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GEOMETRIC COGNITIVE GROWTH: AN INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) APPROACH

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ABSTRACT

This study investigated the geometric cognitive growth of the Van Hiele levels in a technology-enriched environment, as opposed to that of students in a learning environment without any technological enhancements. In order to investigate this, a quasi-experimental non-equivalent comparison group design was used. Similar course content was used for both the control and experimental groups. The students worked through a series of geometry activities and problems. The difference between the groups was that dynamic geometry software was integrated into the teaching of the experimental group. The *Cognitive Development and Achievement Test* (CDAT) Van Hiele geometry test was used to determine all the students' level of geometric thinking before and after the course. The study found that the use of dynamic geometry software enhanced students' geometric visualisation, analysis and deduction, but not their ability to informally justify their reasoning and to understand the formal aspects of deduction.

Key words: Van Hiele Theory, Geometric Cognitive Growth, *GeoGebra*

BACKGROUND AND LITERATURE STUDY

Despite large amounts of money having been invested in equipping schools with technology, there is limited evidence of positive effects on student achievement (Sheldon & Byers, 2012). The assumption was that increased availability of technology in the classroom would lead to increased use, and increased use would then lead to not only efficient teaching and better learning, but also better student achievement (Cuban, 2011). There are researchers who believe that technology, if correctly used, can enhance teaching and learning. Babatunde (2010) found from research that "student-centered, technology-integrated learning environments help to produce students who are better able to think critically, solve problems, collaborate with others, and engage deeply in the learning process". According to Sanders (2008), the appropriate use of dynamic geometry software can enhance mathematics teaching and conceptual development, and enrich visualisation, while also laying a foundation for deductive proof. Wong (2008) contended that the instructional objective with graphing software is to develop and reinforce concepts, to rectify common errors, to check graphical solutions, to solve equations graphically, to test conjectures through problem posing, to encourage users to become metacognitive, to help users to acquire information technology skills, and to enhance the desire to learn. A study by Adekunle (2012) suggested that if technology is used for higher-order learning, it can result in increased mathematical achievement. Wong (2008) also argued that technology-supported collaborative learning has a positive effect on students' performance in problem-based tasks. Guven (2012) explained that the contribution of technology to the teaching and learning of geometry has been associated with the dynamic nature of software such as *Cabri, GeoGebra* and Geometer's *Sketchpad*. The power of the dynamic software does not stem only from the possibility of making constructing; it also allows interactive explorations by the dragging of points, vertices and objects.

THEORETICAL FRAMEWORK

The Van Hiele theory was used to measure the cognitive growth of these students. This theory has made a significant impact upon geometry education, particularly after it became known internationally what its impact had been on Russian mathematics education. Following in the footsteps of Piaget, Pierre and Dina Van Hiele identified five hierarchical, sequential and discrete levels of geometric development that are dependent on a learner's experience. In contrast with Piaget's theory, development is not dependant on age but rather on experience and the quality of instruction. In this context, it is useful momentarily to consider the basic tenets of both Piaget and Van Hiele. Battista and Clements (2009) summarised the two theories as follows: Piaget's theory, on the one hand, describes how thinking in general progresses from being non-reflective and unsystematic, to empirical, and finally to logical-deductive. The theory of Van Hiele, on the other hand, deals specifically with geometric thought as it develops through several levels of sophistication under the influence of a school curriculum.

According to Kotzé (2007), Piaget's argument can be put like this: there is a "maturation process" that takes a learner through acquisition, representation and characterisation of spatial concepts. Van Hiele, however, suggested progress through thinking on sequential levels as a result of experience. This experience is almost entirely dependent on instruction (Larew, 2009). According to their model, learners have to master a level to be able to move to a higher level. The levels, as described by Mason (2009) are as follows:

Level 1 (Visualisation): Students recognise figures by appearance alone, often by comparing them to a known prototype. The properties of a figure are not perceived. At this level, students make decisions based on perception, not reasoning.

Level 2 (Analysis): Students see figures as collections of properties. They can recognise and name properties of geometric figures, but they do not see relationships between these properties. When describing an object, a student operating at this level might list all the properties he/she knows, but may not discern which properties are necessary and which are sufficient to describe the object.

Level 3 (Abstraction): Students perceive relationships between properties and between figures. At this level, students can create meaningful definitions and give informal arguments to justify their reasoning. Logical implications and class inclusions, such as squares being a type of rectangle, are understood. The role and significance of formal deduction are, however, not understood.

Level 4 (Deduction): Students can construct proofs, understand the role of axioms and definitions, and know the meaning of necessary and sufficient conditions. At this level, students should be able to construct proofs such as those typically found in a high school geometry class.

Level 5 (Rigor): Students at this level understand the formal aspects of deduction, such as establishing and comparing mathematical systems. Students at this level can understand the use of indirect proof and proof by contra positive, and can understand non-Euclidean systems.

RESEARCH QUESTION

The study investigates whether the use of dynamic geometry software as an integrated part of instruction is beneficial in increasing students' geometric cognitive growth, measured in terms of the Van Hiele levels.

RESEARCH DESIGN

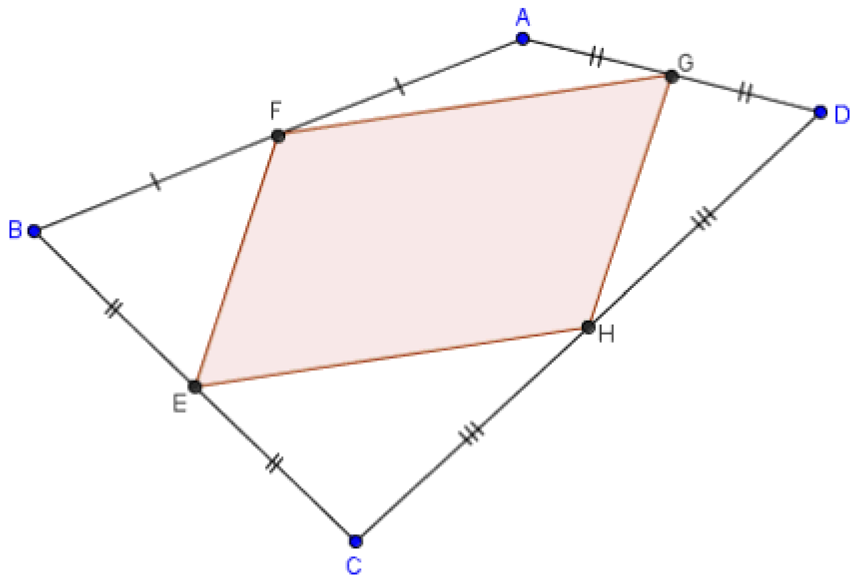
In order to address the above question, a quasi-experimental, non-equivalent comparison group design was used. The reason for this decision was that practically it was not possible to assign the students randomly into two groups because of their timetables. Two geometry classes of a one semester geometry module were used. The study used descriptive statistics, a

McNemar Test on each individual test item, and independent t-tests to investigate whether the use of dynamic geometry software as an integrated part of instruction was beneficial in increasing students' level of understanding, as measured in terms of the Van Hiele levels.

Examples of activities and how *GeoGebra* and *Cabri 3D* were used

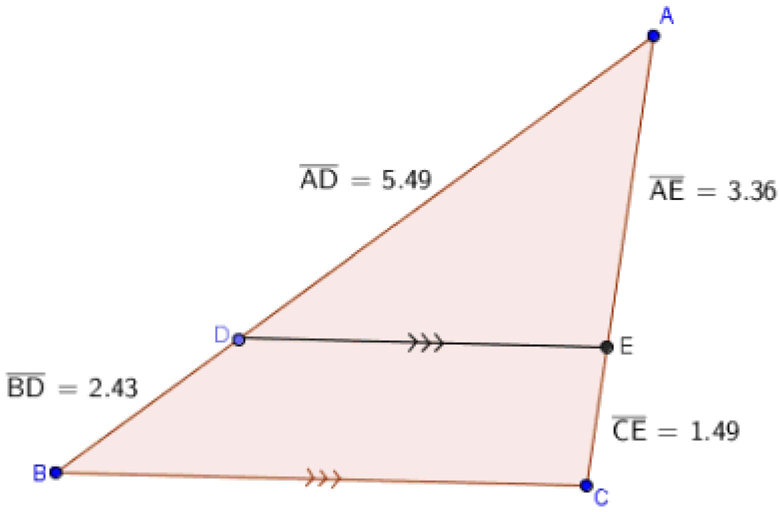
- ***Activity*:** If you have a piece of land that is a quadrilateral, what kind of quadrilateral will be formed if you take the midpoint of each of its four sides and join these midpoints? Explain and justify your answer.

  The idea of the activity was firstly to explore and discover that the new quadrilateral EFGH is a parallelogram. The experimental group used *GeoGebra* to make the construction. The advantage of using *GeoGebra* is that the mouse could be used to drag the quadrilateral vertices A, B, C, and D in order to observe the behaviour of quadrilateral EFGH.



- ***Activity*:** If a line is drawn parallel from one side of a triangle, it will divide the other two sides proportionally.

  GeoGebra was used by the experimental group to make the construction and to measure the segments accurately. The advantage of using *GeoGebra* is that the mouse could be used to drag the vertices A, B and C to create more special cases. *GeoGebra* will measure the segments immediately and also update any calculations.



RESEARCH INSTRUMENT

The research instrument that was used was the *Cognitive Development and Achievement Test (CDAT) Van Hiele Geometry Test* that forms part of the CDAT project developed by Usiskin (1982). The Van Hiele Geometry Test consists of 25 multiple-choice test questions (five questions on each Van Hiele level). This instrument was selected because it was easy to analyse, well tested, and widely used. By using the Kuder-Richardson Formula 20 it was discovered that the pre-test reliability of this test was 0.31, 0.44, 0.49, 0.13, 0.10 and 0.39, 0.55, 0.56, 0.30, 0.26 in the post-test for the questions on Van Hiele levels 1, 2, 3, 4, and 5 respectively. According to Larew (2009), the construct validity of the instrument was established.

DATA ANALYSIS PROCEDURE

Both the experimental and the control group wrote the same pre-test and post-test, namely the CDAT Van Hiele Geometry Test, before and after their courses were presented. During the first and last contact session students were given 30 minutes to complete the five multiple-choice questions on each of the five Van Hiele levels, thus in total 25 questions. As a first step, descriptive statistics were used to determine the average scores of students in both the control and experimental groups on each Van Hiele level before and after the course. Secondly, the study employed an independent t-test for each Van Hiele level, to investigate whether the difference between the pre- and post-test was as a result of the use of *GeoGebra* and *Cabri 3D* during instruction.

RESULTS AND DISCUSSION

The results of the study suggest that students did not have a sound understanding of more advanced Euclidian geometry. The most problematic areas were the construction of proofs, understanding the role of axioms and definitions, and an understanding of non-Euclidean systems. There was a definite descending trend from Level 1 (Q1 to Q5) through to Level 4 (Q16 to Q20), as predicted by the literature (see Figure 1). This was, however, not the case with the Level 5 (Q21 to Q25) questions. The students performed slightly better on the Level 5 questions compared to the Level 4 questions. This was contrary to the Van Hiele model, which suggests that mastering on one level is a prerequisite for mastering on the next level.

In order to determine the impact of the use and non use of dynamic geometry software on students' understanding of individual questionnaire items, a McNemar test was applied (see Table 1).

Table 1: McNemar Test applied to each Individual Questionnaire Item

Question	**Chi-square results (Sig. 2-sided)**	
	Control group	**Experimental group**
Q1	1.000	0.070
Q2	1.000	1.000
Q3	0.500	1.000
Q4	1.000	0.180
Q5	1.000	0.774
Q6	0.832	0.017
Q7	0.607	0.774
Q8	0.383	0.167
Q9	0.754	1.000
Q10	1.000	1.000
Q11	1.000	0.017
Q12	0.664	0.664
Q13	0.004	0.065
Q14	0.096	1.000
Q15	0.185	0.424

Q16	1.000	0.167
Q17	0.508	0.078
Q18	1.000	0.549
Q19	1.000	1.000
Q20	0.238	0.815
Q21	0.063	1.000
Q22	0.065	0.424
Q23	0.001	0.629
Q24	0.180	0.791
Q25	0.000	0.332

Only two items showed that the use of technology has a statistically significant (below the 5% confidence level) impact on students' conceptual understanding. That was Q6, which is about the properties of quadrilaterals, and Q11, which is about mathematical logic. Three items in the control group showed that the non-technological intervention had a statistically significant (below the 5% level) impact on students' conceptual understanding. These questions were Q13, Q23 and Q25. Both Q23 and Q25 focused on mathematical rigor and the students' understanding of formal aspects of deduction. The means were computed to summarise the scores (out of 5) for each Van Hiele level for both the pre- and post-tests (see Table 2). The majority of students did not reach the Van Hiele levels 4 or 5 in both groups and only about half reached Van Hiele level 3. It came as a surprise that not all pre-service students scored full marks on Van Hiele levels 1, 2 and 3 in both the control and experimental groups - not even after the course had been presented.

Table 2: Pre-Test and Post-Test mean Scores per Van Hiele Level

Van Hiele	Group	N	Mean (out of 5)		Mean improvement (out of 5)	SD
			pre-test	post-test		
Level 1	Control	55	3.87	3.93	0.05	1.161
	Experimental	53	4.06	4.28	0.23	0.847
Level 2	Control	55	3.56	3.42	-0.15	1.161

	Experimental	53	3.13	3.49	0.36	1.272
Level 3	Control	55	2.09	2.71	0.62	1.459
	Experimental	53	1.62	2.11	0.49	1.476
Level 4	Control	55	0.80	0.98	0.18	1.073
	Experimental	53	0.89	1.30	0.42	1.232
Level 5	Control	55	0.40	1.33	0.93	1.215
	Experimental	53	1.25	1.21	-0.04	1.224

Comparing the mean improvements of the control and experimental groups in Table 2, it appears that the technology-enriched environment improved the conceptual geometric growth of students in the experimental group on Van Hiele levels 1, 2 and 4. However, there was also evidence of cognitive growth when technology was *not* used on Van Hiele levels 1, 3, 4 and 5. The negative mean improvement score on Van Hiele level 5 suggests that the technology-enriched environment did not enhance students' understanding of the formal aspects of deduction, such as proofs. In the 'rigor' (Level 5) category (questions that covered the more formal aspects of deduction), the score of the experimental group declined, while the control group improved on average by 0.93 (out of 5) on Van Hiele level 5 questions.

CONCLUSION

This study sought to use the Van Hiele theory to investigate the geometric cognitive development of students in a technology (dynamic geometry software) enriched environment, compared with students in a learning environment without any technological enhancement. The results suggest that the technology enriched environment helped to improve the conceptual geometric growth of students on Van Hiele levels 1, 2 and 4 which is about geometric visualisation, recognition of properties of geometric figures, and the construction of proofs. This finding about the improvements on Van Hiele levels 1 and 2 resonates well with the literature, which suggests that technology can help to create an active learning environment in which students can discover, explore, conjecture and visualise.

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