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The Design of Social Agents That Introduce Self-reflection in a Simulation Environment

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ABSTRACT

This study focuses on the design of several social agents that are intended to collect the self-reflections of learners while learners are immersed in simulation activities for knowledge building. The design of the agents follows 5W principles and seeks to encourage learners to expend mental effort upon multi-faceted learning and self-reflection. Using semantic networks, we developed dialogue lines for reflection-prompting agents. We analyzed the participants' answers using natural language processing technology to classify the sentences into positive and negative rankings. A preliminary field study with 117 high school students was conducted over three weeks to test the effects of agent-prompted self-reflection. The results demonstrated that 96% and 62% of participants separately completed the first and the second simulation activities (including the agent-prompted self-reflections respectively). Those who did not finish the activities were generally limited by time restrictions rather than a lack of motivation, as the participants typically considered the interactions with the agents to be interesting. The self-reflections elicited through the agent interviews were consistent with the reflections obtained from paper-pencil questionnaires and appeared to be stable over time. Future study, including investigations using a randomized experimental design with a control group, is needed to fully assess the effects of agent-prompted self-reflection.

Keywords

Simulation, Intelligent agent, Self-reflection, Multiple intelligence

Introduction

In Taiwan, there are high-stakes entrance examinations to high school (after 9th grade) and college (after 12th grade). However, the educational system has undergone a gradual transformation over the past decade; in particular, the system is evolving toward a process in which student placement is less dependent on mandatory university screening based solely on college entrance examination scores but instead incorporates greater flexibility for students to autonomously select educational options based on their personal values and motivations. Self-awareness has therefore become an increasingly critical aspect of student decisions regarding majors and careers. Over time, the curriculum structure and activities offered by Taiwanese high schools have incorporated many elements that seek to elevate students' self-understanding. However, these students often experience issues related to confusion during the process of self-exploration, immaturity, and difficulty with commitment, and as a result, a high proportion of freshmen do not enjoy their educational choices and display less adaptive symptoms in their college lives (e.g., procrastination, absence, or failing grades in their major courses, Ministry of Education, 2012). This observation leads us to regard self-awareness as being critical for everyone (students especially) as part of both the hygiene aspect of active learning (e.g., the regulatory process or self-directed learning, Gibbons, 2002) and the prevention of inadaptive learning (e.g., avoidance or loss of motivation).

Self-reflection is very likely to enhance the accuracy of situation-, task- and self-awareness that are in turn critical components in self-regulation learning (de Bruin, Rikers, & Schmidt, 2005; Greene & Azevedo, 2007). Self-reflection provides the only window into an individual's inner state. Unfortunately, this window is often foggy, especially when individuals report on experiences that span over longer timeframes (Schwarz & Sudman, 1994). Memory is imperfect and susceptible to bias. Some biases can be attenuated through the use of better interviewing techniques (Schwarz & Sudman, 1994). Real-time self-reflection may also avoid the weakness of memory biases (people tend to remember experiences with intense emotions and global experiences rather than specific details (Redelmeier & Kahneman, 1996; Wang, 2001)). Moreover, self-reflection in simulated problem-solving situations can avoid situational biases (retrospective self-reflection is often conducted in a situation very different from the situation that we are interested (Schwarz, 1999, 2007)) and the use of global heuristics (Bank, Dishion, Skinner, & Patterson, 1990). In sum, if activities of self-reflection could be blended with the simulation tasks or situation, the resistance of this repetitive mindful works could be reduced. Therefore, we planned to introduce social agents to prompt multi-faceted self-reflection activities (based upon multiple intelligences (MI), Gardner, 1983) through students' active explorations in a simulation environment.

Previous research has proposed that simulation-based e-learning is an effective knowledge-building approach (Eskrootchi & Oskrochi, 2010; Liu, 2010; Padiotis & Mikropoulos, 2010). Simulations have been demonstrated to be an effective teaching and learning approach in the fields of science (Chen & Howard, 2010; Meij & de Jong, 2006), medicine (John, 2007; Rosen, 2008), engineering (Chen, Hong, Sung, & Chang, 2011; Hsieh & Sun, 2007), social science (Cuenca López & Martín Cáceres, 2010; Liu, 2010), and culture (Peterson, 2010; Ranalli, 2008). Researchers (Chen et al., 2011; Chou, Chan & Lin, 2003; Tan, Tse, & Chung, 2010) have suggested that the benefits of simulations include the dynamic provision of multiple representations, visualization, immersion scenarios, hands-on experiments/manipulations, rich feedback, multiple interactions, and, perhaps most importantly, the engagement of an individual student as an active agent in knowledge building. In simulations, the learner is always in control of the learning process; thus, the regulation of simulation-based e-learning is more critical than the regulation of other instructional approaches that are subject to greater teacher control. Within simulations, problem-solving scenarios, active operations/manipulations, and the provision of abundant feedback/prompts during the exploration process provide ample opportunities to understand the self-competence, cognition, preference, and affection (Chen & Howard, 2010; Ifenthaler, 2012) that shape the core of self-awareness.

The extant studies that have demonstrated how simulation environments and agents can prompt self-reflection are limited; therefore, we developed several principles to guide our design of tasks and agents and then implemented the system. To assess the function of the agent-prompted reflections, a field test was conducted as a preliminary analysis of the degree to which the design of agents embedded in a simulation environment successfully inspired student reflections. Because self-reflection data are typically collected through lengthy self-report questionnaires, we used data collected in this manner to judge the effectiveness of the agent interview. Participants engaged in two simulation activities, three agent-prompted MI self-reflections (pre-simulation, during the 1st simulation activity, and during the 2nd simulation activity), and two paper-pencil MI questionnaires (pre- and post-simulation). Our first aim was to observe whether students successfully finished the simulation tasks and the agent-prompted reflections. Students then compared the MI reflections collected through the agent interviews (situation-specific index) to the paper-pencil questionnaires (situation-general index) to explain which reflection method they preferred to report on their experiences. Finally, the relationships between the agent-prompted reflections and the questionnaires and between the pre- and post-simulation reflections were examined to determine the validity and reliability of the agent-prompted reflections. We sought to answer the following questions.

- How many students successfully finished all of the simulation tasks (including the agent-prompted reflections) within two 120-minute sessions?
- Which reflection method do learners perceive more favorably, agent prompting or a paper-pencil questionnaire?
- For participants that successfully finished the simulation activities and self-reflections, are the reflections related to the five MI aspects that were collected through the agent interviews consistent with those collected through the paper-pencil questionnaires? Do MI reflections, collected through either paper-pencil questionnaires or agent interviews, change over time or remain stable?

Literature review

Simulations

Computer-mediated simulation involves the construction of a computer-mediated environment in which human users can interact as in a real environment, allowing researchers/educators to observe and analyze social relations and collective patterns (Lin & Sun, 2003). Internet-mediated simulation is one kind of computer-mediated simulation. As the Internet supports communication and global access to multimedia information resources, Internet-mediated simulation enables real-time interaction among multiple participants (Martin, 2006).

Simulations are widely used in education because they fulfill the following important functions. (a) Observation and visualization with multiple representations: When the pace of a social or scientific phenomenon is sufficiently fast, slow, large or small that the phenomenon is barely observable in natural situation, simulations can provide vivid observational perspectives (Chen et al., 2011; Meij & de Jong, 2006); in addition, simulations are capable of incorporating multiple representations of information (e.g., verbal and visual-spatial) to enhance learning outcomes for students with various needs. (b) Hands-on activities: Simulations provide learners with the ability to take the initiative in processes of exploration and discovery. Learners can alter the parameters or factors and thus have the flexibility to test the hypotheses that they generate, design scientific experiments, and practice interpreting the data collected from these simulative experiments (Chen et al., 2011; Eskrootchi & Oskrochi, 2010; Padiotis & Mikropoulos, 2010). (c) Feedback: During exploration, simulations can offer immediate, rich and authentic feedback that is beneficial for regulation. (d) Interaction: simulations allow learners to role-play and support multiple interactions with either real humans (such as peers and teachers) or agents. The partial structuring of the students' interactions with simulations can increase learning effectiveness (Eskrootchi & Oskrochi, 2010).

Intelligent agents

Agents are important tools in pedagogical simulations. In multimedia learning systems, animated pedagogical agents perform special, critical instructional functions (Chou et al., 2003; Atkinson, Mayer, & Merrill, 2005; Hsieh & Sun, 2007). Agents can guide the process of knowledge construction either by providing explanatory feedback and highly contextualized problem-solving advice (Moreno & Mayer, 2005) or by eliciting students' thoughts and reflections (Huang, Yeh, Li, & Chang, 2010; Wu & Looi, 2012). They help learners attend to, understand, and deeply process instructional messages (Atkinson et al., 2005; Wu & Looi, 2012). Agents also increase the level of multiplicity in social learning environments and broaden community diversity (Chou et al., 2003). They create virtual relationships with the learners, speak with or respond to learners, and encourage student communication (Atkinson et al., 2005). Pedagogical agents may play authoritative or non-authoritative roles, including the following (Chou et al., 2003; Hsieh & Sun, 2007; Huang et al., 2010; Wu & Looi, 2012): (a) knowledge suppliers – agents are responsible for presenting their stores of knowledge (e.g., tutors or instructors); (b) learning companions – agents act as collaborators or competitors who make learning activities less repetitive and more diversified; (c) tutees – learners act as tutors who teach the agent tutees in a learning-by-teaching environment; (d) consultants – agents provide advanced suggestions; and (e) guides – agents guide learners or help them adjust to environments according to the learning progress.

Intelligent agents can gather information from the environment and interact with it; to achieve this goal, these agents require artificial intelligence (AI) technology to reason and make inferences that permit them to act autonomously. A semantic network is one type of knowledge representation for explaining and simulating human intelligent behavior. By analyzing topics in terms of their concepts and relationships, one can quickly pinpoint how one concept might depend on another, what must be previously known about the topic, and a logical sequence in which topics should be taught. Carbonell (1970) and Mauldin (1994) used a semantic network technique to simulate a Socratic tutor; this type of modeling provided adaptive feedback. Furthermore, natural language processing is used to process human language to facilitate communication between agents and users (Chou et al., 2003). The intention is to transform the human-computer interactions as authentic as human-to-human conversation.

Multiple intelligences

Simulations can provide interdisciplinary components that induce students to integrate various materials. Therefore, simulations can provide learners with ample opportunities to practice the competences described in Gardner's Multiple Intelligences scheme. Gardner (1983) suggests that human intelligence incorporates the following features: (a) the ability to solve real-life problems; (b) the ability to generate new problems to solve; and (c) the ability to make something or offer a service that is valued within one's culture. From the analysis of the competence losses in patients with brain injuries, Gardner discriminates between eight intelligences: linguistic, logical-mathematical, spatial, bodily-kinesthetic, musical, interpersonal, intrapersonal and naturalist.

The MI strengths self-checklist allows learners to conduct self-reflection and identify which types of intelligence are their fortes (Stanford, 2003). Gardner (1993) believes that the best way to measure learner intelligence is through a realistic appraisal of an individual's performance in many types of associated tasks, activities and experiences.

Notation systems can be used to record observations of students that are operating a machine or dealing with disputes, either under real-world conditions or in virtual simulations (Gardner, 1998; Stanford, 2003).

The simulation system

Our goal is for students to have constant opportunities to reflect on both self- competence/capability and preference/affection in enjoyable and natural conversations with social agents that are presented as human-like figures in simulation tasks. In this study, the simulation system allows learners to naturally acquire knowledge from simulated tasks and encourages learners to engage in a doing process to increase the probability of positive transfer and the contribution to meaningful learning. All of the scenarios require manager agents, task controller agents, partner agents, and reflection-prompting agents. Manager, task controller, and partner agents play various roles in the tasks/activities and interact with learners to support task completion. For example, agents may provide instructions/hints/suggestions for solving the tasks, present task results to learners, analyze learner data, control the script procedures, and encourage learners. The reflection-prompting agents play fictitious interrogator roles to prompt student reflections via elaborative interrogation techniques. They then send the self-reflection data to the manager agents for further analysis and notify the task controller agents that the student has finished the self-reflection. The architecture of our system is presented in Figure 1.

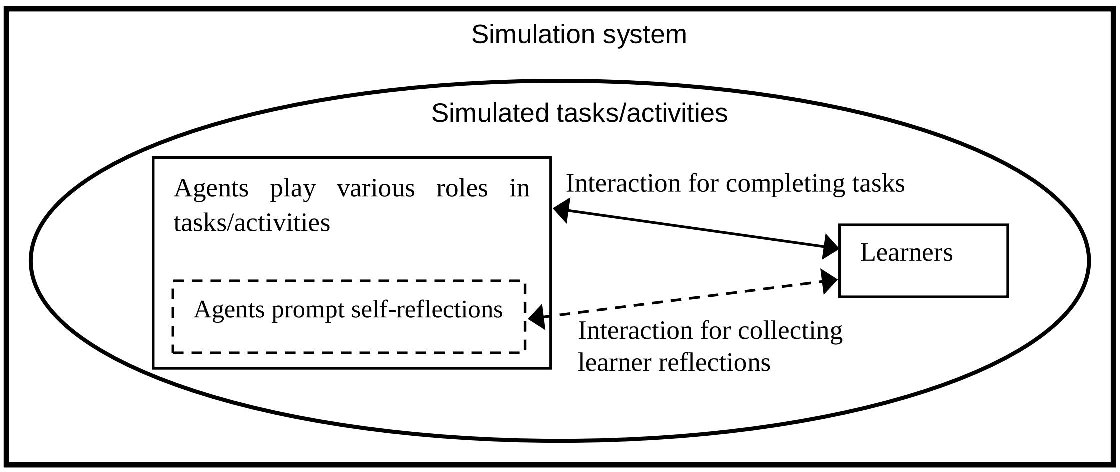

Figure 1. The architecture of our simulation system (the major design of this study is marked with the dotted line)

Figure 2. Sample user interface screen.

The platform of this study is a simulation system. The system has the following general characteristics. (a) It is Internet-based, containing multiple users playing roles in a virtual environment. (b) Users are introduced to the virtual room with a detailed description and illustration of the foreground and background environments. The user interface is presented in Figure 2. (c) Important attributes that determine user status include gender, age, energy and the amount of available money. (d) An online instruction manual is offered to help users with this system. (e) Users can type in text to communicate with other users or agents. (f) The simulation system can support collaborative learning; this study requires participants to collaboratively accomplish several tasks but individually accomplish self-evaluations. (g) Logs of learner behavior are saved in the system, allowing for further analysis by researchers.

The task design

Before it introduces MI self-reflection activities, the simulation system provides interesting and diverse scenarios and agents that support hands-on tasks that allow individuals to exercise five types of MI via role-playing activities. In the field test described in this study, participants had two 120-minute sessions to explore the simulation environment and undertake the problem-solving tasks. Certain of these tasks require linguistic intelligence for reading and writing, because the tasks, scenes and characters are described using Chinese words and phrases. Learners have to read written instructions carefully to complete task requirements. Moreover, learners only communicate with each other or agents through writing and are sometimes required to write a short essay or journal. Several of the tasks require logical-mathematical intelligence, such as the “Tower of Hanoi” problem and the bucket-of-water task (learners have to use 3- and 5-liter buckets to obtain 1 liter of water). Certain tasks require spatial intelligence, such as reading maps and taking bearings to move freely among the scenes in the simulation environment. Certain tasks require interpersonal intelligence, such as asking learners to invite three or four people to work cooperatively to discuss strategies, overcome barriers, and collect treasures. Other tasks require intrapersonal intelligence, providing agents to promote the divergent thinking of learners. For example, these agents may ask learners, “Is doing so all right?”, “Will that be ok for you?”, and “How about doing it another way?”

The environment vividly simulates real-life situations. For example, in train tour scenarios (see Table 1), individuals can enter a train station, get on or off the train, exit the station, and visit local tourist attractions. Learners are asked to solve problems in a variety of situations, such as hunting for treasure in a train station or asking for help (collecting money) from a human partner to buy a train ticket. During the course of these tasks, the interrogator agents are responsible for prompting MI self-reflections. In certain tasks, learners can earn extra points or rewards or jump to the next stage faster as incentives for answering the self-reflection questions.

The design principles of the reflection-prompting agents

In our system, self-reflection is elicited through casual and enjoyable conversations with bizarre, interesting agents in attractive role-playing scenarios. The reflection-prompting agents are committed to preserving enjoyment and social presence in interactions; therefore, they must be immersed within story scenarios and immediately communicate with learners. The agent-learner dialogues that are collected are further transformed by the system. The agent design follows 5W principles, as explained below.

- The “Who” principle: To maintain consistency across learning-reflection situations, the roles that the reflection-prompting agents play in the simulation environment are natural to the scenario. For example, an agent may announce her/himself as paparazzi, chasing learners through the streets; the agent may also be a groundhog in the Loess Plateau, a Bregalad in the Smoky Forest, or a fortuneteller in a fortune-telling house (see Table 1). They interview the learners and initiate reflection-promoting conversations.
- The “How” principle: To ensure that the interactions are as conversational as a typical daily chat, AI technologies (semantic networks and natural language processing) were used to control the conversational context (as described in the later section). In this way, the conversations between agents and learners appear natural and realistic.
- The “What” principle: Five of the eight intelligences in the MI scheme (specifically, the linguistic, logical-mathematical, spatial, interpersonal, and intrapersonal intelligences) were used as the basis for questions that prompted self-reflections. All of the questions asked by the agents are generated in accord with the simulation scenarios/activities that the learners have just explored. Because the tasks in the simulation environment provide ample opportunities for hands-on experience and practice that would enable learners to use various abilities, the

appearances of the reflection-prompting agents are to prompt learners to reflect on their intelligence preferences.

- The “When” principle: To facilitate real-time self-reflection, the reflections are immediately elicited by the reflection-prompting agents while the learners work on relevant simulation tasks. There is no interval between reflection and learning because reflection is part of the learning process.
- The “Where” principle: Our goal was to maintain continuity between the teaching/learning and the reflection activities. Table 1 indicates the places and activity themes: (a) the astrology club (fortune-telling house) where the astrologers (fortunetellers) talk with the learners and predict their future life events; (b) several cities along a train tour where the paparazzi are interested in the learners’ tasks and then collect learners’ information for a news report; and (c) the monster dens where learners exchange information with gatekeeper monsters for the right to enter other dens and seek to perform more tasks. The reflections do not interrupt the progress of the simulation scenarios.

Table 1. The activity themes, scenes, and roles of the reflection-prompting agents.

Reflection Activity Themes	Scenes	Agents’ Roles
Fortune-telling Astrologers (fortunetellers) ask users questions and make predictions for what they will experience next week in terms of close relationships, friendships, schoolwork, financial budgets, and work/career.	**Two booths:** Astrology club Fortune-telling house	**Astrologers:** The Astrology Prince, Vivian, and Liz Tang. **Fortunetellers:** Miss Jen-Yi Lin and Miss Yu Yang.
One-day Train Tour Users travel by train to several cities. Paparazzi follow the users and conduct interviews along the tour.	**Three day tours:** One-day tour to Hualien One-day tour to Taipei One-day tour to Kaohsiung	**Paparazzi:** for example, Stalkerazzi
Treasure Hunt in Monster Dens Users are within a labyrinth and must walk through several gateways guarded by monsters when they need to move from the first to the second floor. By answering questions, users earn keys or tools to enter the second floor.	**Five settings:** Mountain of Doom Gold Cave of Darkness Loess Plateau Dead Marshes Smoky Forest	**Monster:** Balrog **Monster:** Gold Python **Toy:** Groundhog **Monster:** Siren **Monster:** Bregalad

The communication methods between the reflection-prompting agents and learners

We edited the questions using semantic network technology. The question ordering follows semantic network links (an example is illustrated in Figure 3).

The reflection-prompting agents would provide appropriate feedback depending on whether the learner’s replies are positive or negative (as reported below), thereby affecting the subsequent question. The question ordering is different for each student. To ensure that each student is asked each question only once, the design of the semantic networks is kept simple. A semantic network comprises only 5-10 questions. Our fifty self-reflection questions were divided into several semantic networks, integrated with the relevant scripts and scenes, and posted by the agents at the appropriate time. Several semantic networks aligned with potential script developments. Using semantic networks, we are able to develop dialogue lines for agents’ social conversations.

We analyzed the learners’ answers using natural language processing technology to identify the wording in sentences and classify the answers into three categories: positive answers, negative answers and neutral comments. Neutral comments (e.g., "not bad" and "so-so") receive zero points, or answers implying uncertain or nonsensical ideas trigger an agent to repeat the question. Other sentences are divided into adverbs, negatives and adjectives/verbs (see Table 2). If the replies include an adverb of degree (e.g., very, more, much, rather, quite, or too), the adverb section will receive two points; if no adverb is found, it will receive one point. If the replies include a negative, the negative section will receive minus-one point; if no negative is found, it will receive one point. If the replies include a positive adjective or verb, the adjective/verb section will receive one point; if a negative adjective or verb is identified, it will receive minus-one point. Moreover, we found that high school students frequently used slang and expression symbols when answering the questions in the pilot test. For example, “I damn like this…”, “I super hate…”, and “XD”. Therefore, to enhance the identification ability of the natural language processing technology, we expanded the conversation database to include popular slang and expression symbols. Slang for expressing degree (e.g., damn and super) is regarded as an adverb of degree (receiving two points). Positive expression symbols (e.g., ^^, :), and XD, meaning smile or laugh) are regarded as positive adjectives/verbs (receiving one point); negative expression symbols (e.g., ><, :(, and Q_Q, meaning anger or cry) are regarded as negative adjectives/verbs (receiving minus-one point). Points for individual words are multiplied to produce a total score (from -2 to +2) for each sentence/comment. Several examples are demonstrated below.

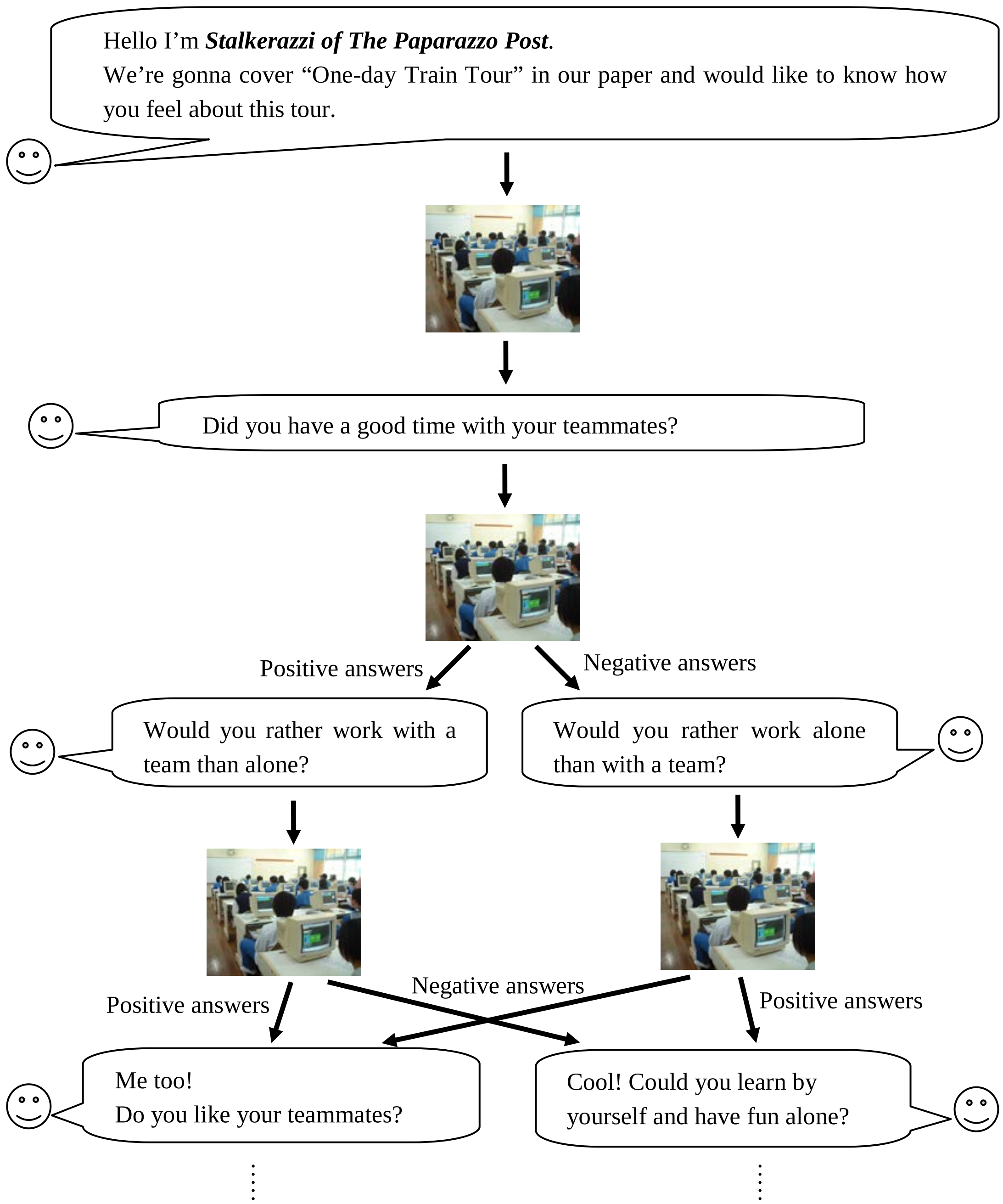

Figure 3. A partial example of a semantic network.

I love him very much.	Neg=1, V=1, Adv=2 → 1*1*2=2 → +2 points
I damn like swimming.	Neg=1, V=1, Adv=2 → 1*1*2=2 → +2 points
Yes, I like it.	Neg=1, V=1, Adv=1 → 1*1*1=1 → +1 point
It is not bad.	→ 0 points
I don't like to play alone.	Neg=-1, V=1, Adv=1 → -1*1*1=-1 → -1 point
><	Neg=1, V=-1, Adv=1 → 1*-1*1=-1 → -1 point
I really hate to keep a diary.	Neg=1, V=-1, Adv=2 → 1*-1*2=-2 → -2 points
I'm not sure.	→ Repeat the question

If the total score is smaller than 0, the sentence is considered to be a negative answer; otherwise, it is a positive answer. The primary purpose of this scoring system is to make it possible to conduct further quantitative analyses and to make comparisons between MI self-reflections collected through the agent interviews and those obtained using the paper-pencil questionnaires.

Table 2. The words are used to analyze learner comments.

Adverbs	Negatives	Positive Adjectives/verbs	Neutral comments	Uncertain or nonsensical ideas
very, too, greatly, pretty, more, much, extremely, often, damn, always, super, the most, fairly, quite, really, absolutely…etc. **【+2 points】**	not, none, without…etc. **【–1 point】**	like, love, yes, fit in with, may, ok, clear, can, agree with, proper, able, sure, want, ^^, :), XD…etc. **【+ 1 point】**	just on, not bad, so-so, no affect, acceptable, passable, common…etc. **【0 points】**	I don't know, uncertain, not sure…etc, or nonsense **【Ask again】**
No adverb	**No negative**	**Negative Adjectives/verbs**		
【+ 1 point】	**【+ 1 point】**	bad, dislike, hate, no, less, disagree, ><, :(, Q_Q…etc **【–1 point】**		

Methods

Participants

The participants were 117 tenth-grade students from the Information Processing Program at a vocational high school in Taiwan. According to prior performance records from the national senior high school entrance examination, students in this school were ranked in the top 30% of all senior high school students in Taiwan.

Measures

Because the participants were high school students in Taiwan, we used Tai's (2002) Chinese High School Students Inventory of Multiple Intelligences, which was developed to measure high school students' MI preferences. The 80-item questionnaire was modified from Armstrong's (1994) MI Inventory for Adults. As mentioned previously, our focus was on five of the eight categories of intelligence; thus, the study used 50 of the original questionnaire items for our purposes, with 10 items relating to each of the following intelligence categories: linguistic, logical-mathematical, spatial, interpersonal, and intrapersonal. All of the items are measured on a five-point Likert scale. Item analysis was used to assess the quality of individual questions and a combination of reliability, and factor analyses were used to evaluate the overall reliability and construct validity. The Cronbach's alpha coefficients, which ranged from 0.8015 to 0.9102, were regarded as acceptable.

Procedures

The test was conducted in computer classrooms over a three-week period. Before the simulation activities occurred, the students were required to fill in a pre-simulation paper-pencil questionnaire (20 minutes), read through the instructions for operating the simulation system (60 minutes), and then complete the pre-simulation agent interview, Fortune-telling (30 minutes, no learning tasks, only simulated interview situations in which agents act as the astrologers), during week 1. The first simulation activity, One-day Train Tour (120 minutes, including the agent interview, agents act as the paparazzi), was completed during week 2. The second simulation activity, Treasure Hunt in Monster Dens (120 minutes, including the agent interview, agents act as the monsters), and the post-simulation paper-pencil questionnaire (20 minutes, it was filled after all of the simulation activities) were conducted during week 3.

Results

Two thirds of the participants successfully completed the simulation activities and agent-mediated self-reflections

We examined each participant's log and record and found that of the 117 high school students, five students could not finish the first simulation activity and 45 students could not finish the second simulation activity (including the agent-prompted reflections in both cases) within the preplanned 120-minute time window. Because the second simulation activity is more difficult than the first one, several students could not generate solutions to those tasks in time. We observed that the time needed by each learner to solve the problems was different, and therefore we suggest that the time limitation or difficulty level should be adjusted to raise the success rate for that activity.
The following is a real conversation transcribed from our system logs. The agent named Golden Python, a virtual monster, interacted with Wantai, a participant.

Golden Python: Hello, I am Golden Python. I am extremely wealthy with unlimited gold, and I love dispensing gold products to people. If you want to receive my gifts, you'll have to be friends with me.
Can we be friends?
Wantai: Yes.
Golden Python: Awesome! I'm so excited!
Besides me, do you have other good friends?
Wantai: Yes. I do have some.
Golden Python: Oh… I envy you.
Do you like outdoor activities?
Wantai: I love outdoor activities very much!
Golden Python: Well then, let's go do something outdoors together next week!
Besides that, do you have any other hobbies?
Wantai: Yes. I like to collect badges.
Golden Python: Hm…I see.
Do you like painting?
Wantai: Yes. I do.
Golden python: Excellent! I love painting too!
Do you like entertainment, like TV programs, movies or magic shows?
Wantai: Yes. I like to watch TV and movies.
Golden python: Wow! Your life is really interesting and exciting!
Do you want to know more about me?
Wantai: Yes! I would like to.
Golden python: I live in this massive gold mine. I have experienced vicissitudes and feel indifferent toward all these people wasting their lives striving for power, fame and wealth. People trick each other and constantly fight their peers. I feel very lonely!

Do you enjoy being with a crowd of people?
Wantai: Yes, I like to be with friends.
Golden python: Me too.
Do you like to be the leader in a group of people?
Wantai: So-so.
Golden python: Huh?
Do you like to play toy models?
Wantai: Yes. I like that.
Golden python: OK. I have to go! It is my pleasure to meet you! I'd like to give you a "Golden Toy Model" in honor of our meeting!

Participants favored the agent-prompted reflection over a paper-pencil questionnaire

The agent interview was preferred by 72.03% of all the participants, whereas 3.50% of the participants preferred the questionnaire. The remaining 24.47% perceived no difference between the two. To further analyze the rationale for each choice, we summarized and categorized participant rationales into the following points.
The reasons for preferring the agent interview include the following rationales:

- It was interactive, interesting, funny and laid-back, just like chatting. I was not bored and felt relaxed, cheery, and amused.
- I answered more carefully because I received some feedback that gave me suggestions.
- It was more flexible, and I could elaborate upon my ideas, thoughts and feelings.
- It was a virtual scenario that accurately simulated a real interview. I found it to be very realistic. Sometimes, the system would ask me to repeat when it could not read my words.
- It was more efficient and interesting to test and play a game at the same time. It could arouse my interest and help me feel more committed to these activities.
- Sitting in front of a computer is quite unique. I was tired of the paper-and-pencil questionnaire.

The reasons for preferring the questionnaire include the following rationales:

- I did not have to read sentences that were irrelevant to the question.
- I did not have to type. The computer sometimes could not read what I meant.
- I had enough time to answer carefully when I used the questionnaire; I did not have sufficient time to think through my answers during the simulation course because the questions kept popping up.

The primary reason for choosing "no difference" follows:

- Both formats were designed to answer questions.

The results indicate that a great majority of students preferred the agent interview to the questionnaire. As a result of the interactions, feedback, and scenarios in the simulation environment, students generally felt that the agent interview was interesting, entertaining, lively, and novel.

The reflections collected by the agent interviews were in accord with those collected through the paper-pencil questionnaires

Table 3 lists the self-reflections (means and standard deviations for MI subscales) (a) collected through the paper-pencil questionnaires on two occasions: pre-simulation and post-simulation (N = 117), and (b) collected through the agent interviews on three occasions: pre-simulation (N = 117), during the first simulation activity (N = 112) and during the second simulation activity (N = 72).

Table 3. The mean and standard deviation statistics for five MI reflections collected on two occasions (pre- and post-simulation) and through two formats (paper-pencil questionnaire and agent interview).

Occasions	**Pre-Simulation**		**Post-Simulation**		
			During 1st sim	**During 2nd sim**	
Formats	Paper-pencil	Agent Interview (N=117)	Agent Interview	Agent Interview	Paper-pencil

	(N=117)				(N=112)		(N=72)		(N=117)	
MIs	M	SD	M	SD	M	SD	M	SD	M	SD
Linguistic	3.11	0.57	3.16	0.37	3.29	0.44	3.41	0.41	3.21	0.51
Logical	3.01	0.62	3.16	0.45	3.27	0.42	3.44	0.41	3.17	0.61
Spatial	3.49	0.61	3.48	0.38	3.58	0.31	3.74	0.30	3.63	0.57
Interpersonal	3.71	0.65	3.75	0.32	3.77	0.26	3.82	0.28	3.80	0.59
Intrapersonal	3.40	0.50	3.43	0.36	3.54	0.27	3.64	0.28	3.55	0.52

Correlation analyses were conducted to determine whether the reflections about the same MIs collected through hetero-occasion same-format means as well as the reflections collected through hetero-format same-occasion means were correlated (in Table 4). The correlation (of the same trait) of hetero-occasion same-format is an index of stability that should be significant and high in magnitude, representing the fact that the two datasets belong to the same theoretical construct. The variance primarily derives from the changes in occasions (in this study, before and after the simulation exploration and problem solving). The results show that the correlations between the five MI reflections collected through the paper-pencil questionnaires on pre- and post-simulation occasions were all significant with high magnitudes (rs = .538 ~ .831, $p < .01$). The correlations of the five MI reflections collected through the agent interviews on different occasions were also significant: between the pre-simulation and the 1st simulation reflection collections, rs = .570 ~ .618 ($p < .01$); between the pre-simulation and the 2nd simulation reflection collections, rs = .374 ~ .645 ($p < .01$); and between the 1st simulation and the 2nd simulation reflection collections, rs = .519 ~ .672 ($p < .01$). The correlations of reflections collected by hetero-format hetero-occasion means were either non-significant (e.g., r = -.065) or significant but low in magnitude (e.g., r = .208, $p < .05$).

The correlation (same-trait) collected through hetero-format same-occasion means constitutes an index known as convergent validity in psychometrics (MTMM, Crocker & Algina, 1986). The very same trait evaluated by two different methods should be significant but to a lesser degree than the stability index mentioned above. Under this type of comparison, the datasets share the same theoretical concept; thus, the major variance derives from various measurement methods (also called the method effect). The results listed in Table 4 indicate that for the pre-simulation occasion, the same MI reflections collected through hetero-formats (paper-pencil questionnaire vs. agent interview) were significantly correlated (rs = .411~.638, $p < .01$). Similarly, for the post-simulation occasion, the same MI reflections collected through hetero-formats (paper-pencil questionnaire vs. agent interview in the 2nd simulation) were also correlated (rs = .314~.485, $p < .01$). A comparison of the correlations obtained if only the individuals present in all collections were considered demonstrates that the same-format hetero-occasion correlations (stability) are higher than the hetero-format same-occasion correlations (convergent validity).

Table 4. Correlations between hetero-format data (paper-pencil questionnaire and agent interview) and hetero-occasion data (pre- and post-simulation activities).

Formats **Occasions**	Hetero-Format **Same-Occasion**		Same-Format **Hetero-Occasion**			
	P / A **Pre-simulations**	P / A **Post-simulations**	A **Pre/1st sim**	A **Pre/2nd sim**	A **1st / 2nd sims**	P **Pre/Post**
MIs	(N=117)	(N=72)	(N=112)	(N=72)	(N=72)	(N=117)
Linguistic	.445**	.340**	.570**	.645**	.672**	.742**
Logical	.638**	.314**	.618**	.496**	.519**	.831**
Spatial	.457**	.485**	.578**	.374**	.559**	.689**
Interpersonal	.411**	.334**	.594**	.565**	.618**	.538**
Intrapersonal	.483**	.387**	.592**	.439**	.641**	.684**

Note. P = paper-pencil, A = Agent interview; ** $p < .01$

As discussed above, statistics demonstrated that the MI preference self-reflections collected through the agent interviews were adequately in accord with the self-reflections collected through the traditional paper-pencil questionnaires. Both self-reflection formats are capable of evaluating self-reflections regarding the five intelligence categories. Thus, it is feasible and appropriate to use the agent interview method to collect and transform conversational comments into quantitative scores.

Discussions

This study developed a new method for collecting self-reflections via agent interviews in a simulation environment. The results support the notion that this new method is reliable and convergent with the traditional paper-pencil methodology. Furthermore, the MI reflections collected through the agent interviews remained rather stable across different occasions. Thus, self-reflection can be effectively prompted not only through questionnaires but also through agent interviews in simulation environments.

Our design allows learners to reflect on themselves through fun, vivid and attractive tasks, thereby enhancing students' motivation and interest in self-reflection. The features of the simulation technology, such as immediacy of response, free options, and bi-directional communications, help enhance the interactions between the users and the medium. Furthermore, educational agents enrich the social context in a learning environment by providing virtual participants that enhance the member multiplicity and by supporting means of fostering communication with real participants. Our reflection collections are blended with the interesting characters, story situations, and scenes in a simulation environment. This method elicits students' curiosity. The participants reported that they preferred casual conversations with the agents to filling in questionnaires.

Investigators have long recognized the need for an assessment tool that is more representative of life experiences than laboratory assessments, global questionnaires, or observer ratings (Redelmeier & Kahneman, 1996). Our design can collect data in a simulation environment in which learners respond to questions throughout the course of working on tasks in a setting that is very similar to their natural learning environment. The advantage of using agent interviews in simulation is that the self-reflections are collected while the participants are still exploring or have just solved problems. The self-reflections are collected in real-time while the problem-solving situation remains ongoing; it may reduce situational biases. Furthermore, the educational value of computer-assisted assessment arises largely from its capacity to provide students with immediate feedback on their comprehension level. Agent interviews can provide substantial and rich stimuli for a learner to display an index of instantaneous reflections about his/her own cognition, comprehension, abilities and affective states during the learning process. The participants do not need to reflect their competences/preferences based upon retrospective memories that may produce memory biases.

Conclusions

In this study, we introduce a new practical application of simulation as an effective learning tool: simulations can prompt multi-faceted self-reflections and thereby enhance self-awareness. We suggest that self-awareness about personal competence, values and affections is critical for high school students in choosing an appropriate undergraduate major program. The introduction of simulations that prompt self-reflections thus provides not only short-term implications for classroom learning but also long-term prospects for career decision guidance.

Simulations meet various teaching requirements and have been widely applied in a broad range of educational and training courses. To understand students' learning processes, performance, or outcomes in simulated environments, three types of measurements are generally applied. First, some systems might automatically record learner outcomes, such as parameter changes (critical indicators presented in the simulation process) and user behavior timestamps (Shute, Ventura, Bauer, & Zapata-Rivera, 2009; Tan et al., 2010). These outcome records consist mostly of quantitative summaries presented after the completion of simulation activities. Quantitative data provide unambiguous feedback for teachers. However, if learners do not learn well, teachers cannot retrieve step-by-step detailed processes of where the students have failed. Second, some systems automatically record detailed action transformations during simulation activities, such as group work interactions or step-by-step decision-making processes (McLaughlan & Kirkpatrick, 2004; Tan et al., 2010). The information generated through this process is often tremendous volume and therefore can make it difficult to formulate a summary report. Teachers also lack the analytical tools to diagnose learning processes, and therefore this type of system is not practical for improving teaching. Finally, some teachers use oral and written briefings, debriefing sessions, interviews, or questionnaires to collect learners' reflections on a simulated learning course (Asakawa & Gilbert, 2003; Martin, 2006). These reflections can help teachers grasp positive or negative impact factors during a learning course. Nonetheless, when briefings, interviews, or questionnaires are conducted simultaneously with the simulation course, they may interrupt immersed learning and reduce the quality of simulation-based learning. If these responses are not measured during the simulation course, some situational and memory biases may occur. Our design retains the advantages of the three types of measurements reported above and mitigates their disadvantages. This self-reflection design provides an adequate method for collecting students' reflections on their own cognition and affective states during the learning process in a simulated environment and assists teachers in understanding students' learning situations in simulation-based e-learning.

We acknowledge at least two study limitations and suggest future studies. First, because this design is an innovative attempt to integrate self-reflection with simulation, it is impossible to test the main effect of this method using typical experimental methods, which would require a control group that experiences traditional classroom instruction. This study used observational techniques to collect students' self-reflections based on the MI scheme; the evidence about its effect in supporting conceptual learning or self-regulated learning is thus clearly preliminary. Future studies are encouraged to adopt mixed research methods (Maxwell & Loomis, 2003) to obtain a deeper understanding of the effects created when teachers introduce innovative assessment techniques in simulations. Second, we used a text-based online virtual reality system as the learning environment; however, this type of virtual reality system is not popular at the present time. As graphics-based virtual reality systems are popular and available, future studies could adopt these systems that incorporate agent interview mechanisms to prompt self-reflection.

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