Original article

doi: 10.1111/j.1365-2729.2010.00367.x

My-Mini-Pet: a handheld pet-nurturing game to engage students in arithmetic practices

C.C.Y. Liao,* Z-H. Chen,* H.N.H. Cheng,* F-C. Chen† & T-W. Chan*

*Graduate Institute of Network Learning Technology, National Central University, Jhongli City, Taoyuan County 32001, Taiwan
†Graduate Institute of Learning and Instruction, National Central University, Jhongli City, Taoyuan County 32001, Taiwan

Abstract In the last decade, more and more games have been developed for handheld devices. Furthermore, the popularity of handheld devices and increase of wireless computing can be taken advantage of to provide students with more learning opportunities. Games also could bring promising benefits – specifically, motivating students to learn/play, sustaining their interest, reflecting their learning/playing status, and facilitating the learning/playing progress. However, most of these have been designed for entertainment rather than education. Hence, in this study we incorporate game elements into a learning environment. The My-Mini-Pet system is a handheld pet-nurturing game environment, in which students learn with an animal learning companion, their My-Mini-Pet. Three design strategies are adopted. First, the pet-nurturing strategy, which simulates the relationship between the pet and its owner, the My-Mini-Pet becomes a motivator/sustainer of learning. Second, the pet appearance-changing strategy, which externalizes the learning status of the student. In other words, the My-Mini-Pet plays the role of a reflector. Third, the pet feedback strategy, which links the behaviours of the student and his/her pet, the My-Mini-Pet acts as a facilitator of learning. A pilot study was also conducted to preliminarily investigate the effectiveness and experiences of the strategies on allowing the student to understand arithmetic practices. The results showed that the strategy was effective, encouraging the students to engage in learning activities. Furthermore, the game attracted the students' attention and stimulated discussion between peers. Some implications about the further developments are also discussed.

Keywords animal companion, game-based learning, handheld device, My-Mini-Pet.

Introduction

Over the last decade, more and more games have been developed for handheld devices. Video game companies are continually releasing new-generation handheld game devices (e.g. Nintendo DS, PlayStation Portable). However, these devices are mostly designed for entertainment rather than education. Only a few have developed adopted location-aware handheld games for educational purposes (e.g. Schwabe & Göth 2005; Huizenga *et al*. 2009). Recently, individual researchers (Klopfer 2008; Squire 2009) and the mobile Game-Based Learning (mGBL) research group (2009) have noted that there are several types of mobile game-based learning games, such as augmented reality games (Klopfer 2008; Squire 2009), treasure games (Barkhuus *et al*. 2005), and pet-orientation digital games (see Chen *et al*. 2007). Moreover, the mGBL group (2009) joined forces to work on the development of a platform for the presentation of educational content in a playful way that would work on handheld devices.

Accepted: 14 April 2010
Correspondence: Calvin C.Y. Liao, Graduate Institute of Network Learning Technology, National Central University, no. 300, Jhongda Road, Jhongli City, Taoyuan County 32001, Taiwan. Email: calvin@cl.ncu.edu.tw

Table 1. Well-known pet-oriented digital games.

Since	Tamagotchi Bandai, 1996	Pokemon Nintendo, 1995	DigiMon Bandai, 1997	NintenDogs Nintendo, 2005
Description	Tamagotchi, a handheld digital pet, housed in a small simple egg-shaped computer. It allows users to feed, play, clean, and otherwise interact with their pet.	Pokemon is a game where collective fictional species have made appearances in the Pokemon media.	DigiMon are monsters of various forms living in a 'Digital World', a parallel universe that originated from Earth's various communication networks.	Nintendogs is a real-time pet simulation video game. Using the touch screen and microphone, the owner can play with, train, pet, walk, brush, and wash their virtual dog.
Subject	Child	Child	Child	Child
Game type	Pet-nurturing game	Pet-collection game	Pet-competition game	Pet-training game
Interactive type	One-to-one	One-to-multiple (up to hundreds)	One-to-one	One-to-multiple (maximum of five)
Platform	Tamago	Game Boy, Nintendo DS	Physical card	Nintendo DS

Parallel developments have been made to incorporate artificial emotion and intelligence into commercial products. For instance, in 1996, the Bandai Toy Company in Japan released a series of devices for pet-nurturing games, called Tamagotchi. Players could raise virtual chickens, interacting with them as if they were real pets. At that time, the game was very popular in elementary schools (Webster 1998). Later, many other companies started to use the concept of pet-nurturing to design games, leading to games such as Pokemon (integrating the concepts of different virtual creatures with competition), DigiMon (combining virtual monsters and physical cards), NintenDogs (adopting touch control and voice control). The authors summarize the features of these pet-oriented digital games in Table 1. Within the area of intelligent creatures, pet-oriented digital games have emerged as one of the most widely available commercial game products with divergent applications in the entertainment industry. In particular, the pet-oriented digital games have been widely used, but only for entertainment.

The design of game-based learning environments for handheld devices is a significant current research issue (Facer *et al*. 2004; Schwabe & Göth 2005; Squire 2009). Rosas and colleagues (2003) have applied digital games for learning mathematics and reading comprehension in primary school. The results showed that digital games not only helped improve mathematical skills but also stimulated student motivation. Students found learning using digital games less boring. Furthermore, studies of games which combine pet-nurturing and learning activities have suggested that pet-oriented digital games may encourage the ability to maintain long-term motivation (Chen *et al*. 2007). In other words, virtual pets could keep motivating students and reminding them to learn materials. However, the pet-oriented digital game was designed only for personal computers (PCs) and laptops, which may limit learning and nurturing behaviours.

Hence, this study focuses on the design and the development of a handheld pet-nurturing learning game, entitled the My-Mini-Pet system (Liao *et al*. 2008). The game incorporates learning activities to build a learning environment that the student is interested in interacting with. Although the portability of handheld devices means that nurturing and learning can occur anytime and permeate daily life, its limitation of screen size also brings the challenge of design. We first propose three design strategies – pet-nurturing, pet appearance-changing, and pet feedback strategies – which can be applied to create a game-based learning environment in handheld devices. The strategies are further adopted to design a complete My-Mini-Pet system, revolving around a virtual pet who is an animal-learning companion simulating the appearance and attitude of a real pet. Through caring for the animal companion, the system can arouse and sustain students' motivation and engage them in learning activities. The My-Mini-Pet system guides students from game to learning activities in order to sustain student efforts. We also examine a prototype

of the My-Mini-Pet system. This pilot project addressed two questions: 'What were the learning effects of My-Mini-Pet?' which is concerned with cognition; and, the second question 'What was the students' affective experience when they use the My-Mini-Pet systems in a classroom environment?' is about affectivity. In short, this pilot project was conducted to evaluate the influences of the game on cognition (effectiveness) and affectivity (experience).

Related research

Mobile learning

Many studies have shown the potential of mobile devices to increase learning opportunities. On the one hand, their portability, makes them suitable for outdoor learning, such as birdwatching (Chen *et al*. 2003), studying animal behaviour (Facer *et al*. 2004), and orientation learning (Schwabe & Göth 2005). On the other hand, the accessibility of the technology (e.g. iPod, iPhone, BlackBerry; Wagner 2008) could prompt more interaction and engagement in the classroom (Pownell & Bailey 2001; Squire 2009) in activities such as augmented reality games (e.g. Klopfer 2008; Squire 2009), and competitive math games (e.g. Cheng *et al*. 2009). One-to-one (1:1) technology-enhanced learning would be possible when every student in the classroom owns a mobile device to help his/her learning (Sharples 2000; Roschelle 2003; Chan *et al*. 2006). The research emphasizes computer support for both formal and informal learning. The one-to-one classroom has the potential to have great positive influences on student's learning (Chan *et al*. 2006; Wagner 2008; Squire 2009). It is suggested that the advantages of handheld devices (e.g. small size, inexpensive price, portability) make them suitable for adoption as the first step towards technology-enhanced learning (Chan *et al*. 2006; Wagner 2008). The use of handheld devices would bring many benefits and opportunities for classroom learning in future.

Game-based learning

Digital game-enhanced learning is increasingly attracting attention because of its positive influence on learning. Game-based learning environments can help motivate students to learn, and provide students with a variety of learning opportunities to improve their learning (Prensky 2001; Gee 2003; Rosas *et al*. 2003; Kiili 2005; Ke 2008; Squire 2009). Malone (1981) suggested that instructors should utilize games as a pedagogical strategy to benefit students' learning. Significant motivational factors that stimulate a student's motivation to learn have been identified. For example, Malone and Lepper (1987) analysed key motivational elements for a successful learning environment. These included challenge, fantasy, curiosity, and control. Keller (1987) proposed a motivational model for classroom instruction which includes four factors: attention, relevance, confidence, and satisfaction. Gee (2003) found that learning principles adopted by game designers have much potential for facilitating learning in positive ways. He suggested that these learning principles should be built into the game design. Crawford (1982), an experienced game designer, also pointed out that digital games often contain multiple motivational factors – such as fantasy, interaction, conflict, and challenge – which should be helpful to motivate people to learn. The aforementioned studies lead one to believe that an enjoyable game-based learning strategy developed for different handheld devices could play a key role in both outdoor and classroom learning.

Handheld pet-nurturing game: design of the My-Mini-Pet system

The My-Mini-Pet system features animal companions (Chen *et al*. 2007) designed to be a child's learning companion (Chan & Baskin 1988, 1990). The My-Mini-Pet includes the pet's attitude, appearance, and feedback, designed to arouse the students' caring nature. The idea is to enhance and transform the learning process by skilfully interweaving learning and nurturing to create a new environment. In other words, a My-Mini-Pet system provides an interchange between learning activities with game activities. In such an easy and active way, students may be more willing to learn. For a further discussion of the elements of a game (e.g. rules, goals and objectives, outcomes and feedback, and so on) please see Prensky (2001). The My-Mini-Pet, based on these principles, operates on a handheld device. The interaction of student with the My-Mini-Pet in this pet-nurturing game-based learning environment motivates them to keep learning and participate in learning activities.

Table 2. Education roles played by the My-Mini-Pet.

	Strategy	Roles
Game activity	Pet nurturing	Motivator/sustainer
	Pet appearance change	Reflector
Learning activity	Pet feedback	Facilitator

Table 2 summarizes the educational roles played by the My-Mini-Pet. This study utilizes three strategies to enhance students' learning and motivation. First, there is the *pet-nurturing strategy* where students learn with their pets. By caring a pet in game activity, the My-Mini-Pet becomes a motivator/sustainer of learning. Second, there is the *pet appearance-changing strategy* where the appearance of the pet changes according to learning status thus reflecting the student's level of accomplishment. Finally, there is the *pet feedback strategy* which proposes that the pet should provide feedback for the learning activity, acting as a facilitator of the learning progress.

Strategy #1: nurturing of the My-Mini-Pet motivates/sustains learning

The custom of nurturing pets has existed in different genders and cultures for a long time. Some researchers (Levinson 1969; Beck & Katcher 1996; Melson 2001) have observed that nurturing pets holds a special attraction to human beings, especially children, who perceive the behaviours of pets as cute, friendly, and innocent. The relationship between a pet and its owner can be developed through caring. Because of this caring for pets, children not only feel love and needs, but also acquire supportive feelings (Levinson 1969; Beck & Katcher 1996). Generally speaking, pets influence children in at least four kinds of ways. First, in terms of physical health, taking care of pets can reduce blood pressure and stress and enhance physical health (Friedmann *et al*. 1983). Second, psychologically, for example, in psychotherapy, pets can be used in patient treatment, such as for children with shyness problems or attention deficit/hyperactivity disorders (Levinson 1969; Katcher 2000). Third, in personality development, caring for a pet is helpful to build a child's sense of responsibility and empathy for another living creature. Children show their pets their care and love by taking care of them (Melson 2001). Finally, for the development of social skills, interaction with the pets can increase children's social skills and learning opportunities (Beck & Katcher 1996; Myers 1998). Therefore, the influence of pets on children is extensive and strong. The aforementioned studies indicate that nurturing pets plays an essential role in students' learning development.

A My-Mini-Pet includes visible attributes (e.g. EduCoins, energy, health, and performance values) and invisible attributes (e.g. mood and boredom values). Students can see change in value of visible attributes on the interface. The value of invisible attributes cannot be directly seen on interface, but students become aware of the pet's status by facial expressions. All values associated with the My-Mini-Pet are changed by the student's actions in various locations in the game world. The design of the nurturing pet strategy in the My-Mini-Pet system is shown in Table 3. In the game activity, the student needs to nurture their pet. The nurturing strategy includes elements of buying, feeding learning, and playing. For example, the My-Mini-Pet's energy decreases over time, unless the student buys food to feed it. In other words, a student has to buy food in order to increase his/her pet's energy. However, buying food requires 'EduCoins (virtual money)', which have to be earned by the efforts made in learning activities, as shown in Fig 1a. In order to gain EduCoins, the student must accomplish learning tasks. The more tasks a student can accomplish, the more EduCoins the student can earn.

If the My-Mini-Pet's 'health' decreases over time, the students have to buy medicine at a virtual hospital. By taking the medicine, the My-Mini-Pet can recover its health. The merchandise (e.g. food, medication) in the food store and hospital cost different prices depending on the values they can increase. That is, the more the merchandise costs, the better the effect it has. Students shop according to their needs. The student can take her/his My-Mini-Pet to play mini-games in a virtual park. EduCoins and energy or health decrease according to the type of mini-game, as shown in Fig 1b. Students become aware of the My-Mini-Pet's 'mood' and level of 'boredom' by their facial expression, see Fig 2a. If the My-Mini-Pet's 'mood' decreases over time, the students have to win a beauty show game. The beauty show game is a kind of pet dress-up game, which only improves mood but also decreases the level of boredom and

Table 3. My-Mini-Pet's different attributes.

Attributes	Value	Change	Action (Location)
Visible attributes	EduCoins	Increase	Learning (library)
		Decrease	Playing (park, sports, beauty show)
			Buying (food store, hospital)
	Energy	Increase	Feeding (home)
		Decrease	Playing (park, sports, beauty show)
			Change with time
	Health	Increase	Feeding (hospital)
		Decrease	Playing (park, beauty show)
			Change with time
	Performance	Increase	Learning (library)
		Decrease	Playing (park, sports, beauty show)
Invisible attributes	Mood	Increase	Playing (park, sports, beauty show) learning (library)
		Decrease	Changes with time
	Boredom	Increase	Changes with time
		Decrease	Playing (park, sports, beauty show)

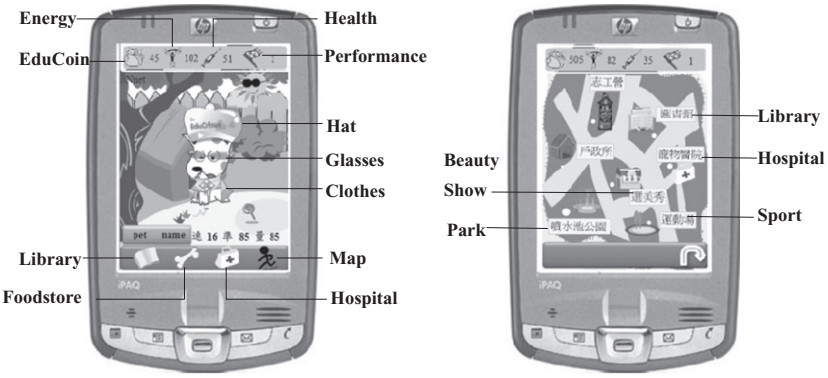

Fig 1 My-Mini-Pet.

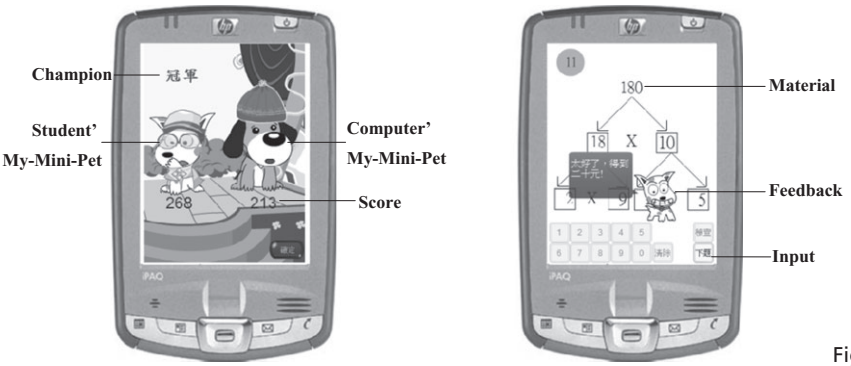

Fig 2 Game and learning interface.

energy value through playing. Ultimately, the buying, feeding, learning, and playing of the nurturing pet strategy create a positive cycle. The desire for consumption may facilitate and sustain the motivation of learning.

Strategy #2: changes in My-Mini-Pet appearance reflects the student's learning status

In the field of intelligent tutor systems, the student model has long played a critical role (Self 1988; Chan

1996; Kay 1997). In this model, data from the interaction between the student and the system are continuously collected and analysed, and used to adapt the educational system to individual learning needs. However, in the past, the student model only utilized information on learning status to give the student assistance. The system never showed the student his/her own student model. In recent years, many studies have discussed how to provide a student model for the students' reflection and inspection. This issue has been addressed by many (e.g. Self 1988; Chan 1996; Kay 1997). Self proposed 'making the contents of learner model open to the learner in order to provoke the learner to reflection (1988, p. 24)'. Chan said that 'the learner model can be used in different ways, other than hiding behind the student as an internal component inside the intelligent tutoring systems (1996, p. 140)', and Kay noted that 'if the learner model can be helpful in determining how a machine teaches, it should make it available to the learner for improving their own learning through better self-knowledge (1997, p. 18)'. The open learner (or student) model could bring more advantages to the student, such as planning learning goals (Bull & Kay 2007), helping with self-assessment (Mitrovic & Martin 2007) and reflection about learning (Tchetagni *et al*. 2007).

Chen *et al*. (2007) utilized an 'active' open learner model when developing animal companions to improve students' knowledge about their own learning status. The word 'active' means that the open learner model is externalized embodied by the emotions and behaviours of a character which are reflected by aspects of the student's learning aspects. In the previous My-Pet and Our-Pet system (Chen *et al*. 2007), the virtual pet automatically showed its emotional expressions to its owner, and expressed itself according to the owner's cognitive achievements. These emotional expressions would motivate the student (i.e. the owner) to take action and help to understand his/her student model and improve his/her learning status.

In a My-Mini-Pet system, the appearance of the animal companion is clarified in the beginning. The appearance can be changed based on the results of the learning tasks. There are four levels. Students must take action to change to a higher level, as shown in Table 4 and Fig 1a. The My-Mini-Pet is transformed in different ways based on the student's average speed of answer, average accuracy of answer, and average number of answers (hat, glasses and clothes, respectively). When a student participates in a learning task, the system records their performance and changes the appearance of his/her pet immediately. In this way, the student is able to monitor and reflect on his/her learning performance (Bull & Kay 2007). The purpose of the pet appearance-changing strategy is to supply students with a clear and definite goal and to facilitate self-reflection.

Table 4. My-Mini-Pet's different status expressions.

Appearance representation Rule	Expression	Level 0 <60%	Level 1 60%–75%	Level 2 75%–90%	Level 3 >90%
Hat	Average speed of answers				
Glasses	Average accuracy of answers				
Clothes	Average number of answers				

The four levels are a concrete representation of the students learning performance. Changing the appearance of the animal companion may give a student incentive to strive for better learning performance.

Strategy #3: pet feedback makes My-Mini-Pet as the facilitator of learning progress

The teacher plays an important role in a traditional learning activity. In a learning task, students are usually informed whether their answers are correct or incorrect but they may have to wait for a period of time for the teacher to make corrections and to finally know their learning status. The traditional way loses the immediateness of thinking and correction but technology can solve the problem, so that students can receive feedbacks and assistance immediately (VanLehn 2006; Milik *et al*. 2008; Zakharov *et al.* 2008). There are three benefits. Firstly, feedback may provide students with suggestions about future actions. Secondly, feedback can reinforce the student's background knowledge. Finally, feedback can encourage students to rethink. There has also been some research focused on the *types* of feedback: cognitive feedback (VanLehn 2006); affective feedback (Zakharov *et al*. 2008); *timing* of feedback (including immediate feedback, Milik *et al*. 2008; delayed feedback); and *content* of feedback (whether positive or negative feedback).

The My-Mini-Pet system provides students with both immediate and delayed feedback, such as emotional expressions (e.g. excited, happy, neutral, sad, and upset), EduCoins and mini-games. The feedback forms shown by the My-Mini-Pet are summarized in Table 5. In other, when students finish a task, they know the result immediately from the emotional expression of their My-Mini-Pet. Students can judge their learning performance by the reaction of the animal companion, as shown in Fig 2b. If conditions are satisfied for an upgrade, feedback can include more EduCoins and access to more mini-games (see Fig 2a). The variety of feedback, gives students an increased sense of achievement, enhances learning motivation, and thus stimulates more efforts to meet higher goals.

Preliminary evaluation

Participants and settings

The participants were nine 10-year-old fourth-grade students (six males and three females) from an elementary school in Taiwan. The participants were selected according to the following rules: parental consent forms; having low familiarity with the content or software; and not participating in other extra-curricular activities (e.g. track and field, choir, and so on) during the time of the experiment. Nine students were selected from 25 students in the class. Every participant was assigned a personal digital assistant (PDA) with wireless capability as the computing device.

Table 5. Different feedback forms in the My-Mini-Pet system.

	Content	Function	Expression	Description
Immediate feedback	NF[1]	Emotional expression	Upset	More than three consecutive incorrect answers Upset emotional expression
			Sad	Two consecutive incorrect answers Sad emotional expression
	Null	Emotional expression	Neutral	Incorrect answer Neutral emotional expression
		EduCoin		Correct answer Neutral emotional expression
	PF[2]	Emotional expression	Happy	Consecutive correct answers Happy emotional expression
Delayed feedback	PF	Mini-game	Excited	Accomplish a unit Increasing type and frequency of games

[1]PF, positive feedback (feedback for correct actions).
[2]NF, negative feedback (feedback for errors).

Measures

Effectiveness

The learning achievement of arithmetic practices (effectiveness) was measured by the number of 10 questions (including the 53 blanks) consisting of two topics: 2-digit * 1-digit (multiplying 2-digit by 1-digit numbers) or 3-digit * 1-digit (multiplying 3-digit by 1-digit numbers), and integer factorization. Each question contained a number of blanks. Students needed to fill in the blanks. The multiplication questions were related to the manipulation of 10's complement (2 questions including 20 blanks) and distributivity (3 questions including 15 blanks). The factorization questions required the manipulation of the multiplication table (5 questions including 18 blanks). Each measure was arranged for a session of 50 min, so that the students could complete all the requirements within the time available. Two experts (mathematics teachers) validated the test according to the learning objectives using a table of specifications for the content of instruction. The internal consistency of the test was 0.92 (Cronbach's α).

Experience

The experience of playing games was measured by the Animal Companion Experience Questionnaire (ACEQ), designed and developed by the authors. The content of the questionnaire was developed based on the experiential gaming model (Kiili 2005), game flow (Sweetser & Wyeth 2005), and nurturing game models (Chen *et al*. 2007). The ACEQ used for this study had 32 items. There were eight items for each component of *pet nurturing (PN), pet appearance change (PAC), pet feedback (PF)*, and *learning material (LM)*. Students were asked to rate their experience on a Likert-type item with five anchors (1 = strongly disagree, 2 = disagree, 3 = not sure, 4 = agree, 5 = strongly agree). The possible total score thus ranged from 32 to 160. Sample items were as follows: 'I cared about the health status of my pet' (PN), 'I cared about the appearance of my pet' (PAC), 'The feedback from my pet kept me going' (PF), and 'After doing several mathematics tasks, I learned from my mistakes and knew what to do next' (LM).

Procedure

The pilot project using a My-Mini-Pet system was conducted in the classroom of an elementary school in Taiwan. The pilot project was divided into four phases: before, during, after, and after 1 month phase.

First phase. To familiarize them with the using the PDA, the students participated in a 30-min training session. This was to avoid influence due to unfamiliarity with the devices. In addition, we also conducted a pre-test (for effectiveness) in order to understand the baseline of arithmetic ability.

Second phase. The students used the handheld devices during eight 30-min sessions for 2 months. During this experiment, two graduate students (one majoring in learning technology and the other majoring in learning instruction) were employed as teaching assistants to observe the students' behaviours, not to judge the students' autonomy of ownership and use.

Third phase. When the students finished the experiment, a post-test and the ACEQ (experience) were carried out. Affective experimental data was collected by the two graduate students who conducted 15–20 face-to-face interviews (semi-open) with the students. The quantitative data were supported by a rich set of qualitative means. A digital audio recorder was used in one of the computer rooms. Photographs were taken with a digital camera to capture the surroundings and activities during the experiment.

Final phase. Delayed post-tests were conducted 1 month after finishing the experiment.

Data collection and analysis

Quantitative data

System records. The system automatically recorded the participants' time-on-task (the learning time), attempt frequencies (the number of math questions they had tried to solve), and correctness frequencies (the number of the questions they had solved correctly). The Friedman Test was conducted to test for differences in *effectiveness* (pre-, post-, and delay-post-test) and *experience*. The α was set at 0.05 for all statistical tests. All analyses were done with the Statistical Package for the Social Science (SPSS Windows vs. 15).

Qualitative data

Field observation. The author and the teaching assistants observed participants behaviours as they

Table 6. Results showing effectiveness: means and standard deviations (n = 9).

	Multiplication				Factorization	
	10's complement[1]		Distributivity[2]		Multiplication table[3]	
	M	SD	M	SD	M	SD
Pre-test	11.33	5.48	3.56	4.33	9.00	5.27
Post-test	19.78	0.67	12.00	3.74	13.67	3.77
Delay-post-test	19.78	0.67	11.78	3.60	13.33	3.67

[1]Possible range for 10s complement (0–20).
[2]Possible range for distributivity (0–15).
[3]Possible range for multiplication table (0–18).

interacted with the handheld game, their peers, and the external environment (including verbal and nonverbal behaviours and facial expressions). A semi-structured observation protocol was developed to guide the author's attention during observation, although the actual observation was open to any situational changes (Taylor & Bogdan 1998a). The authors also wrote the observation comments (OCs).

Interviews. The author and teaching assistants developed a semi-open-ended protocol to facilitate the participants' thinking without influencing what they said (Taylor & Bogdan 1998c; Creswell 2003). Participants were prompted to report whatever went through their mind. The author wrote the interview comments (ICs).

During data analysis, statements or meaning units that emerged as possible commonalities from the protocol and notes (including the OCs and ICs) were coded using the Nvivo7 software. The author then refined these themes by removing overlaps and capturing the main thrust of each theme's meaning (Taylor & Bogdan 1998b; Camic *et al*. 2003). General themes or patterns that emerged through this data coding process were synthesized. Analysis of quantitative data (system records, effectiveness, and ACEQ) and qualitative data (OCs, ICs, and interview protocol) were employed to achieve triangulation verification.

Findings

Effectiveness

The Friedman Test, the counterpart of repeated-measures ANOVA, of a non-parametric test was conducted on achievement scores. There was a significant difference among the pre-test, the post-test and the delay-post-test scores (10' complement: $Friedman_{(2)} = 16$, $P < 0.05$; distributivity: $Friedman_{(2)} = 17.43$, $P < 0.05$; multiplication table: $Friedman_{(2)} = 9.74$, $P < 0.05$). Pair-wise comparison procedures revealed that post-test and delayed-post-test achievement scores were higher than pre-test scores; see Table 6. Although this pilot study found the effectiveness of prototype of the My-Mini-Pet system to be positive, some points still remain to be considered. First, the influence of time, such as 2 months of practice and natural maturity, should be considered. Secondly, a control group should be added in order to evaluate effectiveness improvement more carefully.

Table 7. Results of the ACEQ: means and standard deviations (n = 9).

	Overall experience[1]	M	SD
		130.97	0.91
Game activity	Pet nurturing[2]	33.76	0.83
	Pet appearance change[2]	29.55	1.20
Learning activity	Pet feedback[2]	33.34	0.80
	Learning material[2]	34.32	0.82

[1]Possible range for overall experience (32 ~ 160).
[2]Possible range for PN, PAC, PF, and LM (8 ~ 40).

Experience

The ACEQ results comprise four components; the means and standard deviations (SD) are shown in Table 7. We compare changes in pet appearance with other components; we found PAC to be much lower. The pet appearance change aspect needs to be redesigned.

The results of the questionnaire for the pet-nurturing strategy showed that the students often observed their pet's mood ($M = 4.44$, $SD = 0.88$) and health status ($M = 4.78$, $SD = 0.44$). The students tended to worry that their EduCoins were too few to play the mini-games ($M = 4.33$, $SD = 0.71$). The interview protocols also revealed their perception of the My-Mini-Pet.

> Interviewer: Could you give an example of why you feel it was fun to play with your dog?
> #3: He could talk to me.
> Interviewer: Hum . . . what else?
> #3: I could feed him and he would wag his tail after eating something. He was so cute.
> Interviewer: Hum.
> #3: And I could play with him. When he was moving around, he was so cute, especially when he was jumping.

Some students gradually formed an emotional attachment to their My-Mini-Pet after being engaged in nurturing and being attentive to the pets. Students could build close relationships by interacting with their My-Mini-Pet. They noticed their My-Mini-Pet, took good care of them, bought medicine for them, nurtured them, and played with them. The students often had the same mood as their My-Mini-Pet and indication of the attention paid. In short, the pet-nurturing strategy encouraged the students to take care of their My-Mini-Pet and their motivation to participate in learning activities and mini-games was maintained.

We now discuss the strategy of changing the pet's appearance. The authors observed that the students could perceive the changes in the pets' appearance. Interview protocol data was as follows:

> Interviewer: Could you give me an example?
> #8: Some have glasses but no hat; someone's pet has a whole suit, including a scarf. Someone's didn't have glasses.

The students did pay attention to the appearance of the pets as an indication of their learning status. The questionnaire results indicated that the students would discuss the appearance of their pets with others ($M = 4.11$, $SD = 1.27$). The strategy helped maintain learning attention and promote the learning outcome. It could also be helpful to keep the students' motivated and then improve learning effectiveness.

Next we discuss the strategy of pet feedback. The My-Mini-Pet provided the students with immediate feedback after answering questions, as shown by the interview protocol:

> Interviewer: After answering questions, your pet may give you some response. What do you think about these responses?
> #2: It was important for me!
> Interviewer: Why did you think it was important?
> #2: When we had a wrong answer, the pet told us it was not a correct answer.
> Interviewer: Hum.
> #2: If it was a wrong answer, then we could correct the answer for this question.

Questionnaires also revealed that the feedback from the pet kept the students going ($M = 4.89$, $SD = 0.33$). The students could see the reflection of their performance in the learning activities from the reaction of the My-Mini-Pet. The immediate feedback of the My-Mini-Pet allowed the students to know their answer at once. If they gave a wrong answer, they could correct. It is noteworthy that the My-Mini-Pet encouraged students to reflect on their learning status. Hence, pet feedback in a learning activity encourages the students to be aware of their learning progress.

Regarding the learning materials, the authors observed that most students were fluent in answering the questions. The questionnaire results were the same.

> After doing several mathematics tasks, I could learn from the mistakes and know what to do next ($M = 4.67$, $SD = 0.50$).

After the learning activity, the authors observed that the students would continue to discuss the learning material and compare each others' answering status. The classmates would also sometimes consult and teach each other with difficult tasks. The questionnaire data also revealed that the students would discuss their PDA tasks with each other after the learning session ($M = 4.11$, $SD = 0.93$). The students would expect difficult learning activities earlier ($M = 4.44$, $SD = 0.73$). The interview protocol is as follows:

> Interviewer: What do you discuss?
> #6: We discussed how to answer the question and we taught each other.

Hence, results showed that the My-Mini-Pet facilitated discussion among the students and lengthened the learning time.

Research limitations

It should be emphasized that this is a pilot study for handheld learning games. There are several limitations to this study that should be addressed. First, the subjects participating in the experiment were few, even though they had diverse characteristics (e.g. gender, math abilities, and so on). Second, the study was a one-time implementation of limited duration. Design-based research (Barab & Squire 2004) reminds us that the study lacks a longitudinal component, not only to investigate long-term improvement of math ability but also to explore potential positive and negative effects. We should be careful when generalizing the study findings to interpret the interaction between other types of games and different contexts.

Discussion

These findings have inspired us to rethink and anticipate that handheld games may have great potential and educational value in developing one-to-one digital classrooms. This study shows that they can have some positive influence on cognition and affectivity. In particular, the My-Mini-Pet system, which combined pet-nurturing and learning activities, provides long-term relationship management with the pet and maintains long-term motivation for learning. The feature of long-term management will help learning to promote the adoptability of students and to integrate current learning tools.

Handheld games could promote the adoptability of students

Motivation is an important aspect of effective learning, but motivation needs to be sustained through feedback response and reflection (Keller 1987). The key challenge for effective learning with handheld games is to engage, motivate, support, and interest students. It is also important to have clear learning outcomes which are relevant to real world contexts of practice. The characteristics of handheld games allow students to interact easily and naturally with others (negotiation, coordination, communication, discussion, collaboration, and so on) in the game environment. Zurita and Nussbaum (2004) proposed similar games for learning of math and language in a mobile computer support collaborative learning environment.

Handheld games could promote integrated learning tools

One-to-one (1:1) technology enhances learning by bringing us personalized communication (Sharples 2000; Roschelle 2003), personalized libraries (Sharples 2000; Chan *et al*. 2006), and facilitates open learning (Squire 2009). Personal mobile technologies and game environments for personalized learning could have immense impact. For example, Bell *et al*. (2006) have identified the mobile game, Feeding Yoshi, as a kind of sophisticated design which provides a route to creating an engaging experience. The character of handheld devices (portability and mobility) could lead to the adaption of informal learning into formal learning (Roschelle 2003), to form a seamless learning space. Seamless learning (Chan *et al*. 2006; Borgman *et al*. 2008) means that the students would learn in different contexts, such as time, locality, and space. Through personal devices as the medium, students could easily and quickly change to another context. The wireless network would connect handheld devices outdoors with the desktop PC indoors. The game environment could easily integrate different learning tools and gameplay to keep the students motivated to use these learning tools.

Conclusions and further works

The study explored the design and the development of a handheld pet-nurturing game with a learning environment. Firstly, the My-Mini-Pet was developed to run on a handheld device. The system took advantage of three design strategies: pet nurturing, pet appearance changing, and pet feedback. The design rationale behind the system was that taking good care of the My-Mini-Pet would improve the student's learning status through the open student model. Besides, the My-Mini-Pet system also attempts to promote reflection and helpful interactions among classmates. This study also examined the influence of the My-Mini-Pet prototype. The cognitive results show the students to be positively influenced, but some points still need to be considered. The affective results revealed that the students were engaged in the learning activities. The strategies also attracted the attention and aroused discussion among peers.

Next step

Additionally, we see three directions in which the pet-nurturing game research could be implemented. The first focuses on educational issues, which we would benefit from increased student learning motivation. This could be improved by adjusting changes in pet appearance to balance the difficulty of the learning task (Chen *et al*. 2007). The second direction focuses on technical issues, for benefit of students' learning reflection. This means to redesign the open learner model (Bull & Kay 2007) to more dynamically present the learning status, to encourage students more actively, and to regulate their learning state. The final direction focuses on social issue, related to the benefit of students interacting with others. Enhancing learner interaction (Chou *et al*. 2003) could be accomplished by having the animal companion play the roles of competitor, collaborator, tutee, peer tutor, and so on (e.g. NPC, non-player character in online game). By means of the above, we could improve the design of the game-based learning strategy.

Acknowledgement

The authors would like to thank the National Science Council of the Republic of China, Taiwan for financially supporting this research under Contract No. NSC-98-2631-S-008-001.

References

Barab S. & Squire K. (2004) Design-based research: putting a stake in the ground. *Journal of the Learning Sciences* **13**, 1–14.

Barkhuus L., Chalmers M., Tennent P., Hall M., Bell M., Sherwood S. & Brown B. (2005) Picking pockets on the lawn: the development of tactics and strategies in a mobile game. In *UbiComp 2005: Ubiquitous Computing* (pp. 358–374). Available at: http://eprints.gla.ac.uk/3424/1/youvegotto2pickapocketortwoboys.pdf (last accessed 22 July 2010).

Beck A. & Katcher A. (1996) *Between Pets and People*. Purdue University Press, West Lafayette, IN.

Bell M., Chalmers M., Barkhuus L., Hall M., Sherwood S., Tennent P., Brown B., Rowland D., Benford S., Capra M. & Hampshire A. (2006) Interweaving mobile games with everyday life. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (eds R. Grinter, T. Rodden, P. Aoki, E. Cutrell, R. Jeffries & G. Olson), pp. 417–426. ACM, Montréal, QC. doi: 10.1145/1124772.1124835.

Borgman C.L., Abelson H., Dirks L., Johnson R., Koedinger K.R., Linn M.C., Lynch C.A., Oblinger D.G., Pea R.D., Salen K., Smith M.S. & Szalay A. (2008) *Fostering Learning in the Networked World: The Cyberlearning Opportunity and Challenge, A 21st Century Agenda for the National Science Foundation*. National Science Foundation, Washington, DC. Available at: http://connect.educause.edu/Library/Abstract/FosteringLearningintheNet/47165 (last accessed 22 July 2009).

Bull S. & Kay J. (2007) Student models that invite the learner in: the SMILI:() open learner modelling framework. *International Journal of Artificial Intelligence in Education* **17**, 89–120.

Camic P.M., Rhodes J.E. & Yardley L., eds (2003) *Qualitative Research in Psychology – Expanding Perspectives in Methodology and Design*. APA, Washington, DC.

Chan T.W. (1996) Learning companion systems, social learning systems, and the global social learning club. *Journal of Artificial Intelligence in Education* **7**, 125–159.

Chan T.W. & Baskin B. (1988) 'Studying with the prince' the computer as a learning companion. Proceedings of International Conference on Intelligent Tutoring, ITS88, Montreal, Canada, 194–200.

Chan T.W. & Baskin B. (1990) Learning companion systems. In *Intelligent Tutoring Systems* (eds C. Frasson & G. Gauthier), pp. 6–33. Ablex, New Jersey.

Chan T.W., Roschelle J., Hsi S., Kinshuk, Sharples M., Brown T., Patton C., Cherniavsky J., Pea R., Norris C., Soloway E., Balacheff N., Scardamalia M., Dillenbourg P., Looi C.K., Milrad M. & Hoppe U. (2006) One-to-one technology-enhanced learning: an opportunity for global research collaboration. *Research and Practice in Technology Enhanced Learning* **1**, 3–29.

Chen Y.S., Kao T.C. & Sheu J.P. (2003) A mobile learning system for scaffolding bird watching learning. *Journal of Computer Assisted Learning* **19**, 347–359.

Chen Z.H., Deng Y.C., Chou C.Y. & Chan T.W. (2007) Active open learner models as animal companions: motivating children to learn through interaction with My-Pet and Our-Pet. *International Journal of Artificial Intelligence in Education* **17**, 145–167.

Cheng H.N.H., Wu W.M.C., Liao C.C.Y. & Chan T.W. (2009) Equal opportunity tactic: Redesigning and applying competition games in classrooms. *Computers & Education* **53**, 866–876. doi: 10.1016/j.compedu.2009.05.006.

Chou C.Y., Chan T.W. & Lin C.J. (2003) Redefining the learning companion: the past, present, and future of educational agents. *Computers & Education* **40**, 255–269.

Crawford C. (1982) *The Art of Computer Game Design*. Osborne/McGraw-Hill, Berkeley, CA.

Creswell J.W. (2003) The use of theory. In *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, 2nd edition, pp. 153–178. Sage Publications, Thousand Oaks, CA.

Facer K., Joiner R., Stanton D., Reid J., Hull R. & Kirk D. (2004) Savannah: mobile gaming and learning? *Journal of Computer Assisted Learning* **20**, 399–409. doi: 10.1111/j.1365-2729.2004.00105.x.

Friedmann E., Katcher A.H. & Thomas S.A. (1983) Social interaction and blood pressure: influence of animal companions. *The Journal of Nervous and Mental Disease* **171**, 461–465.

Gee J.P. (2003) *What Video Games Have to Teach Us about Learning and Literacy*. Palgrave Macmillan, New York, NY.

Huizenga J., Admiraal W., Akkerman S. & ten Dam G. (2009) Mobile game-based learning in secondary education: engagement, motivation and learning in a mobile city game. *Journal of Computer Assisted Learning* **25**, 332–344. doi: 10.1111/j.1365-2729.2009.00316.x.

Katcher A.H. (2000) *The Future of Educational Research on the Animal-Human Bond and Animal Assisted Therapy*, Handbook on Animal-Assisted Therapy, pp. 486–469. Academic Press, New York, NY.

Kay J. (1997) Learner know thyself: student models to give learner control and responsibility. In *International Conference on Computers in Education* (eds Z. Halim, T. Ottomann & Z. Razak), pp. 17–24. AACE, Charlottesville, VA.

Ke F. (2008) A case study of computer gaming for math: engaged learning from gameplay? *Computer & Education* **51**, 1609–1620.

Keller J.M. (1987) Strategies for stimulating the motivation to learn. *Performance & Instruction* **26**, 1–7.

Kiili K. (2005) Digital game-based learning: towards an experiential gaming model. *Internet and Higher Education* **8**, 13–24.

Klopfer E. (2008) *Augmented Learning: Research and Design of Mobile Educational Games*. The MIT Press, Cambridge, MA.

Levinson B.M. (1969) *Pet-Oriented Child Psychotherapy*. Charles C. Thomas, Springfield, IL.

Liao C.C.Y., Chen Z.H. & Chan T.W. (2008) My-Mini-Pet: the design of pet-nurturing handheld game. In *Digital Game and Intelligent Toy Enhanced Learning, IEEE International Workshop on* (eds M. Eisenberg, Kinshuk, M. Chang & R. Mcgreal), pp. 138–140. IEEE Computer Society, Los Alamitos, CA. Available at: doi: http://doi.ieeecomputersociety.org/10.1109/DIGITEL.2008.34

Malone T.W. (1981) Toward a theory of intrinsically motivating instruction. *Cognitive Science* **5**, 333–369.

Malone T.W. & Lepper M.R. (1987) Making learning fun: a taxonomy of intrinsic motivations for learning. In *Aptitude, Learning, and Instruction,III: Conative and Affective Process Analysis* (eds R.E. Snow & M.J. Farr), pp. 223–225. Lawrence Erlbaum Associates, Hillsdale, NJ.

Melson G.F. (2001) *Why the Wild Things Are: Animals in the Lives of Children Cambridge*. Harvard University Press, Boston, MA.

Milik N., Mitrovic A. & Grimley M. (2008) Investigating the relationship between spatial ability and feedback style in ITSs. *Intelligent Tutoring Systems*. pp. 281–290. Available at: http://dx.doi.org/10.1007/978-3-540-69132-7_32 (last accessed 22 July 2009).

Mitrovic A. & Martin B. (2007) Evaluating the effect of open student models on self-assessment. *International Journal of Artificial Intelligence in Education* **17**, 121–144.

Mobile Game-Based Learning project (2009) *Project mGBL – mobile Game-Based Learning*. Available at: http://www.mg-bl.com/index.php?id=40 (last accessed 22 July 2009).

Myers O.E. (1998) *Children and Animals*. Westview Press, Boulder, CO.

Pownell D. & Bailey G. (2001) Getting a handle on handhelds. *American School Board Journal* **188**, 18–21.

Prensky M. (2001) *Digital Game-Based Learning*. McGraw-Hill, New York, NY.

QSR International (2006) *Nvivo7 (Version 7)* [Computer Software]. QSR International: Melbourne, Australia.

Rosas R., Nussbaum M., Cumsille P., Marianov V., Correa M., Flores P., Grau V., Lagos F., López X., López V., Rodriguez P. & Salinas M. (2003) Beyond Nintendo: design and assessment of educational video games for first and second grade students. *Computers & Education* **40**, 71–94.

Roschelle J. (2003) Keynote paper: unlocking the learning value of wireless mobile devices. *Journal of Computer Assisted Learning* **19**, 260. doi: 10.1046/j.0266-4909.2003.00028.x.

Schwabe G. & Göth C. (2005) Mobile learning with a mobile game: design and motivational effects. *Journal of Computer Assisted Learning* **21**, 204–216. doi: 10.1111/j.1365-2729.2005.00128.x.

Self J. (1988) Bypassing the intractable problem of student modelling. In *Proceedings of the Intelligent Tutoring Systems conference, ITS'88* (pp. 18–24). Montreal, Canada.

Sharples M. (2000) The design of personal mobile technologies for lifelong learning. *Computers & Education* **34**, 177–193. doi: 10.1016/S0360-1315(99)00044-5.

SPSS Inc. (2006) *Statistical Package for the Social Sciences (Version 15)* [Computer Software]. SPSS Inc.: Chicago, IL.

Squire K. (2009) Mobile media learning: multiplicities of place. *On the Horizon* **17**, 70–80. doi: 10.1108/10748120910936162.

Sweetser P. & Wyeth P. (2005) GameFlow: a model for evaluating player enjoyment in games. *ACM Computer in Entertainment* **3**, 1–24.

Taylor S.J. & Bogdan R. (1998a) Participant observation: in the field. In *Introduction to Qualitative Research Methods* (3th ed.), pp. 44–86. John Wiley & Sons, Inc, New York, NY.

Taylor S.J. & Bogdan R. (1998b) Working with data: data analysis in qualitative research. In *Introduction to Qualitative Research Methods* (3th ed.), pp. 134–164. John Wiley & Sons, Inc, New York, NY.

Taylor S.J. & Bogdan R. (1998c) In-depth interviewing. In *Introduction to Qualitative Research Methods* (3th ed.), pp. 87–116. John Wiley & Sons, Inc, New York, NY.

Tchetagni J., Nkambou R. & Bourdeau J. (2007) Explicit reflection in prolog-tutor. *International Journal of Artificial Intelligence in Education* **17**, 169–215.

VanLehn K. (2006) The behavior of tutoring systems. *International Journal of Artificial Intelligence in Education* **16**, 227–265.

Wagner E. (2008) Realizing the promises of mobile learning. *Journal of Computing in Higher Education* **20**, 4–14. doi: 10.1007/s12528-008-9008-x.

Webster N.C. (1998, June 29).The Marketing 100: Tamagotchi: Brian Goldner. *Advertising Age*. Available at: http://adage.com/article?article_id=65303 (last accessed 22 July 2010).

Zakharov K., Mitrovic A. & Johnston L. (2008) Towards emotionally-intelligent pedagogical agents. *Intelligent Tutoring Systems*. pp. 19–28. Available at: http://dx.doi.org/10.1007/978-3-540-69132-7_7 (last accessed 22 July 2009).

Zurita G. & Nussbaum M. (2004) Computer supported collaborative learning using wirelessly interconnected handheld computers. *Computers & Education* **42**, 289–314. doi: 10.1016/j.compedu.2003.08.005.