Chen et al. *Research and Practice in Technology Enhanced Learning* (2025) 20:33
https://doi.org/10.58459/rptel.2025.20033

Research and Practice in
Technology Enhanced Learning

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Pet-like learning companions: past research and future directions

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Abstract

The objective of this paper is to offer a design framework for pet-like learning companions (P-LCSs) whose concept extends from learning companion systems and integrates with pet-like characteristics, such as pet appearance, pet-owner relationship, and emotional support. Such a close relationship and deep emotions toward pets bring significant potential to benefit student learning in terms of social, cognitive, and affective aspects. After introducing some previous work on the P-LCSs, two further directions are proposed. One is linked to the research field of game-based and gamified design, while the other is connected to interest-driven creator (IDC) theory. Finally, a long-term goal of P-LCSs is discussed, and the reasons why P-LCSs might contribute to realizing the goal are also articulated in the paper.

Keywords: Learning companion systems, Pet-like characteristics, Game-based and gamified design, Interest-driven creator

Introduction

With the rapid development of AI and advanced learning technologies, many intelligent systems are empowered by AI solutions. For example, natural language processing is applied to immediate feedback and necessary learning interventions while students interact with chatbots (Lin & Mubarok, 2021). Data mining is also applied to learning analytics activities for performance prediction (Choi & McClenen, 2020; Ouyang et al., 2023). In addition, image recognition is also used to identify students' facial expressions, gestures, or emotions in educational settings (Leony et al., 2013; Singh et al., 2022).

Based on these rapid developments and applications, it has become promising for students to learn with interactive learning companions, where students are provided with different pedagogical strategies from virtual or robotic learning companions. However, the concept of learning companions has been proposed over thirty years ago (Chan & Baskin, 1988), and a number of studies have been conducted to realize this concept. Thus, there is a need to methodically review related work and offer a clear picture of the future development in the research field of learning companion systems.

Along this line of thought, this paper reviews the previous work on learning companion systems (LCSs), and further proposes a significant development direction: pet-like learning companion systems (P-LCSs), which integrate pet-like characteristics with LCSs to offer more opportunities in terms of different aspects. Moreover, P-LCSs are easily linked to game-based learning and gamified design, as well as Interest-Driven Creator (IDC) theory (Chan et al., 2019) to empower their influences and application, which could contribute to the realization of the optimal goal of LCSs—lifelong learning companions (L-LCSs).

In short, the aim of this paper is to offer a design framework for P-LCSs, which extends the concepts of intelligent tutoring systems, learning companions, and bridges the previous work and future development directions of learning companion systems. As illustrated in Figure 1, the design framework of P-LCSs contains four parts, including (1) intelligent tutoring systems, (2) learning companion systems, (3) pet-like learning companion systems, and (4) lifelong learning companion systems.

Intelligent tutoring systems (ITSs)

Theoretical foundation: applying AI to cognitive science

Educational systems are often empowered by emerging technologies to serve as intelligent systems. One of them is intelligent tutoring systems (ITSs), which attempt to leverage artificial intelligence (AI) technology to offer students personalized and adaptive tutoring

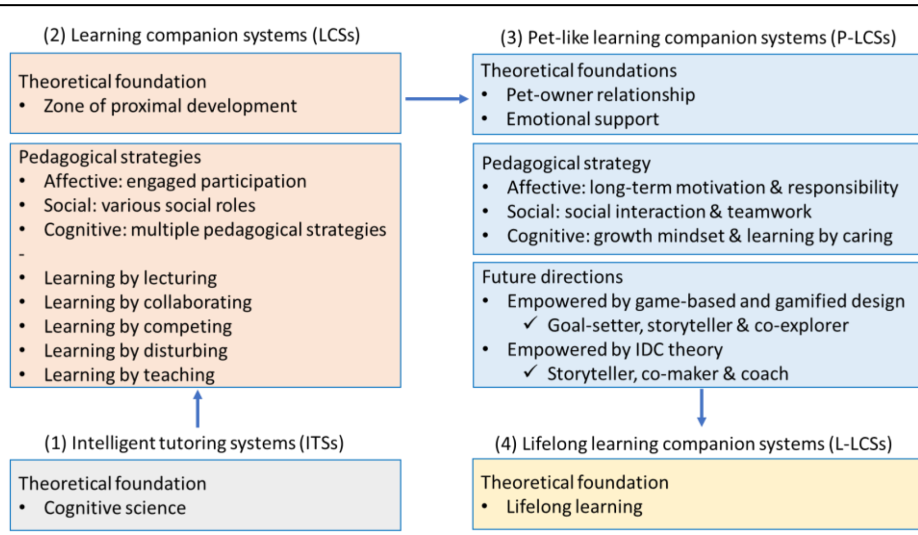

Fig. 1 The design framework for P-LCS

without the intervention of human teachers according to students' individual differences, such as background, prior knowledge, performance, or learning motivation (Carbonell, 1970). The concept of ITSs can be traced back to the 1970s, although AI technology was still in its early stage (Lin et al., 2023).

To foster students' learning more effectively and efficiently, AI technology is applied to ITS based on cognitive science, where computers attempt to model the thinking of human experts, and imitate how human brains operate (AlShaikh & Hewahi, 2021). To this end, different AI and machine learning technologies are applied. For example, clustering is an unsupervised data analysis technique that is used to find patterns through dividing input data into several different groups with similar characteristics. Such a technique is applied to model students' performances in ITSs (Šarić-Grgić et al., 2023). In addition, a Bayesian network is a decision network which describes a probabilistic graphical model with a set of variables and their conditional relationships. The technique is applied to understand and monitor students' current knowledge states (Alday, 2018; Gamboa & Fred, 2002; Santhi et al., 2013).

In such learning environments, ITSs act as the role of a "tutor" to interact with students. Based on AI technology, ITSs are equipped with the expert-level knowledge and pedagogical strategies. Thus, ITSs can provide adaptive instruction and tailored feedback for them so that students benefit from ITSs' tutoring and interacting, just as they do from human tutors, who can offer optimized and personalized instruction.

Structure of four components and pedagogical strategy

To foster the development of ITSs, four key components of ITSs (Self, 1974) are proposed, including domain knowledge (i.e., what), pedagogical strategies (i.e., how), the student model (i.e., whom), and the interface (i.e., where). The structure consisting of four components offers a significant foundation to foster the development of ITSs.

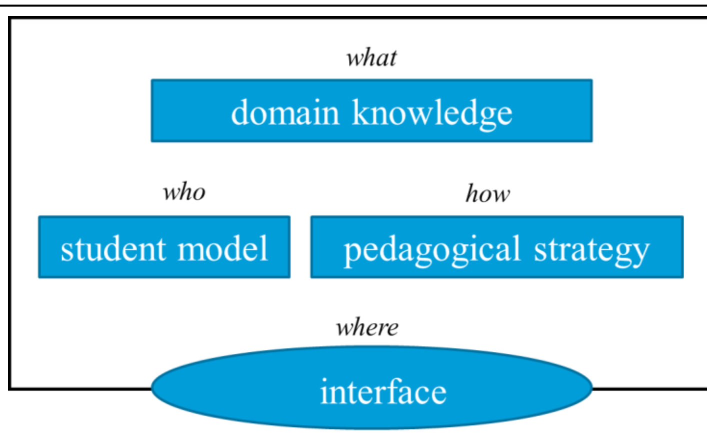

Fig. 2 Four components of intelligent tutoring systems (Self, 1974)

Domain knowledge

Domain knowledge refers to the structure of knowledge or subject matter that the intelligent systems are equipped with for teaching students. Since this component involves the structure and operations of the knowledge for specific topics in the subjects, it determines "what" the ITSs will teach. Based on the domain knowledge, other components are able to further offer automated and adaptive instructions according to different levels of students through the system interface and interaction.

Student model

Student model concerns "whom" to teach, and it collects, organizes, and maintains the data about the students who use the ITSs. This component is fundamental and critical because it empowers the ITS to offer adaptive interaction and feedback—an educational system requires a student model to understand and support the student's individual needs. More specifically, each student has individual differences and varied characteristics. While ITS are equipped with a referenced model to understand and trace the students, the systems can distinguish different students, and further offer them personalized or tailored pedagogies. In other words, the existence of student models increases the ability of system adaptability.

Pedagogical strategy

Pedagogical strategy involves "how" to teach students based on the above two components—domain knowledge and student model. To instruct students, ITSs must have multiple pedagogies, and the systems can choose an appropriate one from them to offer tailored interaction. In other words, the more pedagogies an educational system has, the more opportunities the system can create. For instance, while a student meets difficulties in the problem-solving process, the student might need different perspectives, explanation, or approaches for the problem. In particular, it is valuable for an educational system to offer multiple, flexible, personalized strategies for students. Over the past decades, a number of intelligent tutoring systems (ITSs) have been developed from AI techniques and cognitive science, focusing on providing automated, adaptive, and individualized instruction (Gardner, 1985).

Interface

Interface takes "where" to teach into account while conducting the pedagogical strategy mentioned above. In other words, interface can be regarded as one of instructional resources to facilitate the use of pedagogical strategies. Thus, appropriate formats for the interface could help realize and conduct the pedagogical strategy component. For instance, with the multimedia technology, an intelligent system could be portrayed as a "virtual figure" to demonstrate its identity and humanity, and convey pedagogical strategy. With the robotic and Internet of things (IOTs) technologies, this virtual figure could be represented as a “tangible robot” to interact with students.

One kind of famous ITS is animated pedagogical systems (Johnson et al., 2000), whose goal is to offer lifelike autonomous characters for students to create rich, face-to-face learning interactions. In this way, the systems can optimize their pedagogical impacts by demonstrating complex tasks, employing locomotion or gestures, and even conveying emotional responses to the students. For instance, in the situation of naval training tasks, such systems have been applied to operating the engines aboard US Navy surface ships, where students are engaged in an immersive 3D environment, and rich interaction with characters based on the tracking technique on students’ position and orientation (Johnson & Rickel 1998; Johnson et al., 1998). Such systems are also applied to the domains of botanical anatomy and physiology (Lester, Stone et al., 1999), as well as Internet Protocol Cosmo (Lester, Towns et al., 1999).

Learning companion systems (LCSs)

Theoretical foundation: zone of proximal development (ZPD)

Humans often treat computers as social actors (Nass & Moon, 2000; Nass et al., 1994; Nass et al., 1995), and also respond with social behavior and attributions if computers have features normally associated with humans, such as the use of natural language or a human-like appearance (Moon, 2000). Research also shows that social relationships have significant influences on psychological well-being (Krämer et al., 2011), and companionship is regarded as a special form of friendship that can contribute to this psychological well-being (Rook, 1987) because this relationship is characterized by an inner and intimate bond, intense affection, and a high emotional connection (Bukowski et al., 1993, 1994; Mendelson & Aboud, 2012).

Learning companion systems (LCSs) refer to an educational system, in which computers simulate virtual characters with human-like characteristics, so that such an educational system could play the role of learning peers to benefit students’ learning (Chan & Baskin, 1988; Chou et al., 2003). Unlike the design rationales of applying AI technology to imitate a knowledgeable tutor, LCSs apply AI technology to simulate learning peers whose knowledge is similar to that of students. In this way, LCSs can interact with students by different pedagogical strategies, such as collaborative learning or competitive learning, and thus benefit students’ learning.

This is because students can benefit from different social interaction provided by LCSs based on the theoretical foundation of zone of proximal development (ZPD) (Vygotsky, 1978), in which students reach their potential development when they learn with learning peers compared to individual learning (Chan & Baskin, 1990). In addition, such companions are different from the tutor-tutee relationship, which could enrich their social interaction.

Three development aspects and pedagogical strategies

After the concept of LCSs (Chan & Baskin, 1988, 1990) was proposed, it brought several new possibilities that are different from those of ITSs in terms of the following three aspects: social, cognitive, and affective aspects.

Affective aspect

LCSs not only expand their influence on students' cognition and thinking, but also engage them to participate in learning activities for a long time. How to motivate and sustain students to learn is always a significant issue. According to the theory of interest development (Hidi, 1990, 2006; Hidi & Renninger, 2006; Krapp et al., 1992), students' interest can be developed from situational interest to individual interest. More specifically, while students are situated in a social environment, they interact with different learning companions, which could offer varied challenges, scaffolding and feedback to make learning activities more interesting. In this way, students might be more willing to learn in such learning environments, and gradually develop their curiosity and interest in subject domain, if they find that learning is rewarding and they are satisfied with knowledge acquiring and learning experience.

Social aspect

LCSs offer more social interaction, which is different from ITSs, whose goal is to play the role of "tutor" for offering adaptive instruction based on its intelligent mechanisms and components, including domain knowledge, student model, pedagogical strategy, and interface. In other words, the goal of ITSs is to develop intelligent and smart "tutors" so that the systems can teach students effectively. However, the goal of LCSs is to play as the role of "peer" so that students can learn with various companions with different competences (e.g., high or low competence) or different personalities (e.g., introverted or extroverted).

A classic LCS is the system developed by Hietala and Niemirepo (1998), where students can interact with four learning companions. Each companion has an individual name and

Table 1 Learning companion systems

Aspects	Educational possibilities
Affective aspect	Engaged participation
Social aspect	More social roles
Cognitive aspect	Multiple pedagogical strategies

appearance. However, two companions (one boy and one girl) are strong in the subject matter, and they do not make mistakes. The other two companions (one boy and one girl) are weak in the subject matter, and they might make mistakes in their problem-solving process. The goal of such LCSs design with different knowledge levels is designed to maintain the motivation of students to collaborate with them. This study further suggested that the "personal voice" of LCSs could engage students to learn in addition to the competence of LCSs.

Cognitive aspect

LCSs offer different educational roles to promote students' thinking and learning. As mentioned above, ITSs utilize the pedagogy of "learning by lecturing" to benefit students. As illustrated in Figure 3, learning companions expand such pedagogical spectrum, including applying the pedagogies of "learning by collaborating" (Goodman et al., 1998), "learning by competing" (Chang et al., 2003), "learning by disturbing" (Aimeur & Frasson, 1996; Aimeur et al., 1997), and "learning by teaching" (Biswas et al. 2005; Leelawong & Biswas, 2008). In other words, learning companions do not play the role of "expert" in the subject domains to provide correct knowledge. Instead, learning companions might make mistakes or feel confused while they learn or solve problems. Nevertheless, when students learn with these learning companions, they are motivated to play more active roles (e.g., collaborator, competitor, tutor, tutee) in their learning. Thus, they have more opportunities to be engaged in the learning activities.

For instance, the "learning by disturbing" strategy is used by the LCSs who play the role of "trouble maker" and learn with students. The system will propose a problem to both of students and trouble maker to answer. However, the trouble maker will deliberately give a wrong answer to the problem for encouraging students to propose the right answer. By doing so, students' thinking and problem-solving skill are promoted (Aimeur & Frasson, 1996). In addition, the "learning by teaching" strategy is adopted by the LCSs who play the role of "tutee" based on the shared representation of Betty's Brain to encourage students' explicit teaching and shared responsibility (Biswas et al., 2005; Leelawong & Biswas, 2008). In the learning environment, students can teach, query, and quiz the LCS (i.e., Betty) and benefit their learning.

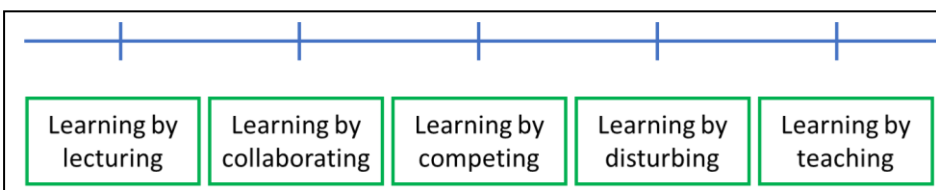

Fig. 3 Spectrum of pedagogical strategies of LCSs (Aimeur & Frasson, 1996; Chen et al., 2008)

With the advance of learning technology such as Internet of Things (IOTs), robots, machine learning and generative AI, more LCSs are designing and developing in either in the form of physical robots (Al Hakim et al., 2023; Cheng et al., 2021) or virtual software. Some of LCSs are featured as conversational agents to build social companionship based on the emotional bond and relationships (Chaturvedi et al., 2023). Their appearances are either virtually embodied or physically embodied, but all of them concern the social companionship that will contribute to the design of human-computer interaction and enrich user experience (Strohmann et al., 2023).

Pet-like learning companion systems (P-LCSs)

Theoretical foundation

Different from the companionship with learning peers, the companionship with pets is a special form of companionship. First, pet-keeping has been a pervasive activity for a long time. In ancient times, some animals may have been wild, living nearby. People might find these animals to be kind, cute and loyal to them. Thus, people began to keep them as pets and gradually develop special attachments to them. This kind of companionship is pervasive and has lasted for a long time in history.

Second, the relationship with pets is not only like companionship with “friends”, but also like that with “children”. More specifically, while people keep pets, they take on the role as “owners”, which is like being “parents” who show deep emotion, love, and concerns selflessly, and are responsible for taking good care of their children. In addition, this firm relationship between “owners” and “pets” is a kind of companionship without pressure. It is noticeable that people work with their pets (e.g., working dog—golden retriever), or study with their pets (e.g., people read newspapers in their house, and dogs just lie down to accompany them). With this companionship, people feel at ease, comfortable, and pleased. In other words, pet-keeping can contribute to developing a kind of close, firm, and comfortable social relationship.

Third, it is argued that this social relationship can be aroused by “subjective reality”—people’s real feeling, memory, and perception aroused by human-computer interaction design (Kusahara, 2000). It implies that well-designed learning or artificial systems could arouse people’s such perceptions and emotions. A famous example is “Tamagotchi”. Although Tamagotchi is designed as a simple toy with some buttons for students to nurture their digital pets, students love Tamagotchi and keep it with them for a long period of time (Kusahara, 2000). Since such perceived reality is subjective, it could be evoked through representations of their pets and interacting with them.

In short, pet-keeping is a special form of social relationship, and has the following two features to show its great and lasting influences, described as follows:

Pet-owner relationship

As described above, the pet-owner relationship is a special form of companionship without pressure. Unlike the relationship accompanied by peers, students feel more at easy and more comfortable when accompanied by their pets. This is because pets are always patient and wait for their owners to continue doing something despite difficulties, without complaining or becoming annoyed. This psychological support is important because it helps students settle their body and mind to be ready to learn something.

In addition, pet-like characteristics help students develop “caregiving” behaviors from a parent’s perspective, rather than a child’s perspective. More specifically, when students keep pets, they become “owners”. They help themselves become active managers by observing and looking after their pets, in which significant elements of self-regulated learning are involved in this process, such as goal-setting, monitoring, evaluating, and reflection. In short, this social relationship helps students “grow up” to become “owners” who need to take care of others and be more responsible, instead of just satisfying themselves.

Emotional support

Nurturing could be regarded as a kind of social relationship development with others, either for children or adults. It has been indicated that pet-nurturing promotes love, care, and responsibility (Lorenz, 1970; Melson, 2001). People (especially children) easily show their love and emotions towards their pets, and they also can learn something important from the nurturing process, such as the concept of birth and death, self-discipline, and responsibility. This “soft” emotional support can firmly consolidate the establishment of the pet-owner relationship as mentioned above.

Moreover, this relationship is popular and could also be found from literature. For example, in the classical literature “The Little Prince”, the main character learns love (e.g., the relationship with the rose) and being loved (e.g., the relationship with the fox) from social relationships (de Saint-Exupéry, 1964). This is because children are weak and need other people’s care. However, when children keep pets, their roles and responsibilities are quite different. They need to play the role of “caregiver” to nurture and look after their pets for a long time. In other words, this relationship is supported by psychological and emotional aspects. The existence of pets helps students develop deeper emotions and relationships, contributing to long-term participation and motivation.

Three development aspects and pedagogical strategies

While LCSs are equipped with pet-like characteristics, they could be further extended as pet-like learning companion systems (P-LCSs), which need to be nurtured and cared for by students. The design rationales of allowing the students to keep their pets lie in the fact that

Table 2 Pet-like learning companion systems

Aspects	Pet-like characteristics	Educational possibilities
Affective aspect	Emotional support	Engaged participation
Social aspect	Pet-owner relationship	More social roles
Cognitive aspect	Learning by caring	Multiple pedagogical strategies

such "pet companionship" could be easily situated in game-based learning or gamified design, and further deepen the influences of P-LCSs in the three dimensions: social, cognitive, and affective aspects.

Affective aspect: enhancing long-term motivation and responsibility

While P-LCSs are linked with game-based and gamified elements, students could also play the role of "owner" to keep their pets. Through human-computer interaction in gameplay, the pet-owner relationship could be established, and further contribute to initiating and sustaining their long-term participation.

How to motivate students to learn and sustain their long-term motivation has been a significant issue. Since pet-keeping is a long-term relationship with pets, letting students keep pets implies helping them set up a new identity of "owner", which involves establishing attachment, commitment, and responsibility to their pets for a long time. Such emotional support from P-LCSs could motivate and maintain students' interest and willingness to learn (Al Hakim et al., 2023; Chen et al., 2012).

In addition, to take good care of their pets, P-LCSs can also promote students' awareness of their learning states and responsibility for self-regulated behaviors (Chen et al., 2007). According to self-regulated learning, it comprises three cyclic phases: planning, performance, and reflection (Schunk & Zimmerman, 1998). When students keep their pets, they need to have good planning for creating a healthy and happy life for their pets, and then monitor their pets' states, and regulate what they can do for them. Although this process fosters students' regulation of pet-nurturing, it is reasonable to apply the regulation of students' learning, because both of them involve the same cyclic phases.

For instance, P-LCSs are designed as a My-Pet, which serves as "open" student models that reflects what students have learned in subject matters (Chen et al., 2007). More specifically, in the My-Pet system, students' learning states are open and classified according to students' performance and behaviors as numbers in different domains, such as "remembering", "understanding" and "applying" in the subject domain, which are quantitatively recorded according to students' mastery level, and "interest" and "effort" in the affective domain, which are determined by the frequency students perform tasks, and the accumulation of time they have spent. Those states also govern and influence P-LCSs' facial emotions and behaviors to remind students of their learning and indicate the topics

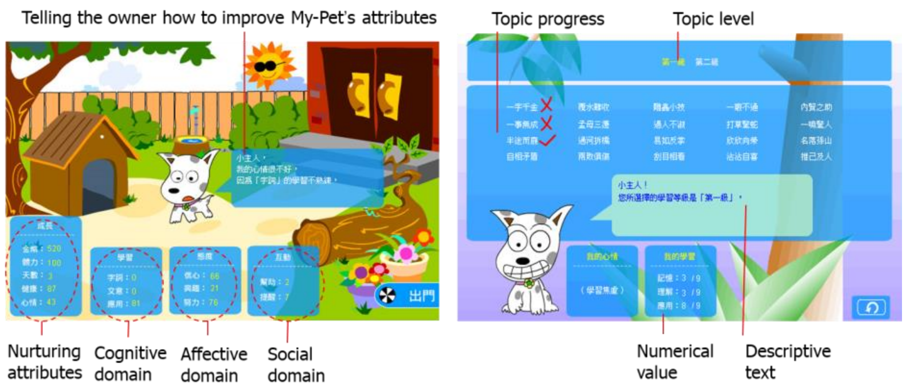

Fig. 4 P-LCS is designed as My-Pet (Chen et al., 2007)

needing to be improved. In this way, students' awareness and regulation could be enhanced, as illustrated in Figure 4.

Social aspect: enhancing social interaction and teamwork

In addition, P-LCSs are also designed to develop positive social interaction in team work (Chen et al., 2007). According to cooperative learning (Slavin, 1990), two significant elements for team members are individual accountability and interdependency. This is because the students are responsible for their learning (i.e., individual accountability), as well as for all of the team members (i.e., member interdependency).

According to this concept, P-LCSs are designed as Our-Pet system for promoting group discussion and team competition (Chen et al., 2007). The former involves the representation of group student model, which is an aggregate of four My-Pet's individual student models. As illustrated in Figure 5, four viewpoints are offered, including "average", "minimum", "maximum" and "variance". These viewpoints help teammates monitor their learning states through comparing My-Pet (i.e., individual student model) and Our-Pet (i.e.,

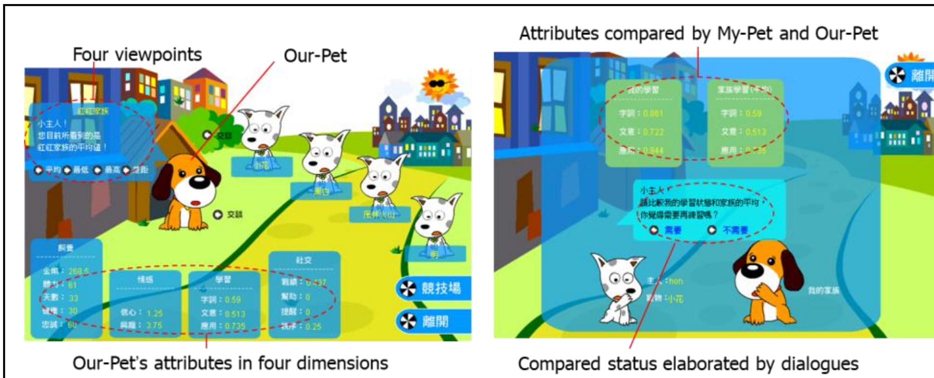

Fig. 5 P-LCS is designed as Our-Pet (Chen et al., 2007)

group student model). For instance, when the "maximum" viewpoint increases the variance among teammates, it will drive the stronger teammates to help the weaker ones so that the gap of variance between them could be decreased. In this way, students' awareness of their group learning and social interaction among them could be largely enhanced.

The latter involves students' participation in a group-based competitive activity, where all teammates establish their common goal—all of teammates must learn together and help each other in improving their learning states for winning the group competition. More specifically, Our-Pet game competition is held regularly, and students need to monitor their learning states to discover the team's shortcomings and adjust their strategy for winning the game competition. To achieve this common goal, their positive learning behaviors and social interactions, such as encouraging, monitoring, help-seeking and help-giving, are further encouraged.

Cognitive aspect: enhancing growth mindset through learning by caring

Based on the pet-owner relationship and emotional support, P-LCSs extend the spectrum of educational roles played by and the pedagogical strategies used by LCSs—"learning by caring" (Chen, 2012; Chen et al., 2007; Chen et al., 2011). The pedagogical strategy of "learning by caring" combines both affective factors (i.e., caring their pets) and cognitive factors (i.e., improving their learning) so that the social relationships (i.e., accompanied by their pets) could enrich and benefit their learning.

More specifically, P-LCSs are designed as the pets that students need to spend time and effort feeding and buying goods for in order to make them happy and promote their well-being. In addition, students also train their pets so that they can attend competitions to win the games, as shown in Figure 6. The findings indicate that students who keep pets show that such nurturing and competition-based activities could serve as a driving force for students to foster their effort-making behaviors (Chen et al., 2011) and preferences (Chen, 2014). That is, students are willing to take actions to do something meaningful and useful for their pets, and they regard gaming and learning as activities that can deepen their emotions and bring them pleasure. In these activities, P-LCSs serve as "surrogates" to shape students' growth mindset and effort-making belief (Chen & Chen, 2014).

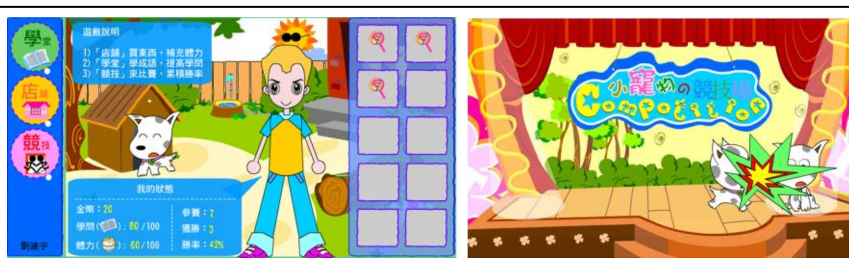

Fig. 6 P-LCS is designed as surrogate competition (Chen et al., 2011)

Fig. 7 P-LCS is designed as delegator NPCs (Chen et al., 2012)

According to attribution theory (Weiner, 1985, 1992), students' concept and behaviors are affected by their perceived causes of achievement. Effort, instead of intelligence or luck, is regarded as a crucial factor that can be controlled and should be encouraged during learning. However, students might not realize its significance (Seligman, 1994), or not believe this mindset can be changed by them (Dweck, 2000).

In addition, P-LCSs are also designed to foster the behavior of goal-pursuing (Chen et al., 2012). According to goal-setting theory (Locke, 1996), establishing goals for students will affect their direction of behavior, degree of effort, and persistence of action. It also implies that concrete, immediate, and clear goals could enhance students' motivation to accomplish their tasks. With the "learning by caring" strategy in the game environment, P-LCSs can be designed as delegator NPCs, who give quests (i.e., tasks, jobs, or duties) to students to do for them, as shown in Figure 7. In this way, the existence of P-LCSs not only could enhance students' goal-setting and social commitment to complete, but also foster their motivation to take actions to do or learn.

Future direction I: P-LCSs empowered by game-based and gamified design

Game-based learning refers to utilizing digital games as learning environments to provide students with goal-oriented activities and clear rules for achieving the goals established in the games (Ke, 2016; Qian & Clark, 2016). Thus, game-based learning involves students playing for specific goals and feedback to regulate their control. Previous studies have indicated that game-based learning could engage students in an interactive environment, and benefit students' learning in different subject domains, such as scientific inquiry (Barab et al., 2005), language learning (Chen et al., 2018), and math (Yeh et al., 2019).

Moreover, the concept of gamification is also applied in the design of learning activities. This is due to the fact that gamified design also shares specific characteristics from games (e.g., goal, fantasy, control, challenge, feedback) that could be aligned with educational design. In particular, three gamified elements from games could empower the influence of P-LCSs in terms of three aspects: meaningful goal, engaging story, and fantasy environment, as illustrated in Figure 8.

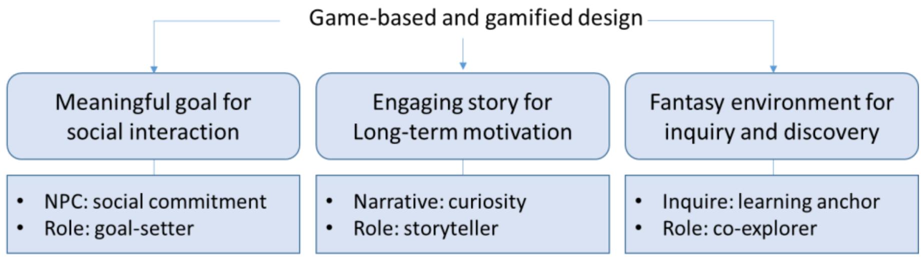

Fig. 8 P-LCS design in the game-based and gamified environment

Meaningful goal: P-LCSs as goal-setter to promote social interaction

First, game-based learning or gamified design often involves avatars (virtual characters controlled by students) and non-player characters (NPCs controlled by AI) to establish immediate and clear goals and deliver information through dialogues. Thus, while P-LCSs are designed as virtual pets (i.e., a kind of NPCs) needing students' care, such design of "soft" demand will increase their emotions and attachments to NPCs, such as keeping their promises to feed, or spending time playing and learning together. In other words, P-LCSs will foster students to establish meaningful goals for them to pursue and foster social interaction.

According to goal-setting theory (Locke & Latham, 2002), goals are a critical factor influencing students' motivation and task performance. Challenging goals require more effort and persistence. When students establish difficult goals in public, their social commitments are also enhanced, which will further drive them to achieve the goals (Erez & Zidon, 1984). Thus, goals could help students deepen social commitment and social interaction with others in the game-based environment and gamified environment.

Such social commitments could be realized and confirmed by P-LCSs, which play the role of "goal-setters" based on the pet-like characteristics (i.e., pet-owner relationship and emotional support). The social commitments are different from that established with their teachers or peers, because their pets always stay with them to offer positive companionships. This helps them confirm their goals with more emotional support without pressure. As "owners", students might strongly feel that they should have more responsibility when they accompanied by their P-LCSs. Thus, their learning in the game-based and gamified environment could be supported and scaffolded.

Engaging story: P-LCSs as storyteller to sustain long-term motivation

Second, game-based learning and gamified environments also involve narrative (i.e., storytelling) environments, which focus on a well-structured storyline to engage students and compose the story in the gaming process (Shih et al., 2015). Because storytelling is an attractive and enjoyable way for students, their attention and connection to their learning can be enhanced, which further promotes their motivation to learn (Eun & Lim, 2009). Thus, such a narrative environment allows students to collaborate, strategize, plan, and interact with other students, objects, or resources (Dickey, 2007; Novak, 2015). In other words, narrative technique can be regarded as a powerful and interactive way to present students with stories, and arouse their curiosity and sustain their interest.

According to motivation theory, students can be motivated from different perspectives, such as value-expectancy theory (Nilsen, 2009), attribution theory (Kelley & Michela, 1980), or social cognitive theory (Bandura, 2003). Among them, there exists some common elements that will contribute to long-term motivation sustenance—values for the goal and driving force for pursuing the goal, which could be enhanced and promoted by storytelling in the game-based and gamified environment.

Moreover, pet-keeping implies a sense of "being together with" (Haring et al., 2011) and "pleasure in spending time together". Because P-LCSs leverage the relationship of pet-owner and emotional supports, such social relationship is quite similar to those among family members. In other words, while NPCs in the game world are designed as P-LCSs that play as "storyteller" to tell students what they do not know by creating knowledge gap (Loewenstein, 1994), it will establish a significant goal for students in terms of both value and pursuit. For value, students might be more aware that their learning involve more companions from their pets, and they are not alone in learning. They engage themselves, and can focus on their goal. For pursuing, if P-LCSs can further offer adaptive or personalized help, encouragement, or suggestions based on this companionship, the students' goal-pursuing process could also be scaffolded.

Fantasy environment: P-LCSs as co-explorer to promote inquiry and discovery

Third, such storytelling techniques in game-based and gamified environments could enrich the game quests and inquiry-based design. Specifically, game quests possess properties that need to be investigated to discover features, histories, or sources. Because inquiry-based learning can trigger interesting or mysterious questions, it not only offers students motivation to initiate their learning, but also more "anchors" for students to offer more opportunities to learn.

Moreover, when students conduct inquiry-based learning, they are actually invited to engage in a series of discovery and reasoning processes. That is, they are encouraged to act as "explorers" for inquiry-based learning in the game-based and gamified environment. This is because inquiry-based learning is an active learning strategy, initiating by interesting questions or meaningful problems in a specific context. Students then discover related evidence from the context, and further try to figure out the possible relationships between questions and evidences. In other words, inquiry-based learning is regarded as a journey of thinking, which provides a valuable context for students to acquire, clarify, and apply what they have learned (Edelson et al., 1999).

While P-LCSs are designed as pets for student learning in the inquiry-based environment, P-LCSs can serve as "co-explorers", accompanying with their owners to explore together, just like the owners with their pets participating in outdoor activities in the real life. When students develop their own knowledge and solutions via inquiry and discovery, their ownership of knowledge could be enhanced. The students can share their experiences with their pets. However, if they have difficulties or problems, their co-explores can discuss with them or exchange their ideas, method, and strategies.

Future direction II: P-LCSs empowered by IDC theory

To increase students' interest and nurture their competences in the 21st century, interest-driven creator (IDC) theory is proposed to emphasize students' three significant cycles—interest, creation and habit (Chan et al., 2019). That is, IDC focuses on taking students' interest into account while they engaged in the creation process. In addition, IDC regards students as interest-driven creator, and also considers it a long-term goal and habit. The concept of IDC is illustrated in Figure 9.

Interest loop: P-LCSs as storyteller to arouse students' curiosity and interest

For the interest dimension, how to arouse students' interest is a significant consideration. Past research on interest has indicated two insights. One is that the development of interest could be evoked from a "situational" aspect to an "individual" aspect (Hidi & Renninger, 2006). It implies that creating an interesting and immersive environment related to what they want to learn is critical in the beginning of interest development. Thus, the question of how to develop students' interest could be rephrased as how to trigger their curiosity. The "knowledge gap", the distance between what students know and what they have yet to learn, will become a driving force to fulfill this gap, and satisfy their curiosity.

The second insight is that the development of interest involves both cognitive and affective factors. Knowledge gap, which represents students' lack of knowing or

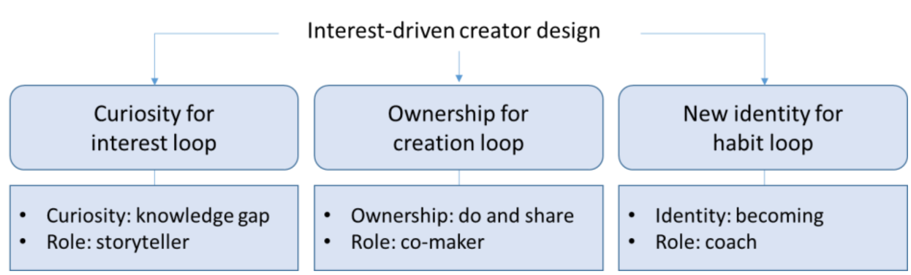

Fig. 9 P-LCS design based on the interest-driven creator (IDC) theory

understanding, is the cognitive factor. The other is the affective aspect (e.g., desiring to learn or know more), which is closely related to their intrinsic motivation. Take language learning as an example: students in the beginning might be curious about what happened while they read or listen to a detective story, and they might gradually develop their interest to know more, or even desire to know how to write such stories. Finally, they might continually improve their skills and become writers.

According to the IDC theory, P-LCSs could play the role of “storytellers” to bridge the cognitive and affective factors, and tell students interesting stories to arouse their imagination and curiosity. More specifically, in the beginning, P-LCSs could focus on the knowledge gap between what they have and haven’t learned in different subjects based on their student models. For instance, after students have learned some basic concepts of insects, they might be introduced to Fabre’s book about insects, which combines science and literature to vividly describe various insect species. Then, P-LCSs might discuss with students what and why Fabre devoted his life to observing and researching the tiny creatures. In this way, students’ interest will be triggered and extended to explore the world of insects, and biology.

Creation loop: P-LCSs as co-maker to facilitate students’ doing and sharing

For the creation dimension, how to promote students’ products and creation is the major concern. According to the IDC theory, the aim of creation loop is to help students improve their own production from what they have imitated through individual combining and social staging. Previous research has pointed out that creation is a kind of remixing process, which combines existing objects with new elements (Knobel & Lankshear, 2008). This concept implies that creation involves connecting or finding a new relationship from existing objects. In addition, this process also involves a “staging” mechanism, which offers a public space to demonstrate, discuss, and improve their products or outcomes. Cognitive apprenticeship (Collins & Kapur, 2022) indicates two key cycles, where the mentor cycle (i.e., modelling, coaching, and scaffolding) is followed by the tutee cycle (i.e., articulation, reflection, and exploration). Staging could be regarded as the mechanism fostering such creation, peer feedback, and revision cycles because the IDC theory regards learning peers as potential mentors.

Since learning-by-doing (e.g., imitation and combining) and sharing-with-others (e.g., staging) are the essential ways to promote students’ creation, P-LCSs could serve as “co-makers”. This is due to the fact that being a maker will enhance their hands-on experience and ownership, whereas collaboration will increase the likelihood of successful opportunities and enhance their confidence. In this way, their ideas, confidence and ownership could be promoted. For example, in coding education or STEAM education, P-LCSs could serve as co-makers to collaboratively plan their goals and strategies, and solve problems to demonstrate their final products to others, making students always feel interesting and capable of creating new things.

Habit loop: P-LCSs as coach to shape students' new identity and habit

For the habit dimension, how to cultivate students' specific behaviors as a long-term habit is a critical concern, rather than short-term one. The literature has pointed out that "cuing environment" and "routines" are two key factors for people to automate their routines (Wood & Neal, 2007). The habit loop of the IDC theory is to make students gradually be self-directed and self-regulated ones, and this process involves their creation and interest development. Thus, in a sense, habit loop is to internalize interest and creation from a long-term perspective, and develop students' identity to "become" an interest-driven creator.

Previous research further indicated that one effective strategy to develop people's habit is to give them a new identity (Clear, 2018). More specifically, people are defined and regarded as what they do every day. For example, people who teach in schools are called teachers; people who drive their taxis are called drivers; people who write articles are named as writers. However, although behaviors are the obvious features that can be seen from others, it is identity that governs their behaviors. In other words, if people regard themselves as teacher, they will develop their competences to teach in schools; if people regard themselves as drivers, they will practice their driving skills; if people regard themselves as writers, they will always improve their writing skills.

Thus, P-LCSs could serve as "coaches" to help students develop a new identity. Like coaches in a sport, their job is to establish a personalized goal for their students, and propose an actionable and reachable plan to accomplish this goal. More importantly, the coach should guide students to develop self-disciplines and self-regulation to realize this planning, and provide critical suggestions. From this viewpoint, two strategies could be applied by P-LCSs. The first one is a goal-oriented strategy: developing students' good habits by enhancing students' goal-setting and self-efficacy. According to value-expectation theory (Nilsen, 2009), increasing the value of the goal and students' confidence to pursue this goal could motivate students to learn. The other one is process-oriented: maintaining students' good habits by maintaining their perseverance, which implies never giving up easily when they encounter difficulties.

Lifelong learning companion systems (L-LCSs)

The creation of lifelong learning companions has been one of the most significant optimal goals (Chan et al., 2001; Chou et al., 2003). Such learning companions accompany the students from childhood to adulthood, and can play different educational roles with various pedagogical strategies while being with students. To pursue this goal, the collection of the student's lifelong portfolio for the learning companion is required, including students' data from different periods of time, and from various subject domains. A future scenario is that students have a set of lifelong learning companions that play different roles and stay with students from childhood to adulthood (Chan et al., 2001; Chou et al., 2003). With the characteristic of pets, P-LCSs have more potential in developing lifelong learning companion systems (L-LCSs) in terms of two dimensions: data collection and learning technologies.

First, for the data collection from different periods of time, the characteristics of pets could attract students to stay with them, and thus increase their willingness to remain with P-LCSs from childhood to adulthood. By doing so, data collected from childhood could be integrated with that from adulthood, and be constructed as more complete and comprehensive student models. In this way, more flexible and adaptive pedagogical strategies could be applied. In addition, for the data collection from different subject domains, AI-based learning technologies are helpful for the development of domain knowledge and student model, whereas game-based and gamified design could enrich the application of pedagogical strategies. In short, these data from different periods of time or subject domains could enrich the collection and analysis of student models, which further empowers the adaptive interaction of P-LCSs for the long-term educational goals offered by the IDC theory.

Second, with the development of learning technologies, such as virtual reality (VR), augmented reality (AR), mixed reality (MR), the Metaverse, robotics, Internet of Things (IOTs) and AI, enables students to learn with multiple connected LCSs with different roles and forms. In this view, P-LCSs could be regarded as "connectors" from childhood to adulthood for seamlessly linking the virtual world with reality. These platforms, in general, are a kind of emotional "connector" that supports better learning experiences for social interaction, but also allow students to have more effective, diverse, and complete learning process and materials. Meanwhile, students' information in student model will be used to improve technology adoption, content development, and learning activity design. Such connectors could be continuously supported and empowered by emerging learning technologies, including AI technology.

Conclusions

Recently, the rapid development of AI technologies has brought more promises and opportunities to benefit the design of ITSs and LCSs. ITSs emphasize tailored feedback and adaptive instruction, which deepens the influences of educational systems in terms of the cognitive aspect. Based on the ZPD theory, students benefit from multiple social interactions that are offered by different educational roles of LCSs. Since LCSs focus on various social interactions with different pedagogical strategies (e.g., learning by collaborating, competing, disturbing, or teaching), they deepen the impact of educational systems in terms of the social aspect.

The three aspects (i.e., affective, social, and cognitive) are significant considerations in the development of educational technology. In this paper, the design of P-LCSs, which extends the original concept of LCSs, and further integrates them with pet-like characteristics (e.g., pet appearance, pet-owner relationship, and emotional support), is the focus. In particular, such close relationships and deep emotions might offer some potential benefits to students in terms of social, cognitive, and affective aspects. In short, LCSs design extends the spectrum of ITSs in terms of the social aspect because they offer more social roles and interaction than just being intelligent tutors. P-LCSs design further extends the spectrum of LCSs in terms of the affective aspect because they offer long-term companionship and close emotional support to students.

In this paper, two research directions of P-LCSs are also proposed to empower their influences: game-based and gamified design, and the IDC theory. On one hand, game-based learning often involves NPCs, narrative, and fantasy environments that might contribute to the application and influences of P-LCSs. For instance, NPCs could offer clear goals and social commitment to promote social interaction; narrative is helpful for students' curiosity and long-term motivation; fantasy environments could serve as learning anchors to promote inquiry and discovery. On the other hand, IDC focuses on the three loops (i.e., interest, creation, and habit) which could offer insights for P-LCSs design. For example, P-LCSs could play the role of "storyteller" to arouse students' knowledge gaps and curiosity in the interest loop; P-LCSs could play the role of "co-maker" to promote students' self-ownership for creation through doing and sharing; P-LCSs could also play the role of "coach" to facilitate students' habit development and new identity.

Finally, with the pet-like characteristics, P-LCSs might not only contribute to long-term data collection from childhood to adulthood, but also integrate with advanced learning technologies in the game-based and gamified environment, either in the form of virtual or robotic representation, realizing the optimal goal of L-LCSs.

Abbreviations

AI: Artificial intelligence; AR: Augmented reality; IDC: Interest-driven creator; IOTs: Internet of things; ITSs: Intelligent tutoring systems; LCSs: Learning companion systems; LCSs: Learning companion systems; L-LCSs: Lifelong learning companion systems; MR: Mixed reality; NPCs: Non-player characters; P-LCSs: Pet-like learning companions; VR: Virtual reality; ZPD: Zone of proximal development.

Acknowledgements

This work was financially supported by the 'Institute for Research Excellence in Learning Sciences' of National Taiwan Normal University (NTNU) and 'International Taiwan Studies Center' of National Taiwan Normal University (NTNU) from The Featured Areas Research Center Program within the framework of the Higher Education Sprout Project by the Ministry of Education (MOE), Taiwan, Republic of China (ROC), as well as General Research Projects by the Ministry of Science and Technology (MOST-111-2511-H-003-005, MOST-113-2410-H-003-019-MY3), Taiwan, Republic of China (ROC).

Authors' contributions
Zhi-Hong Chen was the main author of the paper who conducted literature review, derived the key framework, and wrote the majority part of the paper. Hui-Lin Hsu and Chi-Fang Huang provided insights into the skeleton of the framework, and were involved in tightening up the final version of this paper. Chang-Yen Liao and Chih-Yueh Chou offered crucial ideas in developing the framework and two future directions. All authors read and approved the final manuscript.

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Funding
Not applicable.

Availability of data and materials
Not applicable.

Declarations

Competing interests
The authors declare that they have no competing interests.

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Received: 31 March 2024 Accepted: 20 August 2024
Published online: 1 January 2025 (Online First: 12 November 2024)

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