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Crompton, Helen, "Using Context-Aware Ubiquitous Learning to Support Students' Understanding of Geometry" (2015). *Teaching & Learning Faculty Publications*. 26.
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Original Publication Citation

Crompton, H. (2015). Using context-aware ubiquitous learning to support students' understanding of geometry. *Journal of Interactive Media in Education*, 1(13), 1-11. doi:10.5334/jime.aq

ARTICLE

Using Context-Aware Ubiquitous Learning to Support Students' Understanding of Geometry

Helen Crompton*

In this study, context-aware ubiquitous learning was used to support 4th grade students as they learn angle concepts. Context-aware ubiquitous learning was provided to students primarily through the use of iPads to access real-world connections and a Dynamic Geometry Environment. Gravemeijer and van Eerde's (2009), design-based research (DBR) methodology was used in this study. As a systematic yet flexible methodology, DBR utilizes an iterative cyclical process of design, implementation, analysis, and revision. Using this particular DBR methodology, a local instruction theory was developed that includes a set of exemplar curriculum activities and design guidelines for the development of context-aware ubiquitous learning activities.

Data collection included semi-structured clinical interviews, observations, student artefacts, video recordings and lesson reflections. This study of technology is grounded in a subject content area (mathematics) so the researchers could clearly state the advantages of using this approach in an educational context. A review of the findings indicates that context-aware ubiquitous learning proved useful in avoiding many common errors and misconceptions that students have in learning these concepts, and students demonstrated growth in their understanding of angle and angle measure beyond what is typically expected. From this study, the researchers present four design guidelines and a full set of context-aware ubiquitous activities.

Keywords: Context-aware; ubiquitous; authentic; situated; angle; geometry; mathematics

Introduction

The use of technology is becoming ubiquitous throughout today's society. As philosophies and practice move toward learner-centred pedagogies, technology, in a parallel move, is now able to provide new affordances to the learner, such as mobile learning (m-learning), that can be used to provide learning that is personalized, contextualized, and unrestricted by temporal and spatial constraints (Crompton 2013a). These affordances of m-learning are being explored by researchers and practitioners as a pedagogical approach for teaching and learning difficult concepts.

Geometry, the mathematical concept chosen for this study, is a complex subject incorporating many challenging mathematical concepts. Angle concepts are particularly difficult for students to grasp (Battista, 2007; Clements, 2004). Empirical evidence has led scholars to suggest that real-world connections can provide a way to make abstract mathematical concepts comprehensible to students by contextualizing typically decontextualized learning. Recent technological advancements have led to context-aware ubiquitous learning (context-aware u-learning; Hwang, Wu, & Chen 2007; Yang 2006), a form of mobile learning that provides a means by which users of mobile devices

can study real-world phenomena, while using the mobile devices to provide timely and effective computer support (Lonsdale, Baber, Sharples, & Arvanitis 2004).

There is a paucity of research to explore how mobile devices can be used in this way to support students' understanding of angle. The purpose of this study is to ameliorate this gap in scholarly understanding and to develop an empirically-based instruction theory of how context-aware u-learning can be used to support the teaching and learning of angle and design guidelines of developing context-aware u-learning activities.

Literature review

Mobile learning extending traditional pedagogies

Mobile Learning (m-learning) offers many new opportunities in the evolution of technology enhanced learning (Looi, et al. 2010). The mobile market continues to provide a torrent of new or revised devices and applications. These technologies are seeping into educational settings as their affordances are becoming recognized for the way in which they extend pedagogical boundaries. From a review of the research surrounding m-learning pedagogies, Traxler (2011) found five distinct trends on how mobile devices can be used to offer learning that provides unique affordances to the learner. He found that it could offer: 1) contingent learning, allowing learners to respond and react to the environment and changing experiences,

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2) situated learning, in which learning takes place in the surroundings applicable to the learning, 3) authentic learning, with the tasks directly related to the immediate learning goals, 4) context aware learning, in which learning is informed by history and the environment, and 5) personalized learning, customized for each unique learner in terms of abilities, interests, and preferences. From these five categories, a clear trend towards real-world connections is evident. M-learning can provide a shift from the abstract concepts to the contextualized. In other words, difficult subjects can be made more understandable to students by connecting these concepts to the world in which the students live, rather than the traditional textbook examples often used to teach students.

Context-Aware Ubiquitous Learning

Context-aware u-learning is an emerging sub category of mobile learning. Hwang et al. (2008) described context-aware u-learning as:

The learner's situation or the situation of the real-world environment in which the learner in location can be sensed, implying that the system is able to conduct the learning activities in the real world... context-aware u-learning can actively provide supports and hints to the learners in the right way, in the right place, and at the right time, based on the environmental contexts in the real world. (p. 84)

This is the way context-aware u-learning is being identified in this study. To further explicate context-aware u-learning, Hwang et al. provided a **Table 1** of context-aware u-learning example activities that is included below:

In the examples provided, the students are interacting with the device and the environment to learn particular concepts. The environments described in these examples are atypical classroom environments, although they could also take place in the classroom. The premise of context-aware u-learning is that students use portable devices to learn by physically exploring and interacting with the real world (Colella 2000; Squire & Klopfer 2007).

Technologies to support the teaching and learning of angle

Geometry forms the foundations of learning in mathematics and other academic subjects (Clements 2004). However, school geometry is a complicated network of concepts, ways of thinking, and axiomatic representational systems, that young students can find difficult to grasp. Angle and angle measurement in particular have many unique challenges. Prototype diagrams can lead students to considering non-relevant angle attributes (Yerushalmy & Chazan 1993), such as the length of the rays (lines that make up the angle) of the angle and orientation (Battista 2009). For example, textbook right angles typically are shown facing one way. If the students should come across right angles in different orientations they do not recognize them as right angles.

Model	Context-Aware Ubiquitous Learning Examples
Learning in the real world with online guidance	The students are learning in the real world and are guided by the system, based on the real-world data collected by the sensors. For example, for the students who take a chemistry course, hints are provided automatically based on his or her real-world actions during the chemistry procedures.
Learning in the real-world with online support	The students learn in the real world, and support is automatically provided by the system based on the real-world data collected by the sensors. For example, for the student who is learning to identify the types of plants on campus, relevant information concerning the features of each type of plant is provided automatically based on his or her location and the plants around him or her.
Collect data in the real world via observations	The students are asked to collect data by observing objects in the real world and to transfer the data to the server via wireless communications. For example, observe the plants in this area and transfer the data (including the photos you take and your own descriptions of the features of each plant) to the server.
Identification of a real-world object	Students are asked to answer the questions concerning the identification of the real-world objects. For example, what is the name of the insects shown by the teacher?
Observations of the learning environment	Students are asked to answer the questions concerning the observation of the learning environment around them. For example, observe the school garden, and upload the names of all the insects you find.
Co-operative data collecting	A group of students are asked to co-operatively collect data in the real world and discuss their findings with others via mobile devices. For example, co-operatively draw a map of the school by measuring each area and integrate the collected data.
Co-operative problem solving	The students are asked to co-operatively solve problems in the real world by discussion using mobile devices. For example, search each corner of the school and find the evidence that can be used to determine the degree of air pollution.

Table 1: Models and examples of context-aware u-learning activities. Adapted from Hwang et al., 2008, p. 86.

As students move on to angle measurement, many students believe that the size of the angle is determined by measuring the length of the line segments that are the rays of the angle (Clements 2004; Berthelot & Salin 1998). In a review of the literature Crompton (2013b) found five *problems* as students studied angle; (a) understanding that angles have an abstract nature, (b) understanding the angle as a turn, (c) understanding what the angle is measuring, (d) struggling to see the different angles in different contexts, and (e) determining salient criteria for judging angles.

For centuries, scholars have advocated the importance of connecting mathematics to the real world (e.g. Clairaut 1741/2006). Using real-world connections in mathematics has many recorded benefits, such as enhancing students' understanding of the mathematical concepts (De Lange 1996), amplifying students' ability to think mathematically outside the classroom (National Research Council 1998), and motivating students to learn about mathematics (National Academy of Sciences 2003).

Technology has also been used to support students' understanding of concepts. Dynamic Geometry Environments provide the students with figures and basic tools to create composite figures. A review of the literature revealed that real-world contexts and Dynamic Geometry Environments are two pedagogical approaches to supporting students learning of geometry. There are those who have used context-aware u-learning to make the real-world connection to mathematics. For example, Elisson and Ramberg (2012) used DBR to conduct a study where students were asked to relocate imaginary species from the local zoo to a field close to the school. Students had to use a mobile software application which measures the distance between two mobile devices via Global Positioning System. Students measured and placed cones to demarcate where certain species would live in the field based on the size of habitat required.

Bray and Tangney (2014) have used technology to transform mathematics by creating contextualized activities. In this particular DBR study they had year 10 students (age 15/16) complete activities such as the Human Catapult activity that involved students using foam balls, cameras, and GeoGebra to investigate concepts such as rates of change and velocity. Spikol and Eliasson (2010) also used a DBR approach to work with middle school students to explore geometry both inside and outside. The students used mobile devices with DGE and AR visualizations to explore and understand geometrical concepts.

Purpose of this study

The purpose of this study is to use a context-aware u-learning approach to support students as they learn about angle and angle measure. The research questions guiding this research are:

1. How can context-aware u-learning be used to extend and enhance students' understanding of angle?
2. What design guidelines will inform the development of context-aware u-learning activities?

To this end, the researchers employed Gravemeijer & van Eerde's (2009) design-based research (DBR) methodology. DBR is a systematic yet flexible methodology utilizing an iterative cyclical process of design, implementation, analysis, and revision.

Method

Participants

Two fourth grade teachers chose to participate in the study. This determined the classes from which students participated. There were 30 fourth grade (9–10 years of age) students in each class, for a total of 60 student participants in the study. The study took place in the south-eastern United States. Following Gravemeijer & van Eerde's (2009) DBR approach, two teaching experiments were carried out, one with each class of fourth grade students. Eight of the 60 students completed the pre- and post- instruction clinical interviews. The eight students were made up of four randomly selected students from each class. As each interview was approximately one hour each and took multiple hours to analyse qualitatively, eight students was deemed a good amount by an external research review team.

Research team

The researcher acted as the teacher in both of the teaching experiments. In the DBR process it is not uncommon for one researcher to serve as the teacher implementing the instructional intervention (e.g., Markworth 2010). For both teaching experiments, the class teacher, and mathematics and technology specialists served as witnesses to the teaching episodes, and a technology and mathematics educator acted as co-researcher.

Design-based research protocol for this study

There are various types of DBR including those developed by Bannan-Ritland (2003), Cobb et al. (2003), and McKenney and Reeves (2012). Gravemeijer and van Eerde (2009) DBR was selected as it employs methods that enable the research team to develop a local instruction theory and instructional materials to be used to explore the process by which students learn a particular concept in mathematics. The study involved two macro cycles with one teaching experiment occurring in each macro cycle. The teaching experiments consisted of seven days of mini cycles of thought and instructional experiments to serve the development of the local instruction theory. The local instruction theory in this study involved two components; design guidelines for informing the development of context-aware u-learning activities and a set of exemplary context-aware u-learning activities for extending and enhancing students' understanding of angle concepts. These activities are an embodiment of the design guidelines.

For the context-aware u-learning components of this study, each student was given an iPad2 with Sketchpad Explorer (dynamic Geometry Environment) loaded onto the device with the add-on sketch titled *Measure a Picture* (Steketee & Crompton 2012). Using iPads and Measure a Picture add-on, students interacted with the real-world as they found angles in the environment outside their

school grounds. Measure a picture enabled the students to take photographs of the angles while in the program and use the dynamic protractor and other dynamic tools to measure the angles in the pictures. See **Figure 1** for a screenshot of the program. In addition, students were asked to work with Quick Response codes (QR codes) for other activities within the instructional sequence.

The two macro cycles for this study are illustrated in **Figure 2**. Note in the figure the occurrence of the three phases within each macro cycle (a) the design of instructional materials, (b) classroom-based teaching experiments and mini cycle analysis, and (c) the retrospective analysis of the teaching experiments which informed the next macro cycle.

Cycle One

Design of Instructional Materials. From a thorough review of the literature, a set of instructional materials was designed. The day before the commencement of the teaching experiment, a clinical interview on angle concepts was administered to the four students from the first class.

Classroom Teaching Experiments and Mini Cycle Analysis. Next, using the instructional materials, the first teaching experiment was conducted for seven consecutive school days with the entire class of 30 students. During the teaching experiments, the co-researcher

and witness observed and took notes on the classroom instruction, and the instruction was videotaped. Students' work, such as screenshots and worksheets, was collected at the end of each day. Also, at the end of the day's instruction, the researcher, co-researcher, and witness met to discuss the lesson. The conversations were audio recorded. Following this meeting, the researcher completed a daily reflection journal. During each daily mini cycle of the teaching experiment, the researcher utilized the collected data to modify the next day's instruction when necessary.

The Retrospective Analysis. At the end of the teaching experiments, the entire data collected (video, observation notes, interview responses and scores, artefact collection, and reflection meeting audio recordings) were analysed collectively. Detailed notes were made of the design implications and the initial instructional materials were revised based on the findings of the retrospective analysis.

Cycle Two

This second cycle was a repeat of the first with a new set of students. The second teaching experiment took place two weeks after the conclusion of the first teaching experiment. There were two retrospective analyses conducted, one at the conclusion of each macro cycle. The local instruction theory came from the final retrospective analysis. At the bottom of **Figure 2** is a list of when each

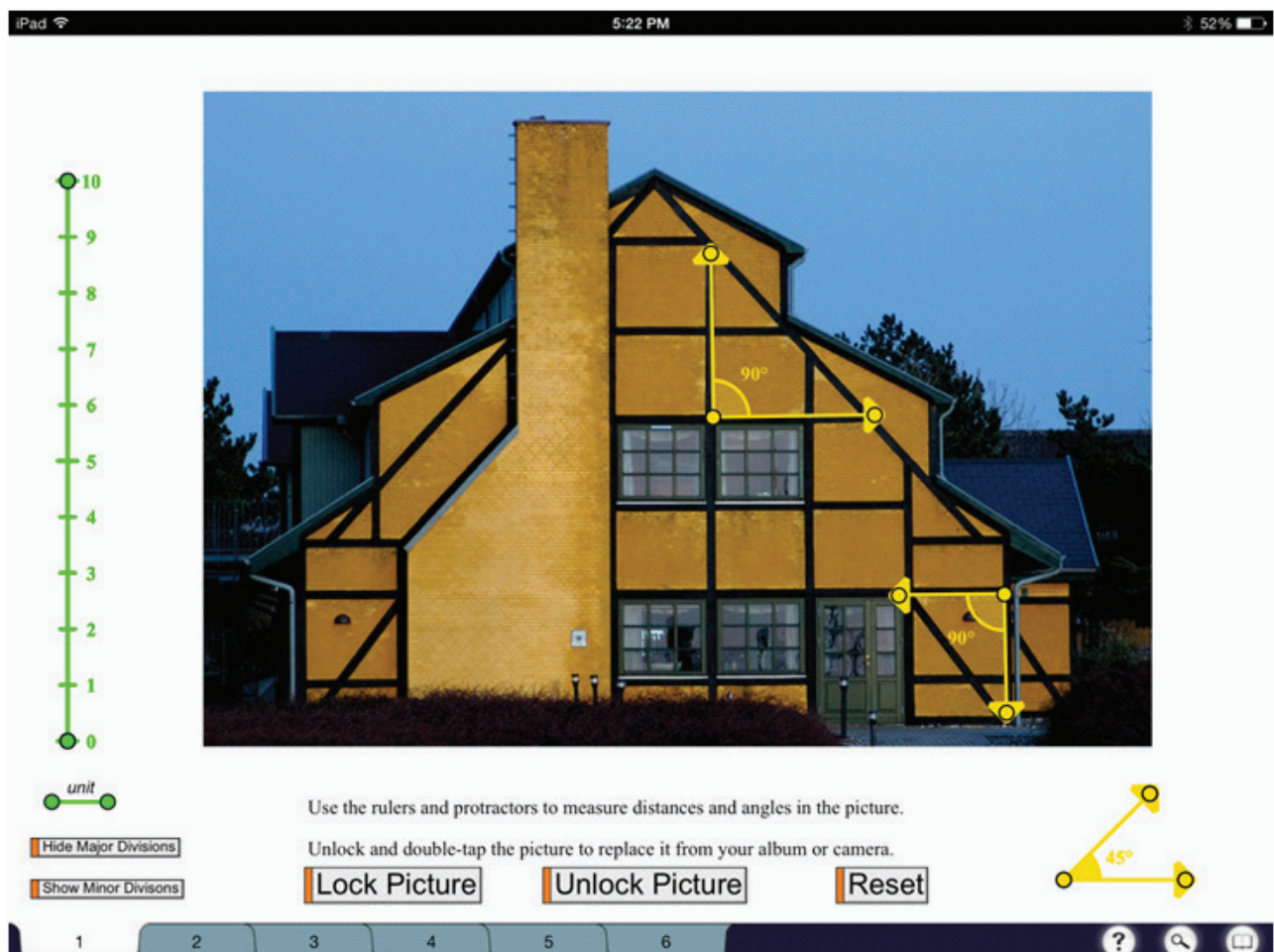


Figure 1: Measure a Picture with Two Angles Measured Using the Dynamic Protractor.

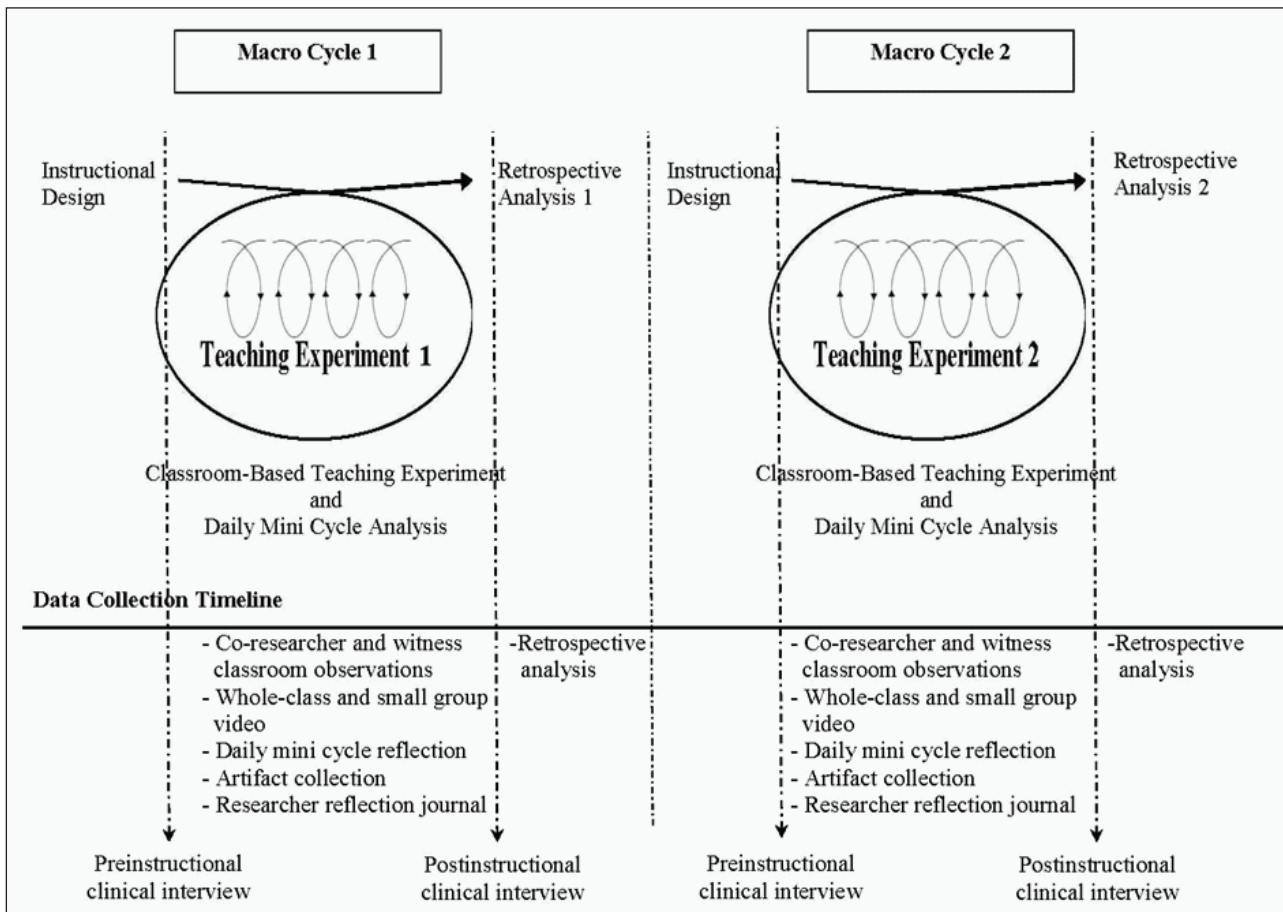


Figure 2: A Diagrammatic Representation of the Study with Points of Data Collection.

of these data was collected in conjunction with each part of the macro cycle.

Data sources

One of the distinct characteristics of DBR methodology is that the researchers develop a deeper understanding of the phenomenon while the research is in progress. Therefore, it is crucial that the research team generated a comprehensive record of the entire process (Cobb et al., 2003). There were several sources of data that were used in this DBR process. These data sources are:

- Pre- and post-instruction clinical interviews
- co-researcher and witness classroom observations
- whole class video recording
- daily mini cycle reflection audio-recording with research team
- artefact collection of student classwork
- researcher's daily reflection journal
- retrospective analysis at the end of a macro cycle

Clinical Interview

Sally's (1990) clinical interviews were used in this study. This interview included a set of six angle activities with a script and scoring guide to determine students' understanding of angle concepts in relation to the van Hiele levels of geometrical thinking. Note that this instrument does not measure knowledge of geometry facts (memo-

riziation) but the students' actual understanding of these concepts. Sally's (1990) clinical interview allowed the investigator to react responsively to data, asking new questions in order to clarify and extend student thinking. The interview design enabled the researcher to gain insight into the depth of student understanding with a collection of both oral and graphical explanations from the students.

The credibility of Sally's clinical interview has been determined with 83% reliability and the content validity of the instrument is established. Furthermore, Sally's (1990) study provided evidence for her to claim that the instruments and scoring procedures could be used effectively by other researchers and in other settings.

Classroom Observations and Whole Class Video Recording

During the teaching experiment, observation notes were collected from the research team which included the classroom teachers, mathematics and technology specialists, and one other researcher. The video recordings were also transcribed and additional observation notes were developed from the recordings.

Daily Mini Cycle Reflection

Immediately after each instructional episode, the research team met together to discuss their observations of the lesson and changes that need to be made to the instruction for the following day. These meetings were audio recorded and used in the retrospective analysis.

Artefact Collection

Student work artefacts from the teaching experiment were collected for analysis. This included screen shots of the students angle findings and measurements as well as worksheets and any rough notes or jottings the students created.

Researcher's Daily Reflection Journal

The primary researcher completed a personal reflection journal for each of the teaching episodes during each mini cycle. The journal was an instrument that allowed the researcher to step back from the action to record impressions, feelings, and thoughts (Holly 2002); and within the context of DBR, future plans were also be recorded. This form of data collection provided a medium for thinking aloud and was a reflective tool for "trying out ideas for action and assessing their implication, and evaluating the effectiveness of attempts to introduce changes" (Holly 2002, p. v). The researcher reflection journal completed during each mini cycle was a catalyst for change during the teaching experiment and the retrospective analysis.

All of these data sources were used during both the daily mini cycle analysis and the retrospective analysis phases at the end of each macro cycle. Data gathered from the final retrospective analysis was used to create a more robust local instructional theory.

Coding the Data for Design Guidelines

To develop a set of design guidelines, data from all of the sources, other than the clinical interviews, were coded. The interviews were not included as they underwent a separate analysis following Scally's (1990) protocol described earlier and were primarily used to provide an empirical understanding of pre and post instruction students' angle understandings. The rest of the data (video, audio, and text) was entered into NVivo 10 and was coded using grounded theory design with a constant comparative method (Strauss & Corbin 1998). The data were open coded to identify important themes from the data regarding the design of activities and they were labelled. The study of these data was an iterative and inductive process. The initial codes led to intermediate coding and the constant comparison of data of information to information, information to codes, and codes to codes.

Results and Discussion

Using DBR, the researchers developed a local instruction theory involving two components; design guidelines for informing the development of context-aware u-learning activities and a set of exemplary context-aware u-learning activities for extending and enhancing students' understanding of angle concepts.

Extending and enhancing students understanding of angle – Interview Data

Using Scally's (1990) clinical interview, students were required to demonstrate understanding of angle concepts, specifically of apperception of the physical attributes of angle; this included the static (configurational) and

dynamic (moving) aspects (Kieran 1986). Students were asked to provide both oral and graphical explanations to show understanding that angles can be represented in multiple contexts, embody generalizable attributes, and demonstrate correct procedures for measuring angle. Scally's interview methodology used the van Hiele levels of geometric thinking (1957/1984) to determine how well context-aware u-learning supported students' growth scores in how well they understood angle and angle measures. **Table 2** and **Table 3** show the pre and post instruction angle understanding scores for macro cycle one and macro cycle two.

The students in macro cycle one began working between the visual and the analysis level for drawing, identifying, and sorting angles. For angle measure and relations the students were working within the visual level. For the post instruction interviews, the four students improved and moved from the visual to the analysis level. The majority of the students were working fully within the analysis level (level two) at the end of the macro cycle.

Students in macro cycle two predominantly scored within the visual level in the pre instruction interview with some students working partially between the visual and analysis level. For the post instruction interview, the majority of the students moved into the analysis level of geometric thinking, however, for drawing angles and angle relations three of the four students were working between the analysis level of thinking and the informal deduction level.

	Pre Instruction					Post Instruction				
	V	VA	A	AI	I	V	VA	A	AI	I
Draws Angles		4						4		
Identifies Angle		4					1	3		
Sorts Angle		4						4		
Angle Measure	4						1	3		
Angle Relations	4							4		

Table 2: Macro Cycle One: Pre- and Post-Instruction Interview Summary. *Note.* V indicates that those students are working at the visual level; A indicates that those students are working at the analysis level, and I indicates that those students are working at the informal deduction level. Two letters indicate that those students are working between two levels. Dominance in one level is not denoted on this table. The numbers represent the students working at that level. Table adapted from "The impact of experience in a Logo learning environment on adolescents' understanding of angle: a van Hiele-based clinical assessment," by S. P. Scally, 1990, Unpublished doctoral dissertation, Emory University, Atlanta, Georgia.

	Pre Instruction					Post Instruction				
	V	VA	A	AI	I	V	VA	A	AI	I
Draws Angles	3	1						1	3	
Identifies Angle	1	3						4		
Sorts Angle		3	1					4		
Angle Measure	4						1	3		
Angle Relations	3	1					1		3	

Table 3: Macro Cycle Two: Pre- and Post-Instruction Interview Summary. *Note.* V indicates that those students are working at the visual level; A indicates that those students are working at the analysis level, and I indicates that those students are working at the informal deduction level. Two letters indicate that those students are working between two levels. Dominance in one level is not denoted on this table. The numbers represent the students working at that level. Table adapted from “The impact of experience in a Logo learning environment on adolescents’ understanding of angle: a van Hiele-based clinical assessment,” by S. P. Scally, 1990, Unpublished doctoral dissertation, Emory University, Atlanta, Georgia.

Following the teaching experiment the students from both macro cycles showed improvement. However, students in macro cycle two demonstrated the greatest increase from pre to post interview scores. Arguably, this improvement is due to the revision to the activities following macro cycle one.

Problem Addressed

Recognizing angles in different contexts. Student lack this ability as indicated by Crompton2013b.

Determining plausible answers

Angles are based on a dynamic rotation. Student lack and understanding of this concept as indicated by Crompton 2013b.

The length of the angle rays (lines) are irrelevant attributes of angles
A misconception indicated by Clements 2004; Berthelot & Salin 1998; and Yerushalmy and Chazan (1993).

Orientation is an irrelevant angle attribute. A misconception indicated by Battista (2009).

By using the mobile devices to take photographs of the angles, the students were able to first see the 3D angles which helped the students connect with the real-world angles. In addition, the camera view reduced the amount of external information the student was receiving to more easily find the angles.

The students could look back from the device to see the physical angles which helped them determine if the final measurement was plausible.

Students were able to understand that an angle is the rotation from a point as the dynamic protractor demonstrated this movement.

Students were supported in understanding that the length of the rays does not change the size of the angle as the rays on the app were changeable in length. In **Figure 3**, the student demonstrates the understanding that the length of the angle ray did not matter as they fit the length of the dynamic rays in the app to a coat pattern.

As students became familiar with looking for angles in the real world, the students realized that angle orientation did not matter. For example, the typical textbook right angle always faced one way. In the real world as the students found right angles and measured them using the dynamic protractor they realized that orientation did not matter. For example, using the app (Measure a Picture), the student in **Figure 3** demonstrated that he/she no longer considered orientation a salient angle attribute and the length of the angle rays did not constitute the measure of the angles.

Extending and enhancing students understanding of angle – Data from the Teaching Experiment and Mini Cycle Analysis

In the review of the literature, a number of problem areas were described as to how students can develop misconceptions and errors as they come to understand angle concepts. Context-aware u-learning was proposed as a pedagogical approach that may ameliorate those problems (See **Table 4**). As the data were analysed during the mini cycle analysis and retrospective analysis it appeared that context-aware u-learning did support the students in these ways:

Set of activities

The results of this study provide a set of activities involving context-aware u-learning. Due to space constraints, the full set of activities developed from this study cannot be provided within this paper but they are included as **Appendix A** and also within this Dropbox file; <https://www.dropbox.com/s/n9xyefflpuy4jl3/DBR%20Lessons.pdf?dl=0>

Design Guidelines

Data collected from this study provided a vast amount of information. These data were coded and four design guidelines emerged.

Design guideline 1. Ensure students do not rely on the technology to do the talking

Discussion is an effective way of promoting learning. “Reflective thought and, hence, learning is enhanced when the learner is engaged with others working on the same ideas” (Van de Walle & Lovin 2006, p. 4). Computers can be used to foster mathematical discourse, augmenting communication from teacher-to-student, or computer-to-student, to richer student-to-student communication

Table 4: Ways in Which Context-Aware Ubiquitous Learning Activities Supported Students Understanding of Angles.

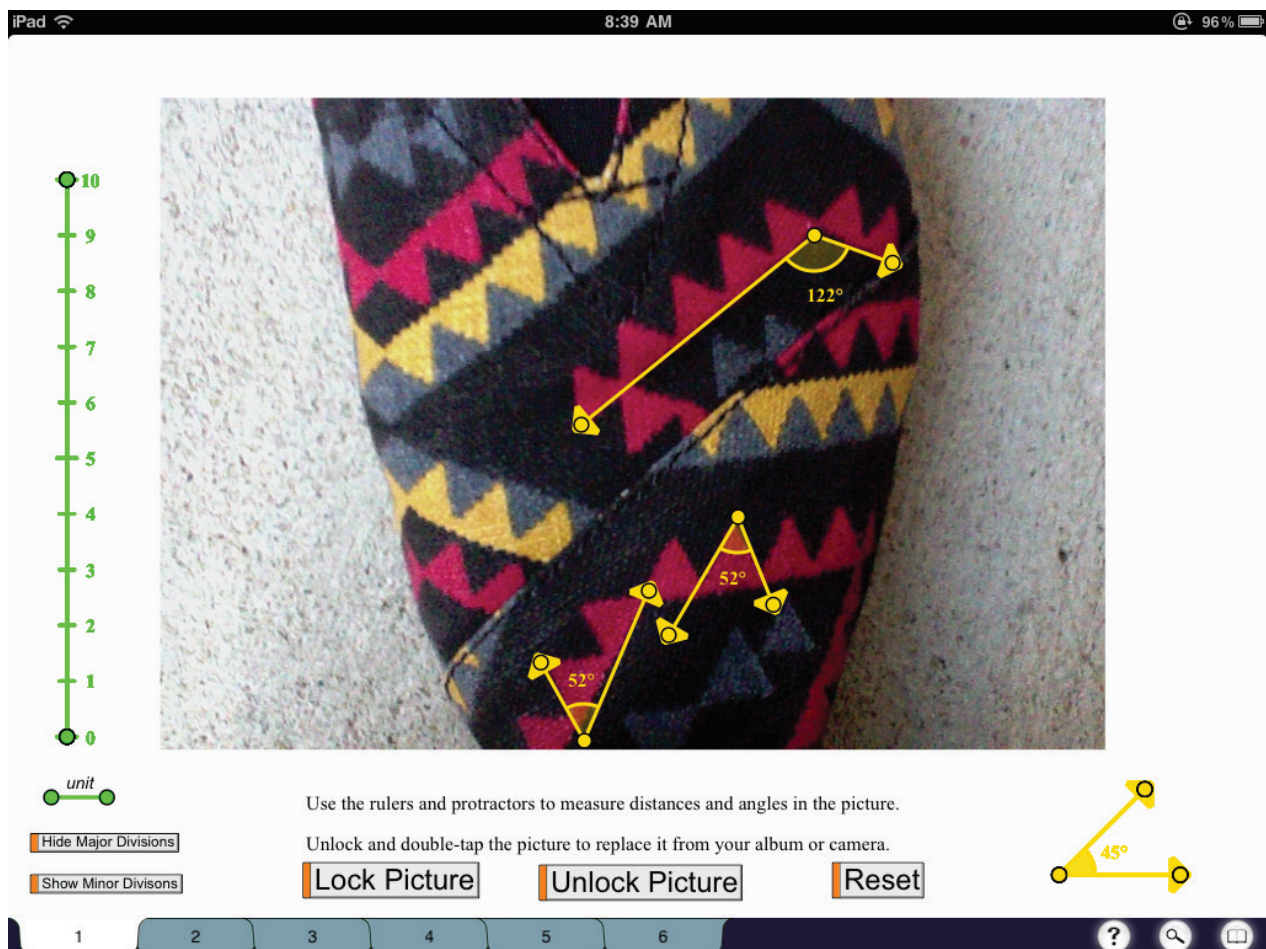


Figure 3: A student uses the App to demonstrate he/she understood that orientation and ray length were not relevant angle attributes.

(Roblyer & Doering 2010). The format of the computer activities, and the instant feedback elicits high motivation to solve the problems (Hentea, Shea & Pennington 2003), providing a perfect avenue for discussion.

During the instructional experiment it was found that students engaged their partners in very little discussion when they were asked to share the angles they had identified. Instead the students used the features of the iPad to share the angles and provided very little verbal explanation. For example, one student was asked by their partner what angles he/she had found and the student responded by pointing to the iPad screen and using the pinch feature to zoom in and out of the image, again pointing each time they did this. The student did not make any verbal connection to the other student during this time.

During the design of these activities it is important to include a specific requirement that the students verbally interact as well as use the features of the technology to get across the information to another student or educator.

Design guideline 2. Reduce cognitive load by not introducing the educational concept and the new technology at the same time. Cognitive load is a detailed field of study that is too great to go into in-depth review or analysis in this paper. However, data from this research show that students strug-

gled to learn two new independent concepts at the same time. At the beginning of the teaching experiment students are first coming to explore the meaning of the term angle and to have them learn the use of a new technological device and program (Measure a Picture) at the same time was too much information for the students to process. This was changed to have students' first focus on the educational concept of study, then on the second day the students were introduced to the mobile devices and the program.

Design guideline 3. Reduce the amount of real-world information that the student is processing

Having the students conduct context-aware u-learning activities will typically have the students interacting with the real-world environment. Although the students may easily connect with a familiar environment, e.g. school grounds, there is a lot of visual information connected with that place when students are asked to explore it for a particular concept. For example, in this study, students were required to find angles in a real-world context. In a 360 degree view of the environment next to a school building there is a large amount of information to review to identify angles. In addition, the students are new to understanding what an angle is.

This information should be reduced and a photo viewer is a good way of reducing the information the student is receiving. This should be included in a context-aware u-learning program to allow students to interact with the real world in a manageable way. As the students are preparing to use the mobile technology, to reduce the load of information students can be required to use a non-digital technology such as a cardboard tube to look through. The students can then move from the cardboard tube to the photo viewer. **Figure 4** shows students preparing to use the tubes for viewing angles.

Design Guideline 4. Mix contextualized learning with decontextualized learning to ensure transfer of contextualized understandings

It is important to have students working with context-aware u-learning activities to gain an in-depth understanding of concepts with connections to the real-world. However, the context-aware u-learning activities must also be mixed with decontextualized learning to ensure the students can transfer that information. In other words, the students may recognize angles on a building in the real world, but they should also be able to recognize an angle drawn onto a piece of paper and make the connection that they are both angles.

Conclusion

This study resulted in an empirically-based instruction theory of how context-aware u-learning can be used to support students' understanding of angle and angle measurement, and a set of design principles for developing context-aware u-learning activities. Using a cyclical iterative process of anticipation, enactment, evaluation, and revision (Gravemeijer & van Eerde 2009), the final set of activities were developed and they are an embodiment of the design principles.

Context-Aware U-learning Activities that Extend and Enhance Students' Understanding of Angle

Using Scally's interview, that matched students' angle understanding to the van Hiele levels of geometric thinking (1957/1984) and using the other data from the mini cycle and retrospective analysis, the findings indicate that the context-aware u-learning activities did extend and enhance students' understanding of angle concepts. In addition, changes made to the instructional activities improved students' understanding in macro cycle two to a higher level than it did with the students in macro cycle one.

Furthermore, evidence from the multiple data sources was triangulated and it would appear that context aware u-learning was supportive for learning about angle concepts in these ways: (a) by using the mobile devices to take photographs of the angles, the students were able to first see the 3D angles which helped the students connect with the real-world angles; (b) as students became familiar with looking for angles in the real world, the students realized that angle orientation did not matter. For example, the typical textbook right angle always faced one way. In the real world as the students found right angles and measured them using the dynamic protractor they realized that orientation did not matter; (c) the students could look back from the device to see the physical angles which helped them determine if the final measure was plausible; (d) students were able to understand that an angle is the rotation from a point as the dynamic protractor demonstrated this movement; and (e) students were supported in understanding that the length of the rays does not change the size of the angle as the rays on the app were changeable in length. These points connected with the misconceptions and errors that students have with angle concepts that were initially identified in the literature review. The final set of context-aware u-learning activities can be found in full in **Appendix A**.



Figure 4: Cardboard viewing tubes to reduce the amount of real-world information being reviewed.

Design Guidelines for Context-Aware U-learning Activities

From this study, four design guidelines emerged for context-aware u-learning activities. These guidelines were not specific to mathematics but for educational designers and scholars across all subject areas and all ages. The four design guidelines are:

1. *Ensure students do not rely on the technology to do the talking.*
2. *Reduce cognitive load by not introducing the educational concept and the new technology at the same time.*
3. *Reduce the amount of real-world information that the student is processing.*
4. *Mix contextualized learning with decontextualized learning to ensure transfer of contextualized understandings.*

Scholarly Contribution, Limitations, and Future Research

From a thorough review of the literature, this study appears to be the first of its kind to determine how a form of context-aware u-learning can be used to support students' understanding in learning about angle concepts. In addition, it is the first study to include the use of dynamic geometry environments in context-aware u-learning activities. Another distinct advantage of this study is that the researchers focused on a technological approach and did this by fully grounding that approach within a specific subject to determine the types of affordances this pedagogical approach can bring to learning.

Nonetheless, the specific focus of the educational concept is also a limitation to this study. Therefore, the researchers cannot claim that these types of activities will work across subject content areas as they have only been tested with students learning angle concepts. Nonetheless, the activities developed for this study and the clinical interview used to determine the efficacy of the technology is not age specific, but instead focuses on a set of mathematical understandings that can be broadly spread from young students to young adults. Therefore, the activities can be applied by teachers of all ages depending on the skill set of the learners.

Finally, as educational designers are provided with a growing number of technologies and new affordances, this study provides a set of design principles for the development of context-aware u-learning activities for extending and enhancing students' understanding of angle. In addition, educational designers and educators are provided with a set of exemplar context-aware u-learning activities that are ready for immediate use.

Competing Interests

The author declares that they have no competing interests.

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How to cite this article: Crompton, H 2015 Using Context-Aware Ubiquitous Learning to Support Students' Understanding of Geometry. *Journal of Interactive Media in Education*, 2015(1): 13, pp. 1–11, DOI: <http://dx.doi.org/10.5334/jime.aq>

Published: 18 August 2015

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 *Journal of Interactive Media in Education* is a peer-reviewed open access journal published by Ubiquity Press.

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