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Exploring Effects of Geometry Learning in Authentic Contexts Using Ubiquitous Geometry App

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ABSTRACT: Geometry is essential for mathematics learning given that it is strongly related to our surroundings; however, few studies concentrated on using geometry in our daily life, especially using mobile devices with their sensors. Thus, this study proposed one app, Ubiquitous Geometry (UG), and explored its effects on learning angles and polygons in authentic contexts. The experiment was conducted for grade four learners of an elementary school. The control group used protractors and pencil/paper in measuring angles and polygons, whereas the experimental group did measurements with UG. The results showed that in terms of learning achievement, the experimental group outperformed the control group. Further investigation of the relationship between learning behaviors and learning achievement in the experimental group found that both learning effectiveness and quantity of learning, including measuring angles of elevation and depression (MED), note drawing, and comment drawing, have significantly positive correlations with learning achievement. These three behaviors also become significant predictors of learning achievement after multiple regression analysis. Moreover, MED was found to be the most critical factor to affect learning achievement. Additionally, in perception evaluation, participants felt satisfied with UG and authentic measurement activities by which their learning motivation and interests in authentic contexts were indeed stimulated. Hence, we suggested that UG was worth promoted and further investigated its effects on authentic geometry learning.

Keywords: Measurement in authentic contexts, Learning behaviors, Cognitive abilities, Ubiquitous Geometry

1. Introduction

In terms of learning, authentic contexts are not as simple as applying real-life practices. The contexts should be based on learning purpose, motivation, and complex learning environment so that these can be explored and applied by learners in their surroundings (Herrington & Kervin, 2007). This can be done by providing learners with real-life problems that can be explored to promote a better learning process. Hence, each experience in the learning process, especially in math, should be aimed to inculcate real-life applications into every task, lesson, and unit to enhance the cognitive development and master learning abilities through failure experiences and more practices (Nicaise, Gibney, & Crane, 2000).

Two educational theories related to the learning process are taken to underpin this study. The first is enactivism, a combination of constructivism and embodied cognition, which holds cognition and environment to be inseparable (Ernest, 2010). Learning, then, occurs when learners interact with their environments. By following this theory, applying real-life problems into learning tasks will make learners do authentic activities and interact with environments. The authentic activity is used to encourage learners' participation (Herrington, Oliver, & Reeves 2003) to apply their knowledge in their surroundings (Hwang et al., 2011; Hwang et al., 2015; Hwang et al., 2019). It can be used as an essential factor in assessing mathematics learning behaviors (Wang et al., 2016) and enhancing cognitive levels (Kong, Wong, & Lam, 2003). Thus, we focused on applying authentic activities in learning geometry, mainly for measuring and learning angles and polygons in surroundings; hopefully, it can enhance students' learning behaviors and help their learning performance as well.

The second theory is social constructivism, which is a combination of the idea of social interaction (on the social level) and learning by doing (on the individual level) to make learning more meaningful and enhance cognitive development (Vygotsky, 1978). Social interaction has a mediation role in which learners could perform successful tasks when they are in the interaction of giving or receiving help to or from other learners. Several studies applied social interaction by applying peer assessment in classroom practice (Barak & Asakle, 2018; Lai & Hwang, 2015). Peer assessment and peer comments, which are a part of social interaction, can improve learning interaction and provide in-depth knowledge by making reflections and doing communication with others (Chung, Hwang, & Lai, 2019; Engeström, 1999). The learning improvement can be satisfied whereby the peer can give helpful comments related to the problems or contexts (Hwang & Hu, 2013). Therefore, as claimed by Vygotsky's (1978), social interaction in peer assessment and peer comments between two or more learners with different levels of skills and knowledge is the core attribute of effective learning. Moreover, doing authentic activities (e.g., measuring real objects), which is an implication of learning by doing, can increase learners' engagement and value of comments. By reflecting on knowledge received in real objects measurements and interactions, these activities and interactions can be designed interestingly and meaningfully by applying learners' knowledge in authentic contexts, especially with the help of ubiquitous apps. Hence, designed learning activities can be effective in improving learning performance. Accordingly, the difference in performance between learners who used the ubiquitous app in authentic contexts and learners who used pencil/paper to do measurement tasks should be investigated. In addition, the correlation between performance and learning behaviors in peer assessment should also be explored to proffer the statistical evidence of the usefulness of peer assessment and peer comments in the educational practice.

Regarding learning behaviors, past studies mentioned that the indicators of learning behaviors include completing the tasks, sharing, and explaining ideas to others (Coolahan et al., 2000; Fredricks et al., 2016). In the present study, learning behaviors are considered necessary for learning, which can be measured by relying on the learning effectiveness and quantity of learning behaviors. The learning effectiveness of learners in authentic activities should be grounded on the scoring criteria of the completed tasks (Lindsay & Pamela, 2001; Tan & Hew, 2016). Learning behaviors in authentic activities is based on a real-life situation, such as measuring angles and length of geometry objects in surroundings. Meanwhile, activities recorded in the learning management systems (LMSs) are implied as to the quantity of learning behaviors that relates to the number of their frequency (Tan & Hew, 2016). Nevertheless, there are few studies available in the literature that combine both learning effectiveness and quantity of learning as an essential part of learning activities while exploring authentic contexts using ubiquitous apps.

The learning effectiveness and quantity of learning behaviors of learners are influenced by how the learning in authentic contexts is designed. In this regard, a hierarchical model of Bloom's taxonomy can be utilized to design learning activities and tasks (Anderson et al., 2001) based on authentic contexts. The first three levels in this taxonomy (i.e., remembering, understanding, and applying) are elaborated by doing some activities relating learners' mathematics knowledge to authentic contexts, such as measuring geometry objects in surroundings and making annotations. In peer assessment, analyzing and evaluating levels are carried out while the learner compares his/her work with others'. Learners can build new meaningful ideas by doing more experiences in authentic contexts to stimulate imagination and do a variety of creative measurements. To determine whether the learning effectiveness or quantity of learning in authentic contexts affects achievement, researchers need to evaluate the influence of learning effectiveness and quantity of learning on achievement by doing correlation and regression analysis. In addition, to know the effect of the designed learning on learners' cognitive abilities, it is needed to investigate not only the influence of the learners' learning effectiveness and quantity of learning to their cognitive abilities but also their perceptions toward the learning design.

Therefore, we recorded learners' learning behaviors in authentic measurement to get complete information on learning effectiveness and quantity of behaviors when learners engage in the ubiquitous learning environment (ULE). Ubiquitous Geometry (UG), a mobile android application, was designed and developed to facilitate learning angle and polygon concepts with authentic measurement and record their learning behaviors, including measurement, annotation, and peer assessment activities. As such, five research questions are addressed below.

- Is there any different learning performance between learners who use UG to do angle measurement tasks in authentic contexts and those who use protractors and pencil/paper to do such tasks?
- When learners engage in authentic learning using UG, what are the correlations between learning effectiveness, quantity of learning, and learning achievement?
- What is the prominent learning effectiveness and quantity of learning that can predict learners' learning achievement who engage in authentic learning using UG?
- What are the learning effectiveness and quantity of learning of learners that influence different cognitive abilities?
- What are the learners' perceptions of UG and their motivation for geometry learning in authentic contexts?

2. Literature review

2.1. Learning activities in authentic contexts

In enactivism, learning is a complex activity, which requires harmony between cognitive, physical, and environmental aspects. Instead, of mastering knowledge or abilities, a complex process that includes understanding, abstracting, and applying becomes the way how cognition and learning environment enact with each other. Enactivism paradigm emphasizes that embodiment and action can influence learners' cognition (Li, Clark, & Winchester, 2010) and become more popular in the interaction design and technology field to help learners create their individual learning environment (Winn, 2006). According to this idea, learning in authentic contexts is an educational implication that merges three essential aspects of enactivism, i.e., cognition, physical activities, and rich contexts (environmental aspect), into the learning activities. Past studies (Crompton, Burke, & Lin, 2019; Ekren & Keskin, 2017) have used the revised Bloom's taxonomy as a framework to examine the processes that took place in learning, which was supported by educational technologies. The technologies can help learners to overcome their difficulties (Hwang, Tsai, & Yang, 2008) while they do math tasks, e.g., angle and polygon measurement, in authentic contexts.

In addition, social interaction based on social constructivism theory has an essential role in cognitive development (Vygotsky, 1978). Vygotsky (1978) claimed that there is a distance between the knowledge developed individually and that developed through interacting with others. This notion was widely used in past studies to design the activities supported by technologies that help learners to do more interaction with others (Amory, 2018; Barbosa, Barbosa, & Rabello, 2016). The implementation of this notion in learning is that a learning process can be supported by a technology that could connect each individual with others via mutual observation, sharing, negotiation, and evaluation of problems (Clements & Battista, 1990). Following Hwang and Hu (2013), we designed peer assessment and comment activities as part of social constructivism that facilitated the interaction and communication with peers when learners learned in authentic contexts.

Enactivism and social constructivism were merged with revised Bloom's taxonomy (Anderson et al., 2001) into the design of learning activities and tasks. We utilized the first five cognitive levels of Bloom's taxonomy. The first three levels in the taxonomy, i.e., remembering, understanding, and applying, became our major focus. Learners should master the three levels while they did tasks individually. The use of authentic contexts would help learners to understand the concepts of mathematics more meaningfully by making daily life applications. After learners worked individually, they could compare their works with those of others in peer assessment, which means they would intend to do activities representing higher levels of cognition in Bloom's taxonomy, e.g., analyzing and evaluating. Learners would analyze and evaluate their works by comparing those with their peers'. They can make a new idea to solve tasks in wider authentic contexts. Moreover, the various experiences in authentic contexts can stimulate learners to draw a shape with specific criteria in its angle. It is useful to promote high cognitive levels in the taxonomy. Therefore, we also used Bloom's taxonomy to design pre-test/post-test and to evaluate cognitive levels based on learners' achievement.

2.2. Enhancing geometry learning with ubiquitous technology in authentic contexts

Learners could discover their knowledge through interaction with environments and could apply it in different conditions (Purba et al., 2019). Learners will receive the knowledge and apply it in a real-life situation which useful to enhance learners' cognitive level. Thus, it was not surprising that designing activities based on learners' daily life would give more benefit to their learning outcomes (Hwang et al., 2015; Hwang et al., 2019).

In the past decade, several studies reported that the use of technologies in learning would support better learning outcomes. Geometer's Sketchpad (Erbas & Yenmez, 2011) and CABRI (Bokosmaty, Mavilidi, & Paas, 2017) are computer-based platforms that are effective in exploring geometry objects to support higher-order thinking and manipulation ability of learners. However, these technologies can only be used in the classroom. They cannot support learning in authentic contexts and have limitations for tracking the learning process.

Recently, many studies have used mobile applications to support learning in authentic contexts. Particularly, the multimedia and portability of mobile devices can provide multiple representations with the tracking learning experience and allow the learner to learn anytime and anywhere (Hwang, Tsai, & Yang, 2008). These can be used to support learning in authentic contexts (Coffland & Xie, 2015). In addition, mobile devices can offer interactive representations that encourage learners' cognitive processes on concrete, visual, and abstract stages (Volk et al., 2017); thereafter, mobile devices will also improve learners' understanding of geometry concepts.

In the previous studies, the experiments were conducted to investigate the effectiveness of UG in learning the perimeter and area of two-dimensional shapes (Hwang et al., 2019; Hwang, Hoang, & Tu, 2020). The results revealed that UG was beneficial to enhance estimation ability, achievement, spatial ability, and geometry problem solving (Hwang et al., 2019; Hwang, Hoang, & Tu, 2020). However, these studies did not deeply address the relationship of learning achievement with learning behaviors (e.g., authentic measurements and annotations) and social interaction (e.g., peer assessment) in authentic contexts. Hence, we designed learning activities (e.g., authentic measurements, annotations, and peer assessment) to enhance the understanding of geometric concepts (Vitale, Swart, & Black, 2014) through authentic manipulation and measurement (Bokosmaty, Mavilidi, & Paas, 2017). Learners will use UG in tablet devices to do measurements in authentic contexts (authentic measurements); thereafter, they will be led to make annotations and do peer assessment. Accordingly, modified UG was required to facilitate learners doing object (in real-world) manipulation with multiple representations of geometric objects in tablet devices (artifact in virtual space). They also needed support to interact with their peers (social human). These three interactions in UG would be involved in four dimension spaces of the ubiquitous learning environment (ULE): real world, virtual space, personal space, and shared space (Li et al., 2004).

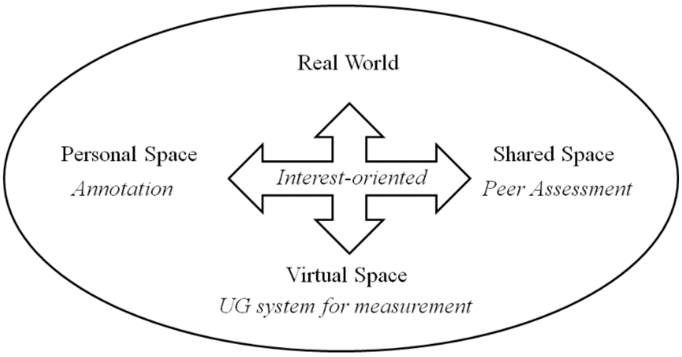

Figure 1. Framework of interest-oriented in the ubiquitous learning environment and learning experience with UG

2.3. Learning behaviors with measuring geometry in authentic contexts

Geometry learning is strongly related to geometry measurement. In geometry, the measurement of real objects, known as authentic measurement, can motivate and increase learning experience and enhance achievement (Hwang et al., 2019), especially for elementary school learners. Regarding geometry measurement in authentic contexts, learning behaviors need to be investigated deeply to know its influence on geometry learning.

With the help of the LMS (Wang, 2017), it is easier to measure and collect the number of activities in learning supported by mobile devices. The study (Rafaeli & Ravid, 1997) regarding the evaluation of learners' behaviors using learner logs indicated that there was a positive correlation between learners' achievement and their quantity of reading tasks. In this study, the quantity of learning behaviors was collected based on the framework in Figure 1, including three learning activities, namely, authentic measurements, annotations, and peer assessment. Authentic measurements comprised measuring angle and length of real geometric objects (MA), measuring elevation and depression angle (MED), and measuring polygon angle among different geographical places (MP), which are based on the angle, length, and polygon concepts. Regarding annotation activities, there were three types of annotations, including note drawing, note text, and note voice. In peer assessment, learners were able to give comments and responses to their peers by typing texts or drawing notes. Hence, we recorded comment drawing (CD), comment texts (CT), respond drawing (RD), and respond texts (RT).

3. Ubiquitous Geometry (UG) app supported by experience API

Experience API (xAPI), also known as Tin Can API and developed by Advanced Distributed Learning Initiative, is an open data interoperability specification originally developed to get a better picture of how, when, and why learning and performance happen both online and offline. xAPI system records data in a standardized format of xAPI statement, which is human and machine-readable. Afterward, the data are stored in the Learning Record Store (LRS) in an immutable format. This learning record has a powerful function in the case of tracing and recording learners' learning behaviors.

UG was designed and developed to help learners learn geometry concepts and record their learning behaviors. All data gathered in UG were stored online. Learning behavior data (xAPI statement) was stored in Yet LRS. Meanwhile, measurement, annotation, and peer assessment data were stored in google firebase. Therefore, learners could continue their work anytime and anywhere, as long as their devices were connected to the internet.

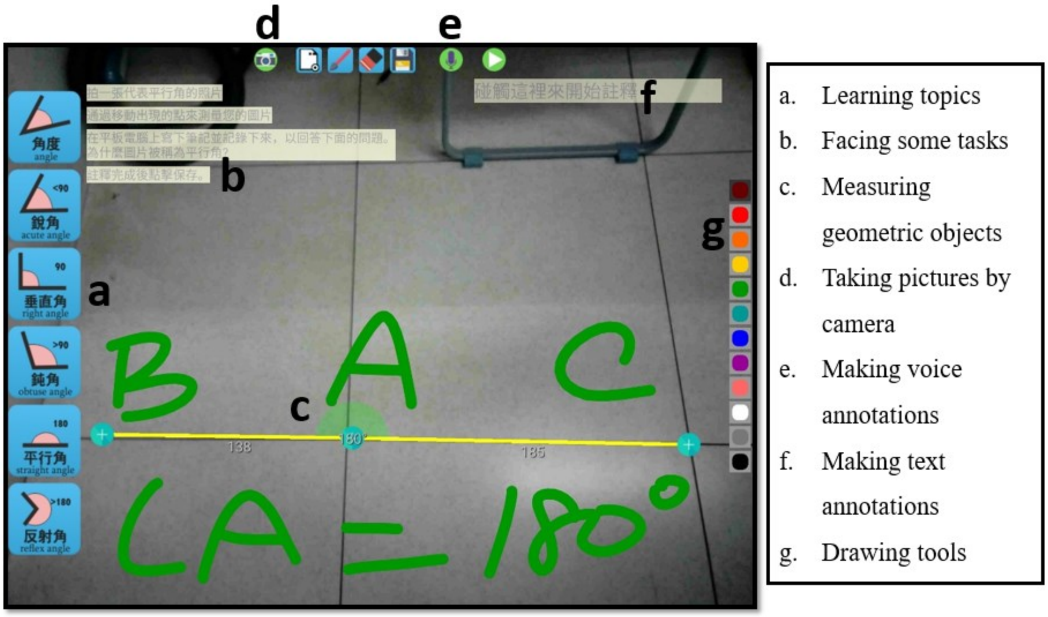

Figure 2. Preview of angle and polygon learning interface

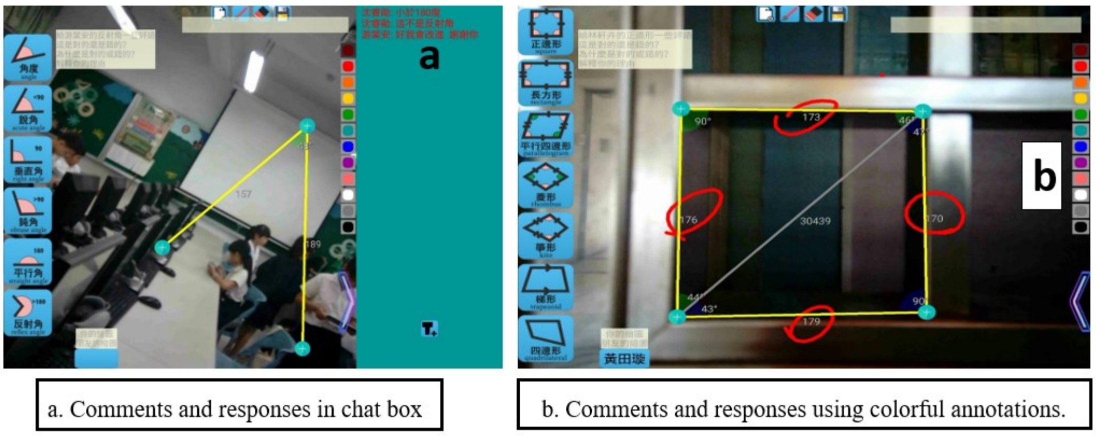

Figure 3. Preview of peer assessment interface

UG required learners to find real objects that represented geometric objects. Then, learners were asked to measure the angle and length of real-objects and to make annotations (see Figure 2). Afterward, learners were also asked to give their comments on peer assessment activity (see Figure 3).

4. Methods

4.1. Participants and experimental procedure

Participants were 53 fourth-grade learners (who were 9–10 years old) from an elementary school in North Taiwan. We had a successful collaboration with this school using information and communication technology (ICT) to enhance the learning and ICT literacy of its learners over ten years. Therefore, the participants were trained and became familiar with UG and the proposed learning activities, thereby having a good knowledge to do the learning activities. They were divided into two groups, namely, the experimental group (EG) and the control group (CG). The EG (26 learners) used UG, whereas the CG (27 learners) used protractors and pencil/paper to finish learning tasks. However, the two groups had the same learning materials and the same instructor with more than 5 years of teaching experience in an elementary school. She had good experiences in teaching with technology; before the experiment, she had used UG and was familiar with it.

The experimental procedure is shown in Figure 4. Before we conducted the experiment, both groups were given a pre-test that aimed to know learners' prior knowledge. We conducted the experiment for a period of four weeks. First, learners in the EG were trained to be familiar with UG. Afterward, the EG were given tasks and allowed to use UG to explore their surroundings during break time and lunchtime. The use of UG was to help learners learn about angle and polygon concepts in mathematics. Conversely, learners in the CG were given protractors to do pencil/paper tasks as homework. According to the use of two different measurement tools, the design of the UG app required learners to do angle and polygon measurements of authentic objects in their surroundings and allowed them to make annotations, including voices, drawings, and texts, in their tasks and to write a comment to others' work immediately in real time. By contrast, the CG did the measurements using protractors to measure angles and polygons and wrote their results with texts and graphs in a paper-based way without authentic exploration and peer comment. This is because paper-based peer comment is not easy to conduct. In the end, we prepared a post-test for both groups and questionnaires and interviews for the EG.

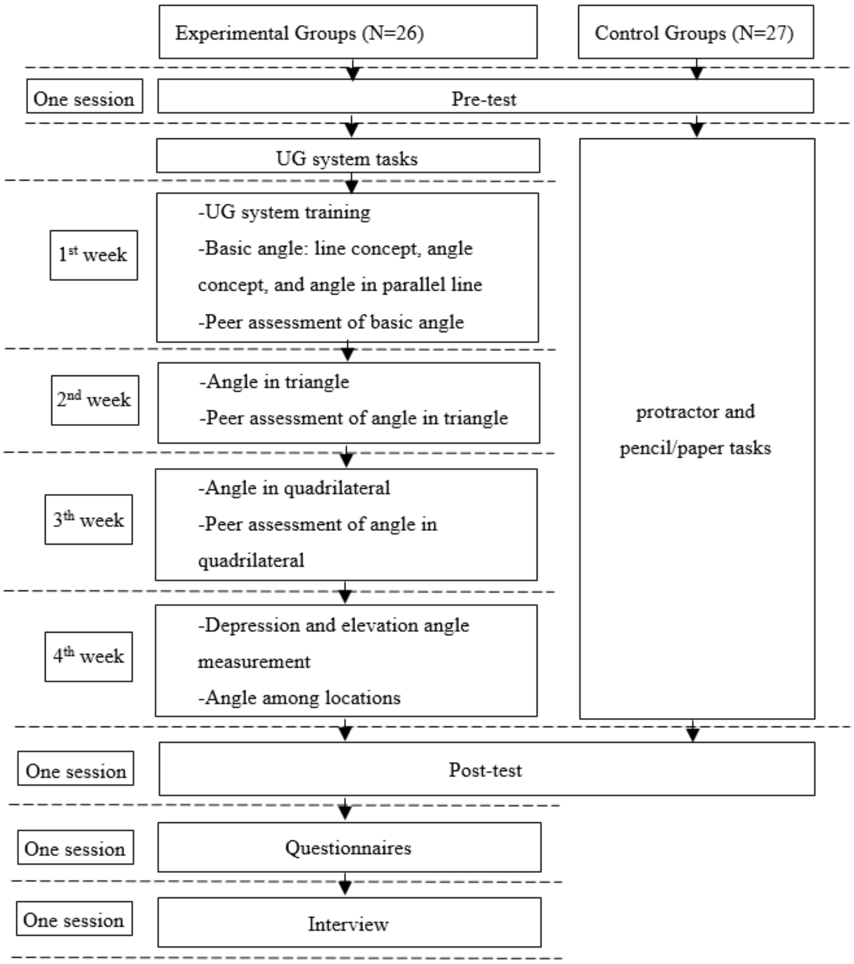

Figure 4. Experimental procedure

4.3. Learning behaviors while using Ubiquitous Geometry

In the EG, we used two sets of data to know the learning behaviors in authentic measurements, annotations, and peer assessment. The first data were taken from the quantity of data recorded by xAPI based on their behaviors when using UG, which means how many times learners would do a particular activity. Besides the quantity of learning activities, the effectiveness of learning behaviors is also considered. This learning effectiveness can be used to evaluate the correctness of measurements, annotations, and peer assessment that had been done by learners. Thus, we consider learning behaviors with geometry measurement in quantity and learning effectiveness aspects. The quantity of learning is related to how many times learners measure authentic objects, make annotations, and do peer assessment in authentic contexts. Conversely, the learning effectiveness considers the correctness of the three mentioned activities, which were scored by a mathematics teacher based on scoring criteria (see Appendix 1). Table 1 provides a detailed explanation of learners' learning behaviors.

Table 1. Learners learning behaviors

	Learning activities	Learners activities	Explanation
Learning effectiveness	Authentic measurements	MA	The score of angle and length measurements
		MED	The score of elevation and depression angle measurements
		MP	The score of angle in polygon measurements among different geographical places
	Annotations	ND	The score of note drawing
		NV	The score of note voice
		NT	The score of note text
	Peer assessment	CD	The score of comment drawing
		CT	The score of comment text
		RD	The score of respond drawing
		RT	The score of respond text
Quantity of learning	Authentic measurements quantity	qMA	Quantity of angle and length measurements
		qMED	Quantity of elevation and depression angle measurements
		qMP	Quantity of angle in polygon measurements among different geographical places
	Annotations quantity	qND	Quantity of note drawing
		qNV	Quantity of note voice
		qNT	Quantity of note text
	Peer assessment quantity	qCD	Quantity of comment drawing
		qCT	Quantity of comment text
		qRD	Quantity of respond drawing
		qRT	Quantity of respond text

4.4. Research tools

4.4.1. Questionnaires

Two questionnaires were used to discover how learners felt when using the system and after using the system in an authentic learning environment. The technology acceptance model (TAM) questionnaire based on past studies (Hwang, Hoang, & Tu, 2020; Purba et al., 2019) was used, and four dimensions (i.e., perceived usefulness (three items), perceived ease of use (two items), attitude toward use (three items), and behavioral intention (two items)) were investigated. In addition, the attention, relevance, confidence, satisfaction (ARCS) questionnaire based on past studies (Hwang, Hoang, & Tu, 2020; Purba et al., 2019) was utilized to know about learners' motivation in their learning activities using UG in the proposed learning environment. ARCS questionnaire consists of 14 items that represent four dimensions: attention (four items), relevance (four items), confidence (three items), and satisfaction (three items). This study used a five-point Likert scale with a starting point for "strongly agree" (5) and enclosed by "strongly disagree" (1).

4.4.2. Pre-test and post-test

The pre-test and post-test comprise twelve angle and polygon concept questions (Q1−Q12) that were designed based on the first five levels of cognitive domain taxonomy (i.e., remembering, understanding, applying, analyzing, and evaluating) (Hwang et al., 2007; Kastberg, 2003; Žilková, Guncaga, & Kopácová, 2015). We discussed and designed the tests together with two experienced mathematics teachers who helped to evaluate the validity and reliability of tests. The first nine questions (Q1−Q9) are multiple-choice questions. These have 0 points (false) and 1 point (correct). Then, three questions (Q10-Q12) are essay questions. This part uses three kinds of evaluation in scoring, 0, 1, and 2 points. In the second part, learners would get the maximum point (2 points) if their answer was totally correct. If the answer were partially correct (the answer not complete or having a misconception), they would get 1 point. Learners would get 0 points if they could not answer, or their answer was totally wrong. Therefore, the total scores of these 12 questions were 15, which were normalized to 100.

Considering learners' cognitive abilities (Forehand, 2010), we used the same instrument (post-test), but we divided it into two group questions. Q1 to Q9 belong to low cognitive ability questions (remembering, understanding, and applying abilities), whereas Q10 to Q12 belong to high cognitive ability questions (analyzing and evaluating). The example of pre-test and post-test items can be found in Appendix 2.

4.4.3. Interviews

Interviews were applied to explore what learners perceived when using UG for learning angle measurements in authentic contexts. Accordingly, three learners were selected to be interviewees based on their scores in the post-test (a student with high achievement, a student with middle achievement, and a student with low achievement). We also prepared open-ended questions, and all audio-recorded contents were analyzed to give an in-depth understanding of statistical results. These questions are as follows:

- Do you like using this system? Could you tell me which part of the system that you like or dislike?
- In your opinion, what learning activities do you think are important? Why?

4.5. Data analysis

Four statistical analyses were conducted using IBM SPSS 20. First, an analysis of variance (ANOVA) was used to identify the equivalent of learners' prior knowledge before participating in the experiment. Second, an analysis of covariance (ANCOVA) was used to identify the differences in learning achievement between the EG and the CG. Third, Pearson correlation analysis was utilized to examine the correlations of learning behaviors with learning achievement. The last was the multiple regression analysis, used to identify prominent learning behaviors predicting learners' learning achievement who engage in authentic learning using UG. Moreover, the collected data from questionnaires were analyzed using Cronbach's alpha reliability test and descriptive analysis.

5. Results and discussions

5.1. Learning achievement

The pre-test was used to know learners' prior knowledge related to angle and polygon measurements. Before doing ANCOVA, prior knowledge in the two groups and homogeneity of variance should be examined. Basically, based on ANOVA, there was no significant difference in learners' pre-test scores (F (1, 51) = 0.002, p = .969) between these two groups (EG (M = 53.30, SD = 18.54); CG (M = 53.09, SD = 20.79)). Levene's test indicates that the variance of pretest (F (1, 51) = 0.003, p = .958) and learning achievement (F (1,51) = .817, p = .370) for learners in the EG and the CG are equal.

Table 2. The ANCOVA results for learning achievement considering pre-test scores as the covariate

Group (N)	Mean	SD	Adj. Mean	F	Sig.	η^2
Experimental group (N = 26)	75.128	17.844	75.063	5.190*	0.027	0.094
Control group (N = 27)	62.221	23.019	62.206			

Note. R Squared = 0.117; $^*p$ < .05.

In Table 2, the results of the ANCOVA test show that there is a statistically significant difference in achievement between these two groups (F (1, 50) = 5.190, p = .027). This result indicates that UG is beneficial for learners' geometry learning; hence, learners in the EG can better understand and solve problems concerning angles and polygons than those in the CG.

UG was designed to be used in tablet devices to support learners in measuring angles and length of real objects, making annotations, and writing comments in peer assessment. Following the enactivism paradigm, these three learning activities give highly positive benefits for learners' learning performance because their activities are inseparable from authentic contexts. Learners were encouraged to apply geometry concepts in real practice by measuring the angles of various real objects in their surroundings. This activity has a positive correlation with learners' geometry learning achievement and their geometry thinking ability (Hwang et al., 2015; Hwang et al., 2019). Through the UG support, learners receive the concept in abstract information and represent their image concept in a real situation.

In addition, tablet devices with multimedia and multiple sensory interactions could support learning with multiple representations, including voices, drawings, texts, and real objects, that facilitate learning outcomes in cognitive, affective, and psychomotor learning domains (Volk et al., 2017). As such, UG is equipped with a feature that enables learners to make multiple representations in their annotations. Annotations can represent learners' understanding of geometry concepts, so those annotations have important roles in increasing learning achievement (Hwang et al., 2011). In terms of social constructivists, learners could review their peer annotation, which could increase their understanding of mathematics concepts (Hwang et al., 2011). Moreover, social interaction while doing peer assessment can enhance their understanding and give them a chance to communicate their idea to others during the process.

Two cofounding variables were related to activity design in this study, namely, authentic exploration and peer comment. However, this study did not elucidate whether the difference in learning achievement between the EG and the CG was influenced by authentic exploration or peer comment. Therefore, we will address this issue in our future experiment.

Table 3. Pearson correlation between learning effectiveness and learning achievement

Var.	LA	MA	MED	MP	ND	NV	NT	CD	CT	RD	RT
LA	1										
MA	0.393*	1									
MED	0.579**	0.177	1								
MP	0.059	0.517**	0.000	1							
ND	0.467*	0.656**	0.368	0.310	1						
NV	0.304	-0.062	0.390*	0.216	0.327	1					
NT	0.127	-0.189	0.114	-0.284	0.090	0.215	1				
CD	0.467*	0.256	0.061	0.073	0.420*	0.103	-0.189	1			
CT	0.311	0.711**	0.154	0.352	0.645**	-0.038	-0.093	0.364	1		
RD	0.353	0.436	0.320	0.217	0.632**	0.068	0.099	0.451*	0.587**	1	
RT	0.241	0.570**	0.075	0.176	0.434*	-0.152	0.021	0.180	0.465*	0.129	1

Note. *$p < .05$; **$p < .001$, LA = learning achievement.

5.2. Correlation among learning effectiveness, quantity of learning, and learning achievement

According to learning behaviors, UG recorded all of learners' activities during the experimental period. Hence, their learning effectiveness can be identified by scoring the outcomes in each activity. As shown in Table 3, learning achievement positively correlated with MA (r = 0.393, p = .047), MED (r = 0.579, p = .002), ND (r = 0.467, p = .016), and ND (r = 0.467, p = .016). MA positively correlated with MP (r = 0.517, p = .007), ND (r = 0.656, p =.000), CT (r = 0.711, p = .000), RD (r = 0.436, p =.026), and RT (r = 0.570, p = .002). MED positively correlated with NV (r = 0.390, p = .049). ND positively correlated with CD (r = 0.420, p = .003), CT (r = 0.645, p = .000), RD (r = 0.632, p = .001), and RT (r = 0.434, p = .027). CD positively correlated with RD (r = 0.451, p = .021). CT positively correlated with RD (r = 0.587, p =.002), and RT (r = 0.465, p = .017).

Table 4. Pearson correlation between quantity of learning and learning achievement

Var.	Post-test	qMA	qMED	qMP	qND	qNV	qNT	qCD	qCT	qRD	qRT
Post-test	1										
qMA	0.068	1									
qMED	0.579**	0.156	1								
qMP	0.152	0.143	0.118	1							
qND	0.397*	0.172	0.221	0.303	1						
qNV	-0.105	-0.263	0.090	0.160	0.437*	1					
qNT	0.073	-0.036	0.103	-0.003	0.487*	0.305	1				
qCD	0.404*	-0.038	0.047	0.101	0.526**	0.245	0.072	1			
qCT	0.309	-0.03**	0.005	0.393*	0.381	0.312	0.365	0.237	1		
qRD	0.272	-0.030	-0.101	-0.234	0.081	-0.367	-0.066	0.192	0.187	1	
qRT	0.191	0.113	0.026	0.352	0.508**	0.224	0.720**	0.162	0.498**	-0.108	1

Note. *$p < .05$; **$p < .001$.

On the other hand, the quantity of learning based on log file data was also analyzed. As shown in Table 4, learning achievement positively correlated with qMED (r = 0.579, p = .002), qND (r = 0.397, p = .045), and qND (r = 0.404, p = .041). qMP positively correlated with qCT (r = 0.393, p = .047). Besides learning achievement, qND positively correlated with qNV (r = 0.437, p = .026), qNT (r = 0.487, p = .012), qCD (r = 0.526, p = .006), and qRT (r = 0.508, p = .008). qNT positively correlated with qRT (r = 0.720, p = .000). qCT positively correlated with qRT (r = 0.498, p = .010).

A significant correlation is shown between achievement (post-test) and MED in both learning effectiveness and quantity of learning behaviors. This implied that measuring real objects was a good activity that could support achievement. In MED, learners were allowed to move from one place to another to explore their understanding of the basic concept of angle measurements. In this activity, learners were excited, and they only focused on the simple angle measurements.

In annotation activities, ND is beneficial for learning achievement in both learning effectiveness and the quantity of learning. In ND activity, learners could use multiple representations such as figures, texts, and symbols in their notes. Furthermore, they could use different colors depending on their interest. This activity could give them a chance to practice their ability to make annotations interestingly.

From peer assessment, CD and qCD were beneficial for achievement. The result also showed that peer assessment behaviors were correlated each other in learning engagement RD to CD (r = 0.451, p = .021), RT to CT (r = 0.465, p = .017), and RD to CT (r = 0.587, p = .002). Unfortunately, most of the learners' CT were "good job" and "you are wrong," which were not followed by reasons for their comments. These kinds of comments are not beneficial for improving understanding, so that becomes a possible reason why only CD correlated with the post-test.

5.3. Multiple regression of variables in quantity of learning and learning effectiveness toward learning achievement

Based on multiple regression analysis results, the predictor variable of the quantity of learning that has the most influence on learning achievement is qMED (M = 7.00, SD = 3.175, B = 3.155, p = .001; see Table 5). Similarly, in learning effectiveness, the predictor variable that would give the most influence on learning achievement is MED (M = 7.00, SD = 3.175, B = 3.106, p = .001; see Table 6). Based on descriptive statistics, all measurements in elevation and depression angles were correct. Such findings could be caused by the fact that this activity was new and used learners' knowledge in simple angle measurements. Learners were able to measure an angle between two objects on the basis of their eyes' viewpoint as the central point. They not only use real objects to apply their knowledge but also use parts of their body, such as their eyes and hands, to measure elevation and depression angles. Therefore, learners felt excited and could further explore their understanding of the basic concepts of angle measurements in a simple object. This finding strengthens those of previous studies (Morris, Finnegan, & Wu, 2005; Wang, 2017), which claimed that learning interaction and learning engagement could affect learning achievement. Regarding the embodiment concept in enactivism, the MED activity encouraged learners to interact in authentic contexts and involve their sensory and motor processes to support cognitive development (Li, Clark, & Winchester, 2010). Thus, teachers need to design such learning activities that can embrace both sensory and motor interaction into learning in authentic contexts.

Table 5. Regression model summary of variables in quantity of learning toward learning achievement

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
(Constant)	48.009	6.718		7.146	0.000
qMED	3.155	0.848	0.561	3.720	0.001
qCD	0.609	0.243	0.378	2.503	.020

Note. R^2 = 0.477, adjusted R^2 = 0.432.

In the second place, learning achievement can also be predicted by both qCD (M = 8.269, SD = 11.069, B = 0.609, p = .02) and CD (M = 6.846, SD = 6.017, B = 1.285, p =.006). Based on descriptive statistics, the number of CD cannot be used as a good representation of data (SD > M). This result shows that the effectiveness of CD has an important role in enhancing learning achievement. Learners could share their knowledge while drawing comments. At the same time, they also could reflect on others' work and compare it with theirs. Learners not only criticized peers' solutions but also helped them to rearrange their solutions to make a good answer and improve their understanding (Hwang & Hu, 2013). Moreover, the use of different colors in the CD makes it easier and clearer for learners to write their comments because they drew directly in peers' solutions without typing texts that need more time.

Table 6. Regression model summary of variables in learning effectiveness toward learning achievement

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
(Constant)	44.585	6.722		6.632	0.000
MED	3.106	0.811	0.553	3.828	0.001
CD	1.285	0.428	0.434	3.003	0.006

Note. $R^2 = 0.522$, adjusted $R^2 = 0.481$.

Table 7. Pearson correlation between learning effectiveness and learning achievement

Learning effectiveness	Low cognitive ability	High cognitive ability
MA	0.353	0.421^{*}
MED	0.553^{**}	0.439^{*}
MP	-0.012	0.238
ND	0.234	0.601^{**}
NV	0.168	0.356
NT	0.195	0.107
CD	0.378	0.347
CT	0.277	0.342
RD	0.252	0.350
RT	0.156	0.309

Note. $^{*}p < .05$; $^{**}p < .001$.

5.4. Correlation between learning effectiveness and cognitive abilities

Considering learners' cognitive abilities, we also investigated the relationship between learners' learning effectiveness and cognitive abilities using Pearson correlation. As shown in Table 7, low cognitive ability had significant positive correlations only with MED ($r = 0.553$, $p = .003$). On the other hand, high cognitive ability had significant positive correlations with three variables: MA ($r = 0.421$, $p = .032$), MED ($r = 0.439$, $p = .025$), and ND ($r = 0.601$, $p = .001$). It was meant that low cognitive ability could obtain positive benefits by doing MED. From the enactivism perspective, the use of particular tasks, e.g., measuring real objects, will influence learners' effective behaviors (Lozano, 2017). These effective behaviors will sustain individual motivation to continue learning in authentic contexts (Simmt & Kieren, 2015). The following opinions were found in the interview of learners with low achievement.

S1: "I think measuring elevation and depression angles is important because it is practical."

The high cognitive ability could obtain positive benefits by measuring the angle in authentic contexts, especially in MA and MED. When learners measured angles and lengths of objects in surroundings using UG, they could explore their knowledge by doing the first three cognitive learning activities, including remembering, understanding, and applying particular geometry concepts in authentic contexts. Learners could also make a good note drawing based on their understanding of angle concepts by analyzing and evaluating the picture of the measured object that implied high cognitive activities in Bloom's taxonomy. Furthermore, in this study, the imagination belonging to the high cognitive ability was possibly stimulated by measuring and drawing a shape with specific criteria in its angles, e.g., a triangle with one angle is an obtuse angle. After completing authentic measurement and peer activities, learners could shape their own learning experiences by comparing with peers' work and get new ideas to make their own conclusion. Learners' conclusions can also make them internalize the concepts used to measure single angles with different criteria in authentic contexts, such as MA and MED, thereby increasing learning achievement in drawing a shape with specific angles. The following opinions were found in the interview of learners with high achievement.

S2: "I like using the system and measuring the angle of the real object because it makes me more understand about kinds of angle."
S3: "I think drawing a note on my work is important because I can understand my work."

Based on the observation of learning activities, in MA, learners applied concepts of single angle in different characteristics by measuring real objects, such as door corners and other objects. In MED, learners imagined the single angle formed while they moved their eyes from a horizontal position to look at the objects up or bottom. By doing MED activity, learners could widen their knowledge of angle concepts application in the abstract space by imagining lines and corners. Thus, MED had contributed to connect the abstract geometry concepts with real applications in physical worlds and enrich learners' embodied experiences. However, a further in-deep investigation was required in future studies to reconfirm the relationship between such activities (MA and MED) and cognitive abilities and the reasons behind them.

The aforementioned findings imply the empirical evidence that the cognitive abilities based on Bloom's taxonomy framework could be used to identify kinds of learning behaviors enhancing geometry learning in authentic contexts.

5.5. Perception and motivation toward learning experience using Ubiquitous Geometry app

Learners' perception and motivation data were collected using TAM and ARCS questionnaires, respectively. The reliability of both questionnaires was tested using Cronbach's alpha test. The results indicate that both questionnaires, TAM (Cronbach's alpha = 0.92) and ARCS (Cronbach's alpha = 0.70), have good reliability and are categorized as acceptable constructs (Hair et al., 2010). TAM questionnaire resulted that most learners scored high for all items. In detail, the means scores are 4.11 for perceived usefulness, 3.67 for perceived ease of use, 3.90 for attitude toward use, and 3.62 for behavioral intention toward using UG. These results indicate that learners have a positive perception of the use of UG while learning in authentic contexts. Furthermore, most of them intend to use UG in the future.

The ARCS questionnaire results show a partially high degree of learners' learning motivation. The mean score of attention, relevance, and satisfaction almost reached 4 points: 3.64, 3.88, and 3.69, respectively. In addition, the mean score of confidence was 3, which implies that learners did not have high confidence toward a used system in an authentic learning environment. According to the learners' perspective, they had difficulties in measuring the real object because, for the first time using UG, they could not find geometry objects in their surroundings. Moreover, learners with low achievement felt confused when they did peer activities (giving comments and responding to the other learners' work). Consequently, it could reduce their confidence while using UG for peer assessment.

6. Conclusions

The study reveals several important findings. First, learners who use UG significantly outperformed those who use protractors and pencil/paper. Regarding the further analysis of learning behaviors in EG, earlier studies have emphasized the learning behaviors and achievement in learning with UG (Hwang et al., 2019; Hwang, Hoang, & Tu, 2020). However, the previous studies focused on the quantity of learning behaviors (Hwang et al., 2019) and problem-solving (Hwang, Hoang, & Tu, 2020) to predict estimation and geometry abilities. In this study, measuring objects in authentic contexts, making annotations, and assessing peers' works highly affect learning achievement and help cognitive development. A possible reason is that, based on enactivism theory, learners enact geometry knowledge and real-life application by doing authentic measurements (Hwang et al., 2019; Hwang, Hoang, & Tu, 2020) and making annotations. Moreover, giving comments with stimuli from multiple representations of authentic contexts in peer assessment is very helpful in enhancing the experiences and effectiveness of learning in authentic contexts (Hwang & Hu, 2013). This is because new knowledge can be developed by interacting with others (Chung, Hwang, & Lai, 2019; Engeström, 1999; Vygotsky, 1978). Second, in the case of the correlation with learning achievement, both learning effectiveness and quantity of learning indicate a similar result that MED activity was the most influential engagement to the learning achievement of the EG. The effectiveness of comment drawing had an important role in improving the learning achievement of EG. Third, learners in the EG with low cognitive abilities were only influenced by MED; those with high cognitive abilities were influenced by MA, MED, and ND. Measuring different angles and lengths of real objects can help learners to understand geometry properties and related knowledge. Additionally, the learners of EG could understand their works by drawing notes in measurement pictures. Another finding is that learners have a good perception of UG (in terms of usability and ease of use) and have high enough motivation (attention, relevance, and satisfaction) in authentic learning.

However, we have several limitations in this study. First, this study could not clarify whether the difference in learning achievement between the EG and the CG was affected by authentic exploration or peer comments. Second, our experiment focuses on how the effectiveness of learning could influence learning performance, but we do not have further analysis on how it could influence cognitive engagements (including interest and strategies of learning). Therefore, in the future, we would like to expand our experimental design to investigate the influence of two different learning activities, i.e., authentic exploration and peer comment on learning achievement. Moreover, we would like to focus on learners' cognitive engagements.

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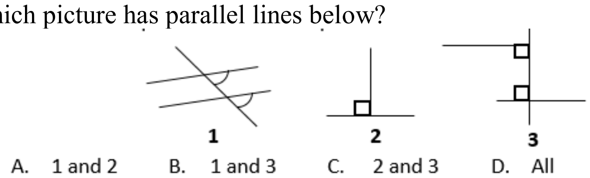
Appendix 1. Scoring the learning effectiveness

Learning activities	Scores
MA, MED, and MP	1: measure the object correctly. 0: measure the object incorrectly.
ND, CD, and RD	4: draw mathematical principles correctly. 3: draw mathematical principles nearly correct. 2: draw mathematical principles incorrectly. 1: draw no meaningful figures. 0: draw nothing or irrelevant figures.
NT, CT, and RT	4: write mathematical principles correctly. 3: write mathematical principles nearly correct. 2: write mathematical principles incorrectly. 1: write no meaningful texts. 0: write nothing or irrelevant texts.
NV	4: record mathematical principles correctly. 3: record mathematical principles nearly correct. 2: record mathematical principles incorrectly. 1: record no meaningful voices. 0: record nothing or irrelevant voices.

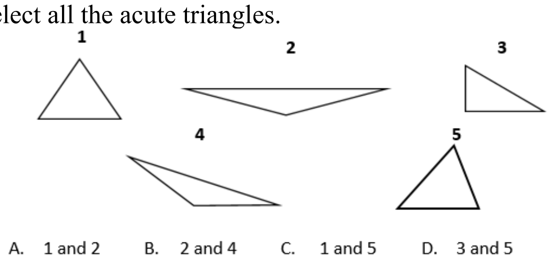
Appendix 2. Examples of pre-test and examples of post-test

Examples of pre-test (Q1 and Q2):

Q1. Which picture has parallel lines below?



Q2. Select all the acute triangles.



Examples of post-test (Q12):

Q12. Draw a quadrilateral formed by two right triangles and an isosceles triangle. (Write the size of each angle of the triangle). Explain if you cannot draw it!

Appendix 3. TAM and ARCS

TAM questionnaire items	Mean	*SD*
Perceived Usefulness	4.11	0.92
UG helps to improve my knowledge in learning Angle and Polygon.		
UG helps to improve my performance in learning Angle and Polygon.		
UG is effective for learning Angle and Polygon concepts.		
Perceived Ease of Use	3.67	1.00
It is easy for me to use UG.		
It is easy for me to understand UG.		
Attitude Toward Use	3.90	1.12
I believe that using UG is a good idea.		
I believe that using UG is advisable.		
I am satisfied in using UG.		
Behavioral Intention	3.62	1.01
I intend to use UG in the future.		
I will continue using UG increasingly in the future.		

Note. SD = standard deviation.

ARCS questionnaire items	Mean	*SD*
Attention	3.64	1.03
It was interesting when I used UG to measure angles of objects in my surrounding.		
Taking pictures, making annotations and sound records helped to hold my attention.		
The learning activities by using UG could stimulate my curiosity.		
The repetition study with peer learning activities caused me to get bored sometimes.		
Relevance	3.88	0.92
It is clear to me how I used UG to learn concept of angle and polygon by using object in my surrounding.		
Measuring angle of object in my surrounding make me know how the concepts of angle were used in daily life.		
During the activities, I know the examples of used concept of angle and polygon in daily life.		
The way of learning concept of angle and polygon using UG was not relevant to my needs because I already knew most of it.		
Confidence	3.00	1.17
When I used UG at the first time to measure the angle, I had the impression that it would be easy for me.		
The learning activities by using UG were too difficult.		
After learning concept of angle and polygon using UG, I was confident that I would be able to pass a test on it.		
Satisfaction	3.69	1.12
Completing the activity measurement using UG gave me a satisfying feeling.		
I enjoyed using UG to explore concept of angle and polygon in my surrounding.		
The learning activities with peer helped me understand about concept angle and polygon.		