Stimulating Students’ Curiosity with a Companion Agent in Virtual Learning Environments

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Abstract: Agent technology can be incorporated into virtual learning environments to potentially address core issues of interest and engagement in learning. This paper proposes a learning companion agent to stimulate students’ curiosity in a virtual learning environment. Curiosity is the intrinsic motivation for learning and has been shown in educational studies to promote deep learning. The curious learning companion is designed based on the psychological theories of human curiosity and the educational practices for stimulating curiosity. The curious learning companion acts as an autonomous peer learner that accompanies students and observes their learning behaviors in a virtual learning environment. It detects curiosity-stimulating factors in the environmental context and stimulates students’ curiosity by asking thought-provoking questions. The curious learning companion is illustrated with a case scenario in Virtual Singapura.

Introduction

Recent research marks a growing interest in deploying immersive virtual worlds for educational purposes. Studies have shown that 3D virtual worlds provide strong support for experimental and constructionist learning (Dickey, 2003), and immersive interfaces offer promising vistas for improving science education (Dede, 2009). One the other hand, weakness of current 3D virtual learning environment has also been spotted in many educational studies. Kemp and Livingstone (2006) noted that immersive virtual worlds provide poor support for learning management, assessment or reflective practice. Coffman and Klinger (2007) suggested that students need scaffolding to solve problems in virtual learning environment.

Meanwhile, various types of agent characters have been proposed in literature tailored for particular purposes, regarding teaching strategies (e.g., trouble maker, challenger, and cooperator) (Frasson et al., 1997; Chan, 1995), roles (e.g., instructor, tutee, and companion) (Johnson et al., 2000; Biswas, 2005; Chan, 1995), and emotions (Okonkwo and Vassileva, 2001). These agent characters designed with pedagogical theories have been shown to promote motivation, stimulation of particular learning activities, flow of communication, and fulfillment of a need for deeper personal relationships in learning (Gulz, 2004). Looi et al. (2011) suggested that agent technology holds great potential to be incorporated into the virtual learning environment to address core issues of student’s engagement, mastery of sophisticated knowledge and skills, transfer of learning, and attaining scale.

These prior studies motivate us to design companion agents in a previously developed virtual learning environment, Virtual Singapura[1], to stimulate student interest in learning and promote engagement. Interest in learning is closely related to intrinsic motivation, which has been shown to result in positive learning effects such as autonomy and self-determination (Pintrich, 2003). In this project, we focus on stimulating students’ curiosity, which is one of the most important intrinsic motivations for learning (Berlyne, 1960).

Curiosity and Learning

Curiosity is an intrinsic motivation that drives learning, especially prominent in young child (Loewenstein, 1994). The field of psychology has provided foundations for pedagogical approaches to stimulate curiosity. Piaget and Valsiner (1930) highlighted the importance of curiosity in early childhood cognitive

[1]http://virtualsingapura.com/game/project/

development. Curiosity is linked to the process of assimilation and accommodation, which are two ways in which children learn about the world. Berlyne (1960) distinguished between “perceptual curiosity” and “epistemic curiosity”. Perceptual curiosity is the sensory seeking for novelty. Epistemic curiosity is a distinct human nature and refers to the desire for knowledge. He also differentiates “diversive curiosity” from “specific curiosity”. Diversive curiosity is a general drive to seek information when one is bored, while specific curiosity is aroused by a particular piece of information.

It has been suggested in literature that curiosity generally improves academic learning. Friedman (2006) has postulated in his book “The World is Flat” that curiosity is more important than intelligence in regard to educational achievement. Educational observations indicate that curiosity promotes “deep learning” which results in enhanced learning performance (Pluck and Johnson, 2011). Various practical strategies have been proposed to stimulate curiosity. Tompkins and Tway (1985) proposed to use word play to maintain language curiosity in elementary school children. Vidler (1974) proposed to apply conceptual conflict and contradiction to educational practices. A conflict arouses curiosity by the successive presentation of opposing facts. Keller (1987) suggested increasing curiosity by asking questions, creating paradoxes, generating inquiry and nurturing thinking challenges in the Attention component of ARCS Motivation Model. In a way, Vidler and Keller puts forward the idea that conflict stimulates curiosity which motivates an individual to engage in higher processes of thinking that can also be reflected in Berlyne’s Taxonomy. Through curiosity, an individual will seek to amend the conflict of knowledge by engaging with various higher cognitive processes such as evaluating or creating.

Arnone (2003) suggested ten instructional design strategies for fostering curiosity, which include curiosity as a hook, introducing concept conflict, providing an atmosphere for questions, allow adequate time for exploration, offering the opportunity for choosing topics, introducing curiosity-arousing elements, controlling the amount of stimulation, encouraging exploration, providing rewards and modeling curiosity. Kowalski (2012) proposed to enhance curiosity using interactive simulations with open-format questions on tablet computers. These studies suggest that asking questions increases metacognition and promotes curiosity. Thus it is through the use of questions that we shall investigate the impact of stimulation of a child’s curiosity to learning.

Based on these observations, we propose a curious learning companion agent which aims to stimulate students’ specific and epistemic curiosity with question probes that entail curiosity-stimulating factors. The agent appraises curiosity based on the psychological theory by Berlyne (1960), who believes that curiosity is an internal motivation that can be externally stimulated. He identified six factors that characterize the curiosity stimuli, including novelty, surprise, change, conflict, uncertainty, and complexity. These factors have been adopted to be part of Arnone (2003)’s instructional design strategies for fostering curiosity in classrooms. For the inference of the six factors in a virtual environment, we model appraisal rules for the agent, adopting first-order logic as a general formal tool. Once the agent detects the presence of curiosity-stimulating factors in the environment, the agent will automatically generate thought-provoking questions that can potentially induce the students’ curiosity. Question templates are created for each of the six categories of curiosity-stimulating factors.

Design of the Curious Learning Companion

The proposed curious learning companion acts as a peer learner to accompany a student in virtual learning environments. The goal of the curious learning companion is to monitor the environmental context and the student’ behaviors (demonstrated by the student’ avatars) in the virtual world and infer curiosity-stimulating factors (e.g., novelty, surprise, etc.) that are currently present in the environment. Based on the curiosity-stimulating factors, the agent can form questions to prompt the student and hence stimulate his/her curiosity.

The architecture of the proposed curious learning companion is shown in Figure 1. The curious learning companion interacts with the virtual learning environment through the sensor and the actuator. It infers curiosity-stimulating factors based on the information perceived from the environment and its own knowledge base. The agent generates question probes based on the inferred curiosity-stimulating factors and its question base. Next, we will introduce the main functions of each component.

Environmental context and the student’s behaviors

In virtual environments, learning contents are embedded in virtual objects, the states of which can be altered by a student. For example, to learn the water transportation process in plants, the student can collect water molecules in the virtual world and choose appropriate doors, each representing a type of transportation method (e.g., osmosis or diffusion), to send water from ground to root. Here, water molecules and doors are virtual objects that can be manipulated by the student. The states of virtual objects change over time and upon the student's actions. For example, the location of water molecule will change from ground to root if the student's avatar chooses the correct transportation method. The states of all the virtual objects form the world state, which is the environmental context for both the student and the agent.

Behaviors of the student are captured in the actions performed by the student's avatar. For example, the student can try different transportation methods to send water into root by controlling the avatar to enter different transportation doors. Each action is designed with precondition-effect pairs which specify the conditional world states for an action to be taken and the resulting world states after the action is performed. For example, the action "enter osmosis door" can only be successful if the solution concentration in ground is higher than that in root.

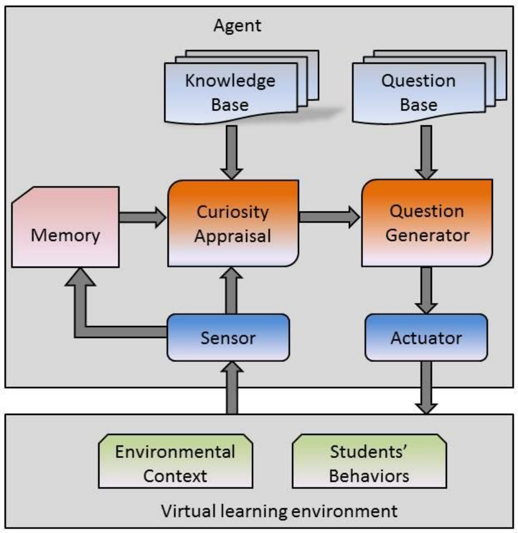

Figure 1. Architecture of the Proposed Curious Learning Companion

Agent's sensor, memory, knowledge base

The curious learning companion monitors the environmental context (world states) and the student's behaviors (actions of the student's avatar) through its sensor. The past world states and actions of the student's avatar are stored in the agent's memory. The agent has predefined expert knowledge about the precondition-effect pairs for the actions of the student's avatar, which means the agent can predict in each world state what actions can be taken by the student's avatar and what changes will result in the world state if an action is performed.

Curiosity Inference

The curiosity inference module infers the curiosity-stimulating factors that are present in the virtual learning environment based on the psychological theory by Berlyne. Berlyne identified six curiosity-stimulating factors, which we briefly review here:

- **Novelty** refers to something new. For example, children are easily fascinated by new toys.
- **Change** refers to the change or movement that occurs while the stimulus in question is acting on receptors. For example, a child can be attracted by the shooting star which causes a sudden change in the quiet sky.
- **Surprise** occurs when one's expectation is not met by the actual outcome. For example, a child will be surprised if a toy car speeds up when he/she presses the stop button.

- **Uncertainty** occurs when there is no clear response to a stimulus. For example, the uncertainty of an answer to a question can engage a child to search for the true answer.
- **Conflict** happens when a stimulus arouses two or more incompatible responses. For example, a child can be interested when he/she has to make decisions on whether to press the forward button of a toy car to win a race or press the backward button to dodge an obstacle, where moving forward and backward are inherently incompatible.
- **Complexity** refers to the diversity or variety in a stimulus pattern. For example, a child would like to choose a jigsaw puzzle with 10 pieces than one with only 2 pieces.

The curious learning companion aims to infer these curiosity-stimulating factors, which can be used to stimulate the curiosity of the student. The inference of these curiosity-stimulating factors requires information about the current world state and the current action taken by the student's avatar (perceived by the sensor), past world states and past actions of the student's avatar (stored in memory), and the expert knowledge about the precondition-effect pairs for the actions of the student's avatar (predefined in knowledge base). To infer the curiosity-stimulating factors, we model for the agent several appraisal rules using first-order logic. The rules are shown in Table 1. The curious appraisal is triggered in real time when the world state changes.

Table 1. The Appraisal Rules for Inferring Curiosity-stimulating Factors

Curiosity-stimulating factors	Inference Rules	Explanations
Novelty	$state(obj,t) \neq null \,\&\, In(Mem,obj) = false \rightarrow Novelty(obj,t)$	If a virtual object exists in the current world state but does not exist in memory, then the virtual object is novel to the student.
Change	$Equal(state(obj,t), state(obj,t-1)) = false \,\&\, action(obj,t-1) = null \rightarrow Change(obj,t)$	If the value of a virtual object changes not due to actions of the student's avatar, then a curiosity-inducing change occurs.
Surprise	$Equal\left(effect(action(obj,t-1)), state(obj,t)\right) = false \rightarrow surprise(obj,t)$	If the value of a virtual object does not change according to the expectation of an action of the student's avatar, then a surprise occurs.
Uncertainty	$Equal(likelihood(state(obj,t+1)),1) = false \rightarrow uncertainty(obj,t)$	If the likelihood of a virtual object to change upon the action of the student's avatar is not equal to 1, then uncertainty occurs.
Conflict	$Satisfy(state(obj,t), precondition(act1)) = true \& Satisfy(state(obj,t), precondition(act2)) = true \& Compatible(act1, act2) = false \rightarrow conflict(obj,t)$	If the current state of a virtual object satisfies the preconditions of multiple incompatible actions, then a conflict occurs.
Complexity	$Feature(obj,t) > \theta \rightarrow complex(obj,t)$	If the number of changeable features of a virtual object exceeds a threshold, then the virtual object is considered complex for the student.

Question base, question generator and actuator

If curiosity-stimulating factors are detected by the curiosity inference module, the agent will generate thought-provoking questions for the student in the question generator module. To automatically form questions, question templates for each curiosity-stimulating factor are designed and stored in the agent's question base. Examples are given in Table 2.

Table 2. Examples of Question Templates in Question Base

Curiosity-stimulating factors	Question Templates
Novelty	Look! What is $name(obj)$ over there? Let's go have a look! Hey! There is a $name(obj)$. What is it used for? Let's go find out!
Change	Did you notice one thing? The $feature(obj)$ of $name(obj)$ has changed. What happened to it? Look! The $feature(obj)$ of $name(obj)$ is changing. What is causing the change? Let's go find out!
Surprise	I expected $effect\big(action(obj, t-1)\big)$. It is surprising to me that it happened to be $state(obj, t)$. What can be the reason? It is really strange that $state(obj, t)$ after $action(obj, t-1)$. Why?
Uncertainty	I am not sure what will happen next. What do you expect to happen?
Conflict	Hey, both $act1$ and $act2$ are applicable. But you cannot choose both. Which one is more appropriate?
Complexity	Look at $name(obj)$ over there. It has quite some adjustable features. What is it used for?

The agent will search for all applicable question templates based on the curiosity-stimulating factors that are detected in the current environmental context and randomly select one question templates from the applicable ones. Then, the agent will replicate the variables (e.g., $name(obj)$) with its values (e.g., osmosis door) in question generator and send the question to the screen via the actuator.

To illustrate the working mechanism of the proposed curious learning companion, next, we will present a case scenario in Virtual Singapura.

Curious Learning Companion in Virtual Singapura: An illustration

Virtual Singapura is a virtual learning environment designed to facilitate lower secondary school students to learn the plant transportation system. Screen captures of the underground environment in Virtual Singapura is shown in Figure 2. Here, students learn about the different transportation methods of water and mineral salts by involving in a narrative that the students need to save a dying banana tree by sending water and mineral salt from the ground into the tree for generating food. Water can enter the tree root via osmosis or diffusion. Mineral Salts can enter the tree root via active transport or diffusion. Each method has different conditions to be taken.

The curious learning companion is embodied by a butterfly which follows the student during his/her exploration. The agent detects curiosity-stimulating factors and prompt thought-provoking questions to the student, which are displayed on the right side of the screen with bars showing the value of curiosity-stimulating factors and chat box showing the agent's questions.

Examples of the curious learning companion's behaviors are shown in Figure 2(a) and Figure 2(b). When the student first enters the underground environment, the water molecules, mineral salts and different transportation doors will be encountered by the student for the first time. Hence, the curious learning companion detects these virtual objects to be novel to the student and prompt questions such as "Hey! There is an osmosis door over there. What is it used for? Let's go find out!" (Figure 2(a)). When the student's avatar attempts to enter the osmosis door and gets blocked out, a surprise results (as a door is supposed to be entered). The curious learning companion detects the surprise and prompts questions such as “It is really strange that we are blocked out after we tried to enter the osmosis door. Why?” (Figure 2(b)).

(a) The curious learning companion detects novelty

(b) The curious learning companion detects surprise

Figure 2. The Underground Scenario of Virtual Singapura for Learning the Plant Transportation System

This illustrates how a curious learning companion in a virtual learning environment can stimulate students’ curiosity through questions it poses. In doing so, a student-centered active learning is established where students learn the content material through problems or gaps of knowledge highlighted by the learning companion. In Virtual Singapura, the environment is set up in a way where students have control of their learning. This student-centered learning paradigm allows the students the opportunity to decide where they want to venture to and what they want to learn. In essence, the students are the authors of their own learning. With the help of a curious learning companion, the student’s learning is taken to a deeper level where observational and analytical skills are involved. Active learning engages the students to actively learn by encouraging the use of higher level order thinking processes (Bonwell & Eison, 1991). Getting the students to think about what they are doing evokes deeper learning through reflection and involves the students’ curiosity on the topic.

By presenting gaps of knowledge with thought-provoking questions, the students become motivated to find the answers and will have to activity inquire into the subject in order to resolve their curiosity. In this way, inquiry-based learning is established where students learn in a question-driven and open-ended process (Edelson et al., 1999). The students’ curiosity elicited by the learning companion’s questions can be a key component to the success of inquiry-based learning, as studies have shown that curiosity is a driving force for dynamic inquiry in student learning (Zion and Sadeh, 2007). Students’ inquiry is related to skills of graphing and interpreting data, conceptual understanding, critical thinking and positive attitudes towards science (Haury, 1993).

The curious learning companion is ideal in stimulating the epistemic curiosity of students. As the plant system is an important topic in academics, Virtual Singapura offers a way for students to learn specific materials in an engaging way. The curious learning companion provokes a students’ curiosity by asking specific questions which leads to a student’s motivation to discover the answer. The questions are an example of how the students’ epistemic curiosity is stimulated.

The curious learning companion draws the students' attention to areas of a topic which might not have initially been thought of as essential to the student. Stimulating students' curiosity through questions not only allows for deeper learning and development of analytical skills, but also develops students' mastery of questioning. By asking specific questions that entails the six factors proposed by Berlyne, the curious learning companion discreetly teaches the students art of questioning which can transfer to other areas of learning.

Summary and Future Work

Curiosity is well acknowledged to be the intrinsic motivation for learning. Educational studies have shown that stimulating curiosity can promote deep learning that enhances students' learning achievement. This research explores the possibility of designing intelligent agents with special personalities (such as curiosity) to stimulate students' curiosity in virtual learning environments. A curious learning companion is proposed based on the psychological theories of curiosity and the educational practices for stimulating students' curiosity. Appraisal rules are designed for the curious learning companion to detect curiosity-stimulating factors in the environmental context based on Berlyne's theory. The curious learning companion attempts to stimulate students' curiosity through thought-provoking questions.

The proposed curious learning companion is currently being implemented in Virtual Singapura. An evaluation of the students' experience is being planned to identify the effectiveness of the proposed curious learning companion. Some implications gained during the design of the curious learning companion are summarized as follows. Intelligent agents are advantageous to stimulate students' curiosity in virtual learning environments because it makes inference in real time through continuously monitoring the students' behavior and the environmental context, which is more intelligent and personalized than prescribed systems in which dialogues are predefined at specific time and space. The curious learning companion can help form a student-centered active learning environment for students to develop observational and analytical skills. Thought-provoking questions generated by the agent may potentially motivate students to find answers and establish inquiry-based learning. The curious learning companion also allows students to learn the art of questioning that are transferable to other areas of learning.

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