Effectiveness of Collaborative Learning with 3D Virtual Worlds

Abstract
Virtual worlds have affordances to enhance collaborative learning in authentic contexts. Despite the potential of collaborative learning with a virtual world, few studies investigated whether it is more effective in affective and academic achievements than teacher-directed instruction. This study intended to investigate the effectiveness of collaborative problem solving and collaborative observation using virtual worlds. Secondary school students (n = 101) participated in the study as part of their coursework in three geography classes. This study found that collaborative problem solving and observation were more effective in facilitating and maintaining intrinsic motivation than teacher-directed instruction. Students in the collaborative observation condition outperformed those in the other conditions when it came to knowledge gains. Lastly, collaborative problem solving and observation were more beneficial for group performance than teacher-directed instruction. These results were discussed in regards to the effectiveness of interactive learning and the cognitive load of using virtual worlds for collaborative problem solving.

Introduction

A growing number of studies have explored the affordances of 3D virtual worlds (VWs) in education. VWs allow learners to create and manipulate virtual objects, explore novel environments (e.g., ocean, space, historical site), have embodied experience, and interact with others through 3D avatars (Dalgarno & Lee, 2010). The virtual learning environment helps students to have the sense of presence and closely interact with people at a distance through 3D avatars. VWs have been used to support collaborative activities such as project-based learning, argumentation, interdisciplinary communication, and role-play (Cho, Lim, & Paik, 2015; Jarmon, Traphagan, Mayrath, & Trivedi, 2009; Keskitalo, Pyykkö, & Ruokamo, 2011). VWs enable students not only to communicate with each other at a distance but also to jointly carry out authentic tasks such as constructing a bridge or building in a virtual place (Keskitalo et al., 2011).

Previous studies have explored the potentials of VWs for diverse learning purposes, provided examples of collaborative learning in VWs, and explored strengths and weaknesses of VWs for peer interaction (Wang & Burton, 2013). Nevertheless, there are few empirical studies on how much collaboration in a VW is helpful for academic and affective achievements. More research is necessary not only to explore new pedagogical models using the affordance of VWs but also to examine the effectiveness of the models for affective and academic achievements. The current study aims to investigate the effectiveness of two collaborative learning activities, collaborative problem solving (CPS) and collaborative observation (CO), using a VW as a learning environment.

Collaborative problem solving and observation

Recently, a growing number of instructional models such as problem-based learning, inquiry learning, and productive failure involve CPS as a primary learning activity. From a constructivist viewpoint of learning, students develop an in-depth understanding through CPS in a small group rather than passively receiving knowledge from an authority (Chi, 2009; Schwartz, 1995). Previous studies have shown positive effects of CPS for an in-depth understanding and transfer of knowledge in real-world contexts (Hmelo-Silver, Duncan, & Chinn, 2007; Kapur, 2010). For instance, Kapur (2010) found that secondary school students who solved complex mathematics problems in small groups without any instructional support until a consolidation session significantly outperformed students who learned mathematics through the cycle of traditional lecture and practice. The former showed higher performance in mathematics problem solving and a better preparation for future learning of advanced concepts than the latter. Although students in small groups were seldom successful in solving complex problems by themselves, they persistently explored diverse representations and solution methods during CPS and developed an in-depth understanding through comparing and contrasting their own strategies with the canonical ones given by a teacher in a consolidation session (Kapur, 2010). CPS allows students to share their knowledge and new information, engage in shared tasks with high situational interest, and elaborate or challenge each other's viewpoints. As a result, a group can create a solution that individuals would not be able to do alone (Chi, 2009; Cho & Lee, 2013; Schmidt, Rotgans, & Yew, 2011).

VWs provide authentic contexts in which students jointly identify, represent, analyze, and solve problems. VWs allow students to have CPS experience that would not be possible in their everyday lives. Magerko (2010) suggested that students collaboratively carry out scientific research or field trips in virtual ecosystems (e.g., virtual coral reef ecosystem) that are developed on the basis of real-world scientific data. Hung, Lee, and Lim (2012) had secondary school students collaboratively create their own river basins by modifying a plot of land in a VW. This CPS activity helped students, who lack experience of natural hydrological systems, to express their naïve understandings of river basins and discuss their evolving intuitions of geography concepts in authentic contexts. Through CPS in a VW, students can interactively build their knowledge *in situ*.

Despite the potentials of CPS in a VW, there are a few limitations that should not be overlooked. Previous studies pointed out that 3D virtual environments would impose high cognitive load because of extraneous materials used to increase representational fidelity (Moreno & Mayer, 2004; Whitelock, Romano, Jelfs, & Brna, 2000). The extraneous cognitive load, which exceeds working memory capacity, is detrimental to knowledge acquisition (Paas, Renkl, & Sweller, 2004). In addition, students may be easily distracted from learning tasks and spend time on off-tasks such as modifying their avatars and addressing technical issues in using a VW (Sierra, Gutierrez, & Garzon-Castro, 2012). Traphagan et al. (2010) found that a VW was less helpful in higher level cognitive processing for a collaborative task than a text-based chat tool. Students were not only less familiar with the VW than the chat tool but also easily distracted from their discussion topic in the VW. These barriers may reduce the effectiveness of CPS in a VW and prevent teachers from using VWs for their lessons.

To reduce extraneous cognitive load, students can observe a teacher-controlled avatar that carries out a task in a VW. This observational or vicarious learning can be enhanced if students negotiate the meaning of what they viewed and collaborate to solve similar problems (Chi, Roy, & Hausmann, 2008; Muldner, Lam, & Chi, 2014). In this study, CO refers to the observational activity followed by collaborative work. When compared to CPS, CO can be more easily implemented in school because students do not need to learn how to use VW software; a teacher can prepare what students will observe in a VW; CO can be conducted with a minimum number of ICT devices; and a teacher can prevent students from being distracted due to the VW. In addition to the practical advantages, CO can facilitate deeper learning because students can jointly make sense of the events observed and collaboratively apply their knowledge to similar problems (Chi et al., 2008; McKendree et al., 1998). Chi et al. (2008) found that students who collaboratively watched a videotape of tutoring and solved physics problems together in pairs learned as much as tutees who directly interacted with a highly experienced teacher. In addition, collaboratively observing the tutoring videotape was more effective for knowledge gains than individually observing it. CO is effective because students can construct an in-depth understanding through active interaction with their peers.

For teachers who want to use VWs for collaborative learning, CO is more scalable than CPS because CO can be easily implemented in a classroom. However, it is not certain whether CO is as effective as (or more effective than) CPS. Muldner et al. (2014) found that CO of a tutorial dialogue video was less effective than one-on-one tutoring for secondary school students, although the former was as effective as the latter for university students. It is a legitimate concern that younger students may lack collaborative and metacognitive skills which are required for effective CO. In addition, more research is needed to examine the effectiveness of CO in a natural learning environment like a classroom in order to increase the ecological validity of research. Previous studies (e.g., Chi et al., 2008; Muldner et al., 2014) have been mainly conducted in a laboratory, which is somewhat different from a classroom in terms of time, resource, rules, culture, etc.

This study intends to explore the effectiveness of CPS and CO as part of coursework in secondary school. A VW is used as a learning environment for CPS and CO. The two activities are compared with a traditional classroom practice, teacher-directed instruction (TD), in regards to (a) intrinsic motivation, (b) knowledge gains, and (c) group performance. Based on literature reviews, this study has made the hypothesis that CPS and CO will be more effective in learning outcomes than TD. Students will be more engaged in constructive and interactive learning activities in CO and CPS than TD. Another hypothesis is that CO will be more effective for knowledge gains than CPS in which students can be easily distracted and overloaded.

Research methods

Participants

This quasi-experimental study was conducted in three geography classes at a secondary school in Singapore. The three classes were randomly assigned into CPS, CO, and TD conditions. Although 120 students initially participated in this study, 19 students were excluded from data analysis because they did not complete the tasks or tests required in the study. As a result, the data of 101 secondary school first grade students (65 males and 36 females) were analyzed to examine the effectiveness of CPS and CO. In the pre-test, there was no significant difference in prior knowledge of topographical maps among the CPS (n = 31, M = 2.61, SD = .84), CO (n = 36, M = 2.47, SD = .97), and TD (n = 34, M = 2.62, SD = .99) conditions, F (2, 98) = .27, p = .76.

Procedure

The study was carried out as part of coursework in geography classes, which were taught by the same teacher. First, students took pre-tests of their prior knowledge about topographical maps and intrinsic motivation in geography. Next, students carried out learning tasks according to their research conditions for three sessions (55 minutes for each session). In the CPS condition, students collaboratively solved such problems as calculating bearings and compass directions with the reference of virtual objects (e.g., trees) and creating a contour map of the landform in a VW (see Figure 1). Before the learning activity, students learned basic skills to move an avatar, communicate with other avatars, and collect geographical information (e.g., coordinates) in the VW. In a computer room, students worked in groups of four to solve topographical map problems through using their own avatars in the VW. In the CO condition, students observed a teacher-controlled avatar that carried out tasks in the VW and collaboratively discussed their observation to solve problems. For instance, a teacher showed students how contour lines changed by moving a contour plane in the VW, and students collaboratively sketched a contour map of the landform. Then, the teacher changed the position of an avatar and the camera angle (e.g., aerial and eye-level views) in the VW so as to help students to make sense of their contour maps in authentic contexts. In both CPS and CO conditions, the teacher explained key ideas of topographical maps for 15 minutes before the learning activities (25 minutes) and had a whole-class discussion to compare student-generated solutions and reflect on the activities at the end of each session (15 minutes). In the TD condition, a teacher explained concepts of topographical maps with pictures of landforms and two-dimensional contour representations in a textbook. The teacher also demonstrated how to create a contour map with Cartesian grids, and students individually solved problems without observing or exploring the landform in the VW. Lastly, students took post-tests of intrinsic motivation, comprehension, application, and group performance. They also carried out delayed post-tests of comprehension, application, and group performance 12 weeks after the post-tests.

Learning environments

Students in the CPS condition carried out tasks in a computer room in which everyone was able to use a computer with access to the high speed Internet. Students in the CO and TD conditions conducted learning tasks in general classrooms equipped with a computer, a beam projector, and the Internet. Figure 1 shows the 3D virtual environment that was used for CPS and CO. To prevent students from being distracted, the virtual environment did not include objects irrelevant to geographical lessons. Five trees around a lake were used for tasks of calculating bearings and compass directions. The virtual environment was designed to provide authentic contexts of geographical problem solving.

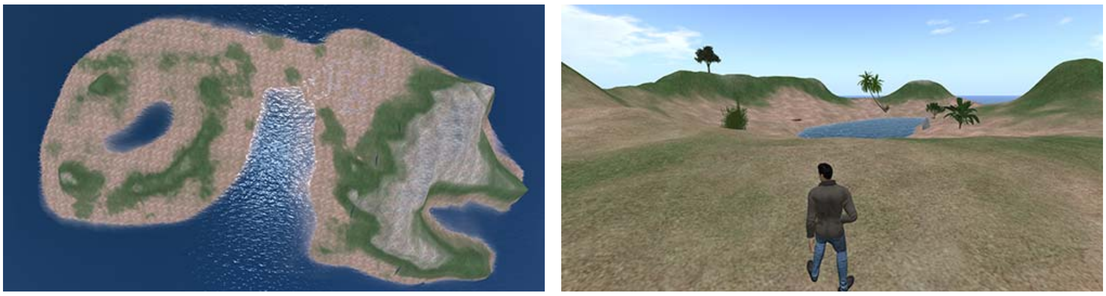

Figure 1: Virtual learning environment

Data collection and analysis

The pre-test included an intrinsic motivation survey and comprehension problems to examine students' prior knowledge. The post- and delayed post-tests included problems about comprehension, application, and group performance as well as the intrinsic motivation survey. Intrinsic motivation in geography was measured with nine survey items using a five-point Likert scale (1: strongly disagree, 5: strongly agree). The survey was modified from the Children's Academic Intrinsic Motivation Inventory (Gottfried, 1985). The reliability of intrinsic motivation survey items was high (Cronbach's alpha = .81). Comprehension problems consisted of five multiple-choice questions about a topographical map (e.g., "What is the bearing of the bridge from the post office?"). In application problems, students sketched a landscape on a grid based on a teacher-provided description (see Figure 2). Lastly, group performance problems required students in a group of three or four to collaboratively solve a decision-making problem (e.g., "Decide the best place to locate a hotel resort on the map.") and provide reasons to support their solutions. These problems were developed through discussions with three secondary school geography teachers.

Sketch the landscape based on the description given below on the grid given.

You are located at X at the peak of a hill at 620 metres on an island. Imagine you are able to have a bird's eye view of the area. Contour lines are to be drawn at 50 metres interval. Draw a sketch of the following features:

1. A river flows on the southern slope of the island
2. The southern slope is gentle and has a beach area covered coconuts, chalets and a jetty.
3. The northern slope is steep.

You are to use symbols to represent the features drawn.

Figure 2: Example of application problems

Two researchers rated students' answers to the application and group performance problems with rubrics. The rubrics included specific rules (e.g., "Give 0.5 marks if students wrote that the proximity to the police station would provide tourists with a sense of security"). The rules were developed through discussions with three geography teachers. Inter-rater reliabilities (Cohen's kappa) ranged from .9 to .97, and disagreements between raters were all resolved through discussions.

A repeated-measures ANOVA was carried out to investigate how intrinsic motivation changed from the pre-test to the post-test. In this analysis, the research conditions (i.e., CPS, CO, and TD) were used as a between-subjects factor. To investigate the influence of research conditions on knowledge gains, ANCOVAs were carried out for comprehension and application scores in the post-test and the delayed post-test. In the ANCOVAs, prior knowledge was used as a covariate. Lastly, an ANOVA was carried out to investigate the effect of research conditions on group performance in collaboratively solving geographical problems. Groups were used as a unit of the analysis.

Results and discussion

Intrinsic motivation

As shown in Figure 3, intrinsic motivation in geography decreased in the TD condition (M = 3.75 vs. 3.24), while the motivation was sustained in both CPS (M = 3.65 vs. 3.59) and CO (M = 3.48 vs. 3.49) conditions. A repeated-measures ANOVA showed that this interaction effect was statistically significant, F (2, 98) = 4.99, p = .009. This result shows that CPS and CO are more effective in facilitating and maintaining intrinsic motivation than TD.

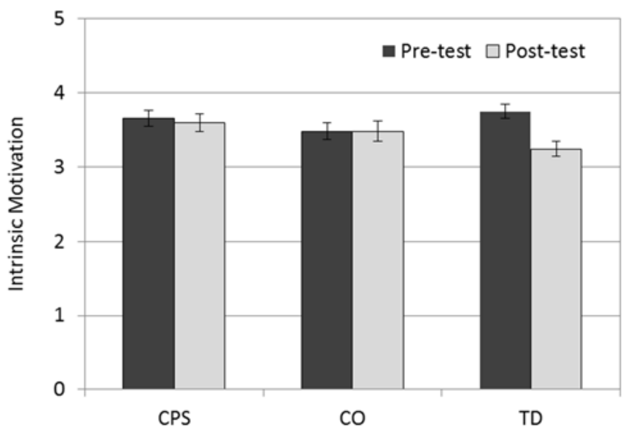

Figure 3: Means and standard error bars of intrinsic motivation

According to self-determination theory, students' intrinsic motivation can be facilitated and maintained by social environments supporting innate psychological needs for autonomy, competence, and relatedness (Ryan & Deci, 2000). The CPS and CO provided students with autonomy to collaboratively explore problems in authentic contexts, whereas TD seldom allowed students to have a choice in learning process. Schmidt et al. (2011) also found that problem-based learning was more effective in increasing and sustaining situational interest than direct instruction in which students' interest decreased significantly from the beginning of the lesson. Authentic and challenging problems are likely to encourage students to have desire to learn more about knowledge needed to solve the problems (Cho & Lee, 2013; Schmidt et al., 2011). In CPS and CO conditions, students collaboratively solved novel and challenging problems that are situated in the virtual landform, which might be beneficial for their intrinsic motivation about geography.

Knowledge gains

An ANCOVA showed that prior knowledge significantly influenced comprehension of topographical maps in the post-test, F (1, 97) = 5.73, p = .019. When the effect of prior knowledge was controlled, comprehension scores were significantly different among the three conditions, F (2, 97) = 4.65, p = .012 (see Table 1). The follow-up comparison (Bonferroni) showed that students in the CO condition outperformed those in the CPS condition, p = .01. However, this difference disappeared in the delayed post-test, F (2, 97) = .29, p = .747.

An ANCOVA also indicated that prior knowledge significantly influenced application scores in the post-test, F (1. 97) = 4.45, p = .037. When the effect of prior knowledge was controlled, there were significant differences among CPS, CO, and TD, F (2, 97) = 7.3, p = .001. The follow-up comparison showed a significant difference between CO and TD, p = .001. In the delayed post-test, an ANCOVA showed that the research conditions had a significant effect on application scores, F (2, 97) = 4.64, p = .012, although the effect of prior knowledge was not significant, F (1, 97) = .11, p = .743. Follow-up comparison showed that students in the CO condition got significantly higher application scores than those in the CPS condition, *p* = .019. The difference between CO and TD was marginally significant, *p* = .056. Thus, CO was more effective in application of geographical knowledge than TD in the post-test and CPS in the delayed post-test.

Table 1: Means and standard deviations of comprehension and application scores

Dependent variables	Conditions			Significant post-hoc comparison
	Collaborative problem solving (CPS)	Collaborative observation (CO)	Teacher-directed instruction (TD)	
Comprehension				
Post-test	2.77 (1.02)	3.50 (1.08)	3.09 (1.06)	CO > CPS*
Delayed post-test	2.03 (.79)	2.00 (.86)	1.88 (.88)	
Application				
Post-test	2.13 (1.02)	2.65 (1.02)	1.74 (1.14)	CO > TD**
Delayed post-test	3.77 (1.43)	4.61 (.96)	3.91 (1.26)	CO > CPS*

Note. Values in the parentheses are standard deviations; * p < .05, ** p < .01

These results support the effectiveness of CO for knowledge gains. In the CO condition, students had more opportunities to share their ideas, elaborate and challenge each other's opinions, and explore multiple representations and solutions than students in the TD condition (Chi et al., 2008; Cho & Lee, 2013). This result is consistent with the assertion that interactive learning is more effective than passive learning (Chi, 2009). In addition, CO was more effective in knowledge gains than CPS, and there was no significant difference between CPS and TD. In the CPS condition, students might be distracted from learning tasks because of novel objects and other avatars in the VW, and extraneous cognitive load might be substantially increased because students should control their avatars (Whitelock et al., 2000). By contrast, CO encouraged students to focus on learning tasks on topographical maps because students did not need to pay attention to how to control an avatar and change a camera angle.

Group performance

As shown in Table 2, small groups in collaborative learning conditions (CPS and CO) showed higher performance than those in the TD condition. However, the differences among the three research conditions were not statistically significant in the post-test, F (2, 26) = 2.58, p = .095, and the delayed post-test, F (2, 27) = 2.95, p = .069. The power of the analysis was low (.47 and .53) because of the small sample size of research conditions (i.e., 9-10 groups for each condition).

Table 2. Means and standard deviations of group performance

Group performance	Conditions			Significant Planned contrast
	Collaborative problem solving (CPS)	Collaborative observation (CO)	Teacher-directed instruction (TD)	
Post-test	2.63 (.88)	2.38 (.92)	1.68 (1.08)	CPS+CO > TD*
Delayed post-test	3.9 (.84)	3.55 (1.17)	2.9 (.74)	CPS+CO > TD*

Note. Values in the parentheses are standard deviations; * $p < .05$.

Planned contrasts were carried out in order to examine whether collaborative learning conditions (CPS and CO) were more effective than the TD condition and whether CPS is more effective than CO when it came to group performance. The planned contrasts showed that students in collaborative learning conditions acquired higher group performance scores than those in the TD condition at the post-test, t (26) = 2.18, p = .038, and the delayed post-test, t (27) = 2.28, p = .031. There was no significant difference between CPS and CO when it came to group performance in the post-test, t (26) = .56, p = .579, and the delayed post-test, t (27) = .84, p = .409. Students in the CPS and CO conditions might learn how to collaborate with peers because they had more opportunities to share their knowledge and solve geographical problems in small groups than students in the TD condition.

Conclusion

A growing number of studies have interests in collaborative learning and problem solving in VWs (Cho et al., 2015; Dalgarno & Lee, 2010). Despite the potential of VWs, few studies have investigated the effectiveness of collaborative learning with VWs in K-12 school. This study showed that CPS and CO using a VW were beneficial for facilitating and maintaining students' intrinsic motivation in geography. Students had more autonomy in exploring authentic and challenging problems in the CPS and CO conditions than the TD condition. In addition, the collaborative learning activities were helpful for improving collaboration skills. Small groups in the CPS and CO conditions outperformed those in the TD condition when it came to collaboratively solving an authentic problem in geography. As this study expected, collaborative learning activities with the VW were effective for intrinsic motivation and group performance. It is highly recommended to use VWs for collaborative learning in authentic contexts (Keskitalo et al., 2011; Vrellis et al., 2010).

In regard to knowledge gains, CO was more effective than the other conditions. CO allowed students to collaborate with peers in authentic contexts without high demands in controlling an avatar in the VW. In the CPS condition, students might be easily distracted because of the novel and realistic environment and the dynamic movement of other avatars (Sierra et al., 2012; Traphagan et al., 2010). The high degree of freedom in the VW might also distract students from focusing on learning tasks (Vrellis et al., 2010). In this study, students were allowed to go anywhere in the virtual island while conducting geographical tasks. By contrast, CO might not increase extraneous cognitive load because students observed a teacher-controlled avatar in the VW. In addition to the effectiveness in knowledge gains, CO has more strengths in scalability than CPS. Teachers can easily implement CO in a normal classroom with a minimum number of ICT devices. Future research is needed to develop an effective and sustainable CO model that can be applied in diverse contexts.

This study has a few limitations that should be overcome in the future studies. The number of research participants needs to be increased in order to enhance the statistical power of a test. Particularly, the sample size is crucial in examining the effects of collaborative learning with the VW at the level of groups. Due to the small sample size of groups, this study had difficulty in examining the effectiveness of CPS and CO in group performance. In addition, this study has a limitation in explaining why CO or CPS was more effective than TD. To answer this question, future research needs to investigate collaborative learning process through analyzing interaction patterns, discourses, and situational interests as well as cognitive loads during the learning activities. By explaining how the variables are related to learning outcomes, future research can suggest a specific guideline for the design of collaborative learning with a VW.

Statements on open data, ethics and conflicts of interest

a. The research data can be accessed upon request.

b. This research received ethics clearance from Institutional Review Board at Nanyang Technological University, Singapore. The authors provided sufficient information about this research and received consent from participants before conducting the research. Students participated in the research on a voluntary basis, and they could withdraw from the research at any time. Personal data of participants were replaced with anonymous identifiers and treated confidentially.

c. The authors declare that there is no potential conflict of interest in this research.

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