed exact significance for question 3 (obedience) and 2-tailed exact significance for all other questions. In Table 2 the test results are presented together with the medians.

As presented in Table 2, differences between the two test groups were only significant ($p < .05$) for questions 3 and 5. Obedience scores from participants interacting first with ViPleo were significantly higher than scores from participants interacting first with PhyPleo (see Figure 10), with a medium to large size effect ($.3 < abs(r) < .5$) according to Cohen's criteria[41]. Regarding question 5, scores for the *ViPleo first group* ($MeanRank = 27.48$) were significantly higher than scores for the *PhyPleo first group* ($MeanRank = 20.44$), with a medium size effect ($abs(r) \approx .3$) according to Cohen's criteria. We performed a similar analysis regarding answers for *questionnaire set II* (results in Appendix B) and

[6]Some of the values presented diverge from the corresponding values in the work by Segura *et al.*[16] because here we took a more conservative approach to the quantitative data by using the mentioned subsamples.

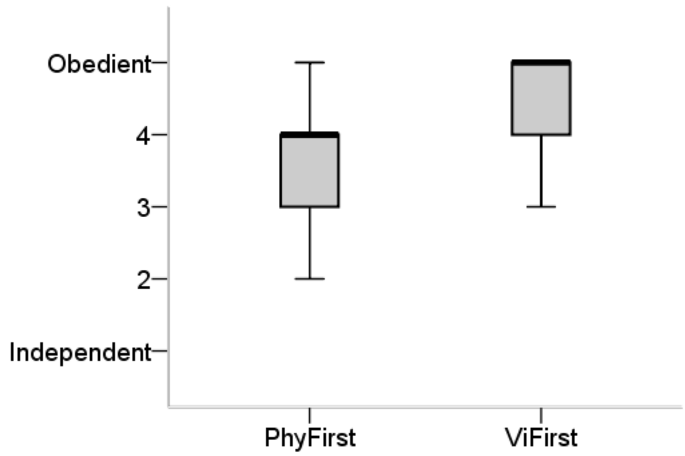

Figure 10: Obedience scores for participants interacting with PhyPleo first (PhyFirst) and interacting with ViPleo first (ViFirst)

there were no significant differences (α-$level = .05$).

Before and after migration: We have just compared the *questionnaire sets* separately. In order to analyze the effect migration had on children's perceptions we will now look into differences between these sets. Data from part I and II is considered, so we will use the *conservative subsample*. Each participant's score in *questionnaire set I* is compared with the same participant's score in *questionnaire set II*. We again divided the results according to the two independent groups (*ViPleo first* and *PhyPleo first*). Consequently we perform two Wilcoxon signed-rank test[42] for each of the nine question pairs. In this case we had no a-priori hypothesis, so we always used 2-tailed significance.

As presented in Table 3, there were only significant differences ($p < .05$) for questions 2 and 9 (difficulty and closeness). Difficulty scores for participants starting with PhyPleo were significantly higher in *set II* ($Mdn = 4.0$) than in *set I* ($Mdn = 3.0$). Moreover, difficulty scores for participants starting with ViPleo were also significantly higher in *set II* ($Mdn = 4.5$) than in *set I* ($Mdn = 2.0$). In both cases the effect size is large ($abs(r) > .5$) according to Cohen's criteria and in fact having the same approximated value to the nearest 0.01 unit. Turning to closeness, for *ViPleo first* participants scores were significantly higher in *set II* ($Mdn = 7.0$) than in *set I* ($Mdn = 5.5$), with a large size effect. However, for *PhyPleo first* participants closeness scores in *set II* were not significantly different from closeness scores in *set II*.

Gender: With no a-priori hypothesis, as in the previous section, we compared score differences according to gender. We focused on data from questionnaire II since when children answered the corresponding questions they had already spent more time with the prototype and had witnessed migration. Since data

Table 3: Related Measures (questionnaire set I and questionnaire set II) comparison

		variable	*Mdn*		*z*	*sig*	*r*
			set I	**set II**		$\alpha = .05$	
PhyFirst	1	Fun	5.0	5.0	.00	*ns*	.00
	2	**Difficulty**	3.0	4.0	-2.80	$p < .05$	-.70
	3	Obedience	4.0	4.0	-.26	*ns*	-.07
	4	Understand	4.0	4.0	-1.70	*ns*	-.42
	5	Be understood	4.0	4.0	-.71	*ns*	-.18
	6	Like	5.0	5.0	-1.41	*ns*	-.35
	7	Be liked	4.0	4.5	-1.67	*ns*	-.42
	8	Take home	5.0	5.0	-.58	*ns*	-.14
	9	Closeness	6.0	7.0	-1.73	*ns*	-.43
ViFirst	1	Fun	5.0	5.0	-1.00	*ns*	-.27
	2	**Difficulty**	2.0	4.5	-2.62	$p < .05$	-.70
	3	Obedience	4.5	3.0	-2.04	*ns*	-.54
	4	Understand	4.0	4.0	-1.67	*ns*	-.45
	5	Be understood	4.0	4.0	.00	*ns*	.00
	6	Like	5.0	5.0	-1.00	*ns*	-.27
	7	Be liked	4.0	5.0	.00	*ns*	.00
	8	Take home	5.0	5.0	.00	*ns*	.00
	9	**Closeness**	5.5	7.0	-2.56	$p < .05$	-.69

Table 4: Gender (questionnaire II) - values marked with * were constant for the corresponding Gender/Embodiment

	variable	**PhyFirst *Mdn***		**boys**	**ViFirst *Mdn***		**boys**
		boys	**girls**	**vs girls**	**boys**	**girls**	**vs girls**
1	**Fun**	4.5	5.0	<	4.0	5.0	<
2	**Difficulty**	4.0	3.0	>	5.0	4.0	>
3	**Obedience**	3.0	4.0	<	3.0	3.5	<
4	Understand	4.0	4.0	=	4.0	4.5	<
5	Be understood	4.5	4.0	>	4.0	4.0*	=
6	Like	5.0	5.0	=	5.0*	5.0*	=
7	Be liked	4.5	4.5	=	4.5	5.0	<
8	Take home	5.0	5.0	=	5.0*	5.0*	=
9	**Closeness**	6.0	7.0	<	6.0	7.0	<

Table 5: Between Groups (boys and girls) comparison *questionnaire set II*

	variable	***Mdn***		***U***	***z***	***sig***	***r***
		boys	**girls**				
1	Fun	4.0	5.0	55.0	-2.79	.009	-0.51
2	Difficulty	4.5	3.5	64.5	-1.92	.059	-0.35
3	Obedience	3.0	4.0	80.0	-1.23	.234	-0.22
9	Closeness	6.0	7.0	79.5	-1.26	.216	-0.23

from the second questionnaire is considered we used the *conservative subsample*.

In Table 4 the medians for responses to questionnaire II are presented, divided by gender and order of embodiment interaction. We rated the relation between the scores of boys and girls using the medians: >, boys have a higher median score than girls' median score; <, girls have a higher media score than boys; = boys have and girls have the same median score. One can note that these relations are only consistent across order of embodiment interaction (the same in both *ViPleo first* and *PhyPleo first*) for questions 1, 2, 3 and 9. Girls tended to give a higher score in fun, attitude (more obedient) and closeness, while boys tended to give a higher score in difficulty.

The number of participants in each *gender/first embodiment* group varies between 4 and 10. With such small groups, and since we already detected some consistent gender differences in the medians of question 1, 2, 3 and 9, we decided to compare results for these questions aggregating data from different *first embodiment* groups. The results for the corresponding Mann-Whitney tests using a 2-tailed exact significance are presented in Table 5. Differences are only significant ($p < 0.05$) for fun, with a large size effect ($abs(r) > .5$) according to Cohen's criteria. We present a more detailed description of this question's results in Figure 11.

Initial References: Diverging from the previous sub-sections for which results

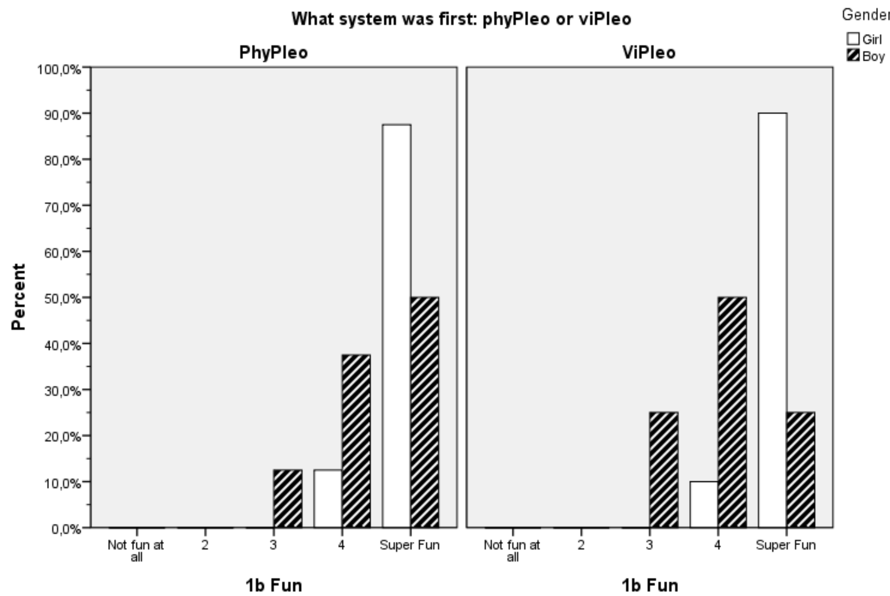

Figure 11: Fun ratings grouped by first embodiment interacted with and gender

were directly taken from the questionnaires, we proceed by quantifying a qualitative analysis of the interviews. We considered to which embodiment children would refer to (ViPleo or PhyPleo) when faced with a question that could be related to either of them (e.g. "What have you done with Dino and what did he do?"). Specifically, we looked at the beginning of the interview where they were initially asked what they had done with the artificial pet. We analyzed for each session what was the first embodiment mentioned implicitly or explicitly. For instance, in session 18, at the beginning of the interview, one child said:

> "We clicked on a button in the cellphone, and then we had to click the little red button"

This was counted as reference to ViPleo. On the other hand, in session 5, one child said "So, we gave him the leaf like this (*grabbing the leaf on the table*)", which was considered a reference to PhyPleo. We did per session analyses, rather than per participant, because the children would often complete each other's answers.

Although almost every child stated preferring PhyPleo (another question in the interview), the first embodiment mentioned would in many cases be ViPleo. Sessions were divided into the following categories: **first**, the first embodiment mentioned is the one children interacted with first; **second**, the first embodiment mentioned is the one children interacted with secondly; **both**, embodiments are initially mentioned together; **unclear**, it is unclear in which of the above categories the session fits. Considering the *conservative subsample*, and

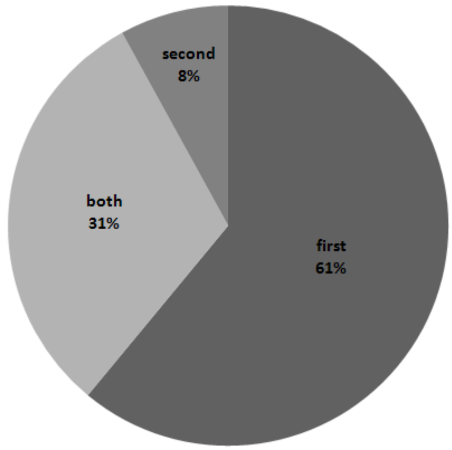

Figure 12: The embodiment children implicitly referred to when asked about "Dino".

counting *unclear* as misses (12%), we have the following percentages: *first* 61%, *both* 31% and *second* 8% (see Figure 12).

Number of Dinosaurs: As with initial references, the number of dinosaurs children claimed to have interacted with was taken from the interviews. Since the question was asked at the end of the experiment, the *conservative subsample* was used. The results were the following: one dinosaur 43.3%, two dinosaurs 40.0%, three dinosaurs 13.3%, more than three dinosaurs 3.3% (see Figure 13).

4.3.3 Discussion of Results and Qualitative Aspects

When designing the experiment we hypothesized that children would indicate they interacted with only one dinosaur after being exposed to the whole prototype. Note that the concept of migration was never explained at any time, and the results show that 43.3% of the children were still able to understand that both embodiments were actually the same entity.

However, we would also like to analyze why 56.7% of the children could not fully understand that ViPleo and PhyPleo represented the same entity. As mentioned above, one of the main reasons is that the concept of migration was not explained to the children at any time; in fact, we were really trying to see if they could understand this concept without any help and how natural it was for them. Theories on embodiments such as the work by Sonesson[43] suggest that children around 18 to 24 months acquire a representational ability called semiotic function; thus, they have no problem with perceiving unicity of embodiments. Yet, here, given that our subjects are somehow older when faced with two separate objects, children had the challenge of abstracting the concept of a common entity. Hence, in a more natural scenario, upon receiving

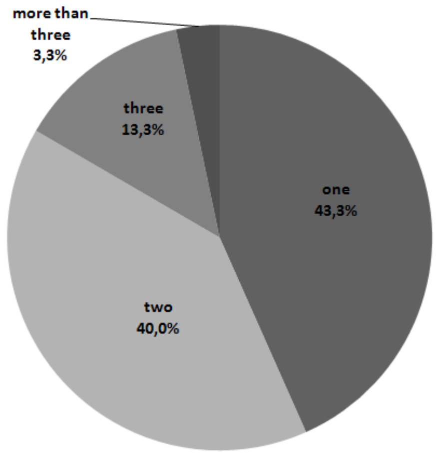

Figure 13: Number of dinosaurs participants in the conservative sample claimed having interacted with.

an artificial pet with two embodiments, the process should have cues regarding the migration, in order to help children grasp the migration concept in a more natural way.

Furthermore, there could be more reasons that led children to consider two different entities. In the work by Segura *et al.*[16], it was highlighted that timing in the moment of migration influenced the children's choice. In some cases it happened smoothly, but in others there was a small gap or slight overlap. This last case seemed to favor interpretations of more than one dinosaur.

Another plausible explanation could be the different perception of obedience. The retrieved data supported our hypothesis that ViPleo is considered more obedient. During the interviews, children claimed that PhyPleo did not always obey them. Namely, that it would sometimes decide not to eat, even when presented with a leaf. Although this was caused by technical difficulties concerning action recognition, they apparently gave the illusion of the pet having its own will. This fits rather well with Kaplan's idea[33] that we have a tendency to attribute agency to machines that do not work, thus appearing not to be obeying. If we analyze ViPleo from the same perspective, it always obeys: when the user drops a leaf in the virtual playground, ViPleo will immediately walk towards it and eat it. We believe that having a more direct response to users actions also led ViPleo to appear to better understand them, hence the higher value in the variable "*be understood*". There is indication that the just mentioned differences are in fact result of perception differences regarding the two embodiments: in questionnaire set II, after children have been exposed to both embodiments, the result differences of *ViPleo first* and *PhyPleo first* fade away.

Also concerning the identity of the pet, when children were initially asked about "Dino", many talked exclusively about the first embodiment (61%) they interacted with, regardless of if it was ViPleo or PhyPleo. It appears that by describing the story of the experiment giving more focus to one embodiment, or at least being the first one presented after the story, this first embodiment was more strongly connected to the concept of "Dino" entity. Consequently, we believe that as a design guideline, when a pet with two embodiments is presented to users, equal emphasis should be given to both embodiments right from the start.

Children rated the experience as harder after they witnessed migration. The process of relearning how to appease the pet's needs in a different embodiment is one possible reason for the increase in perceived difficulty. Another reason might be the absence of migration cues (e.g., visual cues, audio cues). In the tested prototype there was no cue that the migration process was starting: one embodiment would just stop and the other would start. Thus, migration without cues appears to add difficulty to the playing experience.

Nonetheless, such added difficulty does not seam to have strikingly affected the child-pet connection, since children perceive as closer in the end. Despite the possible time effect (longer exposure to the prototype), migration does not seem at least to harm the short-term relation between the child and the artificial pet. A potential problem regarding the closeness measurement is that it was originally designed to assess adult relations in a couple situation[36], not human-pet relations. However, we explained what we meant when in the questionnaire children reached that question.

Finally, girls rated the experience as more fun than boys. A plausible explanation for this result could be cultural, since in Portugal and other occidental countries, girls encouraged to exercise a nurturing functions with dolls; this could lead to a closer attachment to the artificial pet and a higher enjoyment of the interaction. However, the gender of the experimenters might be a possible confounding variable (the guide was male and the other experimenter female). Furthermore, boys were inadvertently grouped together as well as girls. Since all children interacted with both embodiments, and we would alternate the order by which we presented them, this issue is more problematic for the just mentioned gender analysis. Hence, the relationship hypothesis between artificial pets, migration and gender this study indicated is an interesting research work that needs to be further explored in the future.

5 Conclusions

Agent migration between a physical body and a virtual world, where only one agent is active at a time, is a research topic that presents many questions that are still unanswered, such as: (i) To what extent do users naturally understand agent migration? (ii) Do users perceive the agents in different embodiments as the same entity? (iii) Does the migration process enhance the user interaction? (iv) How can we take advantage of the unique characteristics of each embodiment?

In this work, we developed two embodiments of an artificial pet that can migrate between a mobile phone and a robotic pet, where the aim was to address some of the questions above. The robotic pet is a dinosaur with touch sensors, several motion motors, speaker capabilities, and some limited object recognition attributes, while the virtual pet is the same dinosaur that has been designed to run as an Android application. While designing the migration process, we followed the soul-shell approach[32], in which the *personality* of the artificial pet is preserved regardless of the pet's embodiment. Hence, the *personality* is reflected in both embodiments in a consistent way, with only one embodiment active at a time. In addition, the two embodiments are driven by interaction needs, since these characteristics can help the development of the *personality* of the two embodiments.

We conducted a user study with elementary school children to investigate the user experience and to what extent agent migration was a natural process to the users. Note that the concept of migration was never explained to children at any time, yet the results show that 43.3% of the children considered the two embodiments as the same entity; in addition, the results show that the virtual dinosaur was more obedient than the robotic dinosaur. In fact, the different perception of obedience could be one of the reasons why the children perceived the two embodiments as different entities, along with absence of migration cues.

The key contributions of this work are fourfold. First, we combine research on virtual pets and agent migration, and develop a unified autonomous prototype with a virtual and physical embodiment. Second, a user study was conducted to help us investigate the user experience and how natural was the agent migration process. Third, the described experiment procedure may help the scientific community develop a standard for evaluating agent migration. Fourth, the user study's conclusions generated design guidelines that can be used in agent migration. For instance, (i) when a pet with two embodiments is presented to users, equal emphasis should be given to both embodiments right from the start; (ii) there should always be visual cues of the agent migration.

As future work, we would like to enhance the features of our embodiments, such as the inclusion of migration visual cues, in order to improve the playing experience. The mentioned improvement could also help us explore an hypothesis that emerged from the study: *agent migration without visual cues of migration causes the overall interaction experience with the agent to be perceived as more difficult*. Moreover, we would be interested to research if the non responsiveness of a physical embodiment due to sensor limitations would continue to be perceived as part of a non obedient attitude in longer and repeated interactions. Additionally, we could further research the gender differences that were detected: whether girls enjoy the experience of witnessing an agent with two embodiments more than boys, or maybe that the migration process has a greater appeal to girls.

We see this work as the stepping stone towards enhancing the user experience in virtual pets, where the pet can migrate between embodiments and take advantage of the unique characteristics of each embodiment.

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References

[1] Krzysztof Arent, Pedro Cuba, Kerstin Dautenhahn, Xiao Yan Deng, Kheng Lee Koay, Bogdan Kreczmer, Lukasz Malek, and Dag Sverre Syrdal. Deliverable d8.1 - foundations of migrating companions - lirec, 2008.

[2] Michael Wooldridge. *An introduction to multiagent systems*. Wiley, 2008.

[3] Thomas Holz, Mauro Dragone, and Greg MP O'Hare. Where robots and virtual agents meet. *International Journal of Social Robotics*, 1(1):83–93, 2009.

[4] David Robert and Cynthia Breazeal. Blended reality characters. In *Proceedings of the seventh annual ACM/IEEE international conference on Human-Robot Interaction*, pages 359–366. ACM, 2012.

[5] Paul Milgram, Haruo Takemura, Akira Utsumi, and Fumio Kishino. Augmented reality: A class of displays on the reality-virtuality continuum. In *Photonics for Industrial Applications*, pages 282–292. International Society for Optics and Photonics, 1995.

[6] Shaun W. Lawson and Thomas Chesney. The impact of owner age on companionship with virtual pets. In *Eighth International Conference on Information Visualisation (IV'04)*, volume 4, pages 1922–1928, 2007.

[7] Tristan Donovan. Focus groups, testing, and metrics: Developers speak. `http://www.gamasutra.com/view/feature/134870/focus_groups_testing_and_.php`, 2011. [Online; accessed 23-May-2013].

[8] Jyotsna Pattnaik. On behalf of their animal friends: Involving children in animal advocacy. *Childhood Education*, 81(2):95, 2004.

[9] Sherril L. Adkins and D. W. Rajecki. Pets' roles in parents' bereavement. *Anthrozoos: A Multidisciplinary Journal of The Interactions of People & Animals*, 12(1):33–42, 1999.

[10] Rebecca A. Johnson, Richard L. Meadows, Jennifer S. Haubner, and Kathy Sevedge. Human-animal interaction: A complementary//alternative medical (cam) intervention for cancer patients. *American Behavioral Scientist*, 47(1):55–69, 2003.

[11] K. Wada and T. Shibata. Living with seal robots in a care house - evaluations of social and physiological influences. In *IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2006.

[12] Ylva Fernaeus, Maria Håkansson, Mattias Jacobsson, and Sara Ljungblad. How do you play with a robotic toy animal?: a long-term study of pleo. In *Proceedings of the 9th international Conference on interaction Design and Children*, pages 39–48, 2010.

[13] Mattias Jacobsson. Play, belief and stories about robots: A case study of a pleo blogging community. In *The 18th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN 2009)*, 2009.

[14] M. Csikszentmihalyi. Flow: the psychology of optimal experience. *Harper Perennial*, 1990.

[15] P. F. Gomes, E. M. Segura, H. Cramer, T. Paiva, A. Paiva, and L. E. Holmquist. Vipleo and phypleo: Artificial pet with two embodiments. In *The Proceedings of The 8th International Conference on Advances in Computer Entertainment Technology*, Lisbon, Portugal, November 2011. ACM.

[16] Elena Márquez Segura, Henriette Cramer, Paulo F. Gomes, Stina Nylander, and Ana Paiva. Revive!: reactions to migration between different embodiments when playing with robotic pets. In *Proceedings of the 11th International Conference on Interaction Design and Children*, IDC '12, pages 88–97, Bremen, Germany, 2012. ACM.

[17] Michael A. Goodrich and Alan C. Schultz. Human–robot interaction: A survey. *Foundations and Trends in Human–Computer Interaction*, 1(3):203–275, 2007.

[18] Sandra Y. Okita and Daniel L. Schwartz. Young children's understanding of animacy and entertaiment robots. *International Journal of Humanoid Robotics*, 3(3):393–412, 2006.

[19] Ginevra Castellano, Iolanda Leite, André Pereira, Carlos Martinho, Ana Paiva, and Peter W. Mcowan. Multimodal affect modeling and recognition for empathic robot companions. *International Journal of Humanoid Robotics*, 10(1):1350010, 2013.

[20] EU FP7 ALIZ-E project. http://www.aliz-e.org. last checked: November 2013.

[21] Paul Baxter, Tony Belpaeme, Lola Canamero, Piero Cosi, Yiannis Demiris, and Valentin Enescu. Long-term human-robot interaction with young users. In *IEEE/ACM Human-Robot Interaction 2011 Conference (Robots with Children Workshop)*, 2011.

[22] Raquel Ros, Marco Nalin, Rachel Wood, Paul Baxter, Rosemarijn Looije, Yannis Demiris, Tony Belpaeme, Alessio Giusti, and Clara Pozzi. Child-robot interaction in the wild: Advice to the aspiring experimenter. In *Proceedings of the 13th International Conference on Multimodal Interfaces*, 2011.

[23] Maria Vircikova and Peter Sincak. Experience with the children-humanoid interaction in rehabilitation therapy for spinal disorders. In Jong-Hwan Kim, Eric T. Matson, Hyun Myung, and Peter Xu, editors, *Robot Intelligence Technology and Applications 2012*, volume 208 of *Advances in Intelligent Systems and Computing*, pages 347–357. Springer Berlin Heidelberg, 2013.

[24] Tawanna Dillahunt, Geof Becker, Jennifer Mankoff, and Robert Kraut. Motivating environmentally sustainable behavior changes with a virtual polar bear. In *Pervasive 2008 Workshop Proceedings*, pages 58–62, 2008.

[25] Calvin Liao, Zhi-Hong Chen, and Tak-Wai Chan. My-mini-pet: The design of pet-nurturing handheld game. In *Second IEEE International Conference on Digital Games and Intelligent Toys Based Education*, pages 138–140, 2008.

[26] Zhi-Hong Chen, Calvin C. Y. Liao, Tzu-Chao Chien, and Tak-Wai Chan. Nurturing my-pet: Promoting effort-making learning behavior by animal companions. In *Sixteenth International Conference on Computers in Education*, 2008.

[27] Joana Dimas, Iolanda Leite, André Pereira, Pedro Cuba, Rui Prada, and Ana Paiva. Pervasive pleo: Long-term attachment with artificial pets. In *Please enjoy!: Workshop on playful experiences in Mobile HCI*, 2010.

[28] Angus McIntyre, Luc Steels, and Frederic Kaplan. Net-mobile embodied agents. In *Proceedings of Sony Research Forum*, 1999.

[29] Kheng Lee Koay, Dag Sverre Syrdal, Michael L. Walters, and Kerstin Dautenhahn. A user study on visualization of agent migration between two companion robots. In *13th International Conference on Human-Computer Interaction (HCII 2009)*, 2009.

[30] David Robert, Ryan Wistorrt, Jesse Gray, and Cynthia Breazeal. Exploring mixed reality robot gaming. In *Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction*, 2011.

[31] D. Y. Robert. Imaginative play with blended reality characters. Master's thesis, Massachusetts Institute of Technology, 2011.

[32] K. L. Koay, D. S. Syrdal, K. Dautenhahn, K. Arent, L Malek, and B. Kreczmer. Companion migration - initial participants' feedback from a video-based prototyping study. In Xiangyu Wang, editor, *Mixed Reality and Human-Robot Interaction*, volume 1010, pages 133–151. Springer Netherlands, 2011.

[33] F. Kaplan. Artificial attachment: Will a robot ever pass ainsworth s strange situation test? In *Proceedings of Humanoids 2001 : IEEE-RAS International Conference on Humanoid Robots*, pages 125–132, 2001.

[34] C. Bartl and D. Dörner. Psi: A theory of the integration of cognition, emotion and motivation. In *2nd European Conference on Cognitive Modelling*, pages 66–73, 1998.

[35] K. A. Brennan, C. L. Clark, and P. R. Shaver. *Attachment theory and close relationships*, chapter Self-Report Measurement of Adult Attachment. Guilford Press, 1998.

[36] A. Aron, E. N. Aron, and D. Smollan. Inclusion of other in the self scale and the structure of interpersonal closeness. *Journal of Personality and Social Psychology*, 63(4):596–612, 1992.

[37] M. E. Henerson, L. L. Morris, and C. T. Fitz-Gibbon. *How to measure attitudes*, volume 6. SAGE, 1987.

[38] M. T. Orne. *Artifacts in behavioral research*, chapter Demand Characteristics and the concept of Quasi-Controls, pages 143–179. Academic Press, 1969.

[39] Andy Field and Graham Hole. *How to Design and Report Experiments*, chapter Experimental Designs, pages 60–61. Sage, 2003.

[40] H. B. Mann and D. R. Whitney. On a test of whether one of two random variables is stochastically larger than the other. *The Annals of Mathematical Statistics*, 18(1):50–60, 1947.

[41] J. Cohen. *Statistical Power Analysis for the Behavioral Sciences*. Lawrence Erlbaum, second edition, 1988.

[42] F. Wilcoxon. Individual comparisons by ranking methods. *Biometrics Bulletin*, 1(6):80–83, 1945.

[43] Göran Sonesson. *The extensions of man revisited: From primary to tertiary embodiment*, pages 27 – 56. Embodiment in Cognition and Culture. John Benjamins Publishing Company, 2007.

A Elementary School Children Study Questionnaire

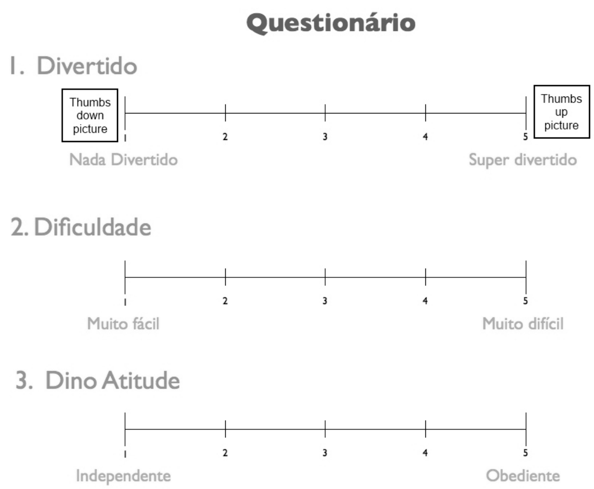

Figure 14: Questionnaire - Page 1

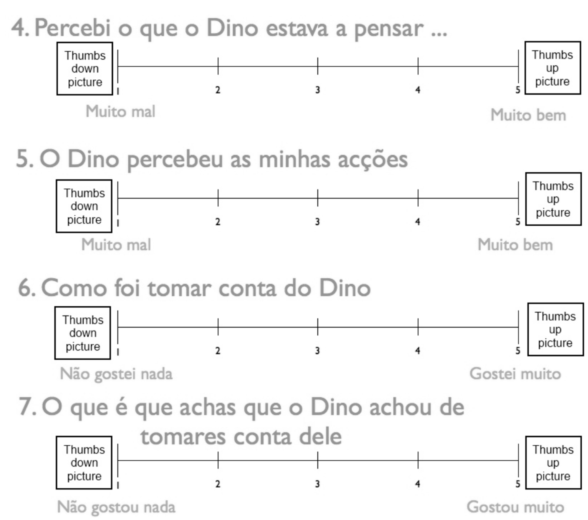

Figure 15: Questionnaire - Page 2

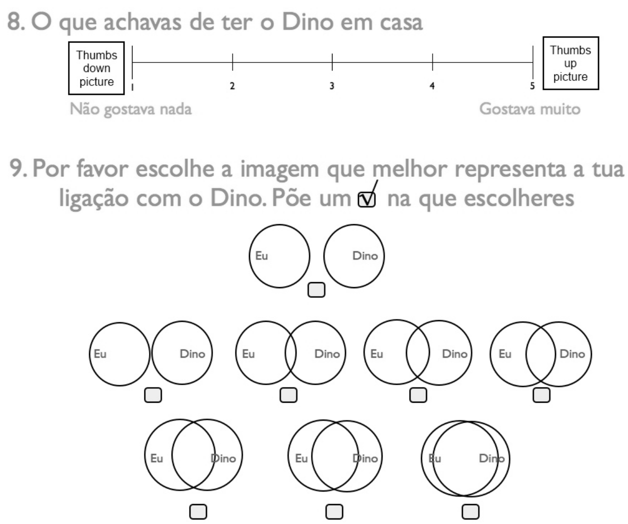

Figure 16: Questionnaire - Page 3

B Elementary School Children Study Between Groups Questionnaire Set II

Table 6: Between Groups (PhyPleo first and ViPleo first) comparison *questionnaire set II*

	variable	***Mdn***		***U***	***z***	***sig***	***r***
		PhyFirst	**ViFirst**				
1	Fun	5.0	5.0	109.5	-.13	*ns*	-.02
2	Difficulty	4.0	5.0	90.0	-.95	*ns*	-.14
3	Obedience	4.0	3.0	90.0	-.95	*ns*	-.14
4	Understand	4.0	4.0	90.0	-.98	*ns*	-.14
5	Be understood	4.0	4.0	100.0	-.55	*ns*	-.08
6	Like	5.0	5.0	84.0	-1.98	*ns*	-.29
7	Be liked	5.0	5.0	109.0	-.14	*ns*	-.02
8	Take home	5.0	5.0	84.0	-1.97	*ns*	-.29
9	Closeness	7.0	7.0	108.5	-.15	*ns*	-.02