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Teaching and Learning Middle School Mathematics through Cyber Learning System : The Concept of Centroid[1)]

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I. Introduction

As the development of technology accelerates, people have expected that technology could impact on teaching and learning of mathematics, and further students deeper understanding (Ayersman, 1996; Borba, 1995; Clements & Del Campo, 1989; Hannafin, Hill, & Land, 1997; Johnson-Gentile, Clements, & Battista, 1994). Along with these aspects that technology might bring to the educational field, it was expected that students proactive participation in mathematics classroom and creativity in exploration could be accomplished (Bransford, Stein, Delcos, & Littlefield, 1986; Dreyfes & Gullo, 1984; Kwon, Kim, & Kim, 2002). One of the softwares that brought peoples attention to the research study in mathematics education relating to students understanding in 1980s was the LOGO, so called Turtle Geometry (Papert, 1980). This software is especially limited to geometry and the level is appropriate for low graders in elementary school. One thing that stands out in LOGO is to guide students to know geometrical figures conceptually by stimulating students thinking power and leading their voluntary participations rather than students get the results by inputting the data into the machine or mechanically memorize the concepts of geometrical figures.

In the sense that not only LOGO was the newly introduced mechanical tool but also it encouraged students active participation, people began to foresee the other possibilities that they could do with this. One of the first things that we can easily observe in the technology-based classroom is the change of proportion of the power in the classrooms between teachers and students (Hannafin, Hill, & Land, 1997). With the appearance of increasingly powerful, useful, and adaptable technologies, unprecedented learning environments which are different from those of traditional classrooms have emerged. Especially these systems, called open-ended learning environ-

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ments (OELEs) (Hannafin, 1992), provide electronic tools and resources with which students attempt to address authentic situated problems (Hannafin, Hill, & Land, 1997, p. 94). As we can guess easily, the power in the traditional classrooms is almost centered to teachers, that is, the teacher who is in charge of leads a class from the beginning to the end and students are asked to do as they are told. Whereas, although it depends on the design of class in the technology-based classroom, much proportion of power in classrooms is naturally divided into the hands of students. This change requires not only the reformed curriculum so that new environments can play roles that are expected but also the preparation of teachers and active participation of students are necessary for successful teaching and learning of mathematics.

We believe that we have quite a lot of technology in educational field. Here, technology specifically means a computer. In addition to the number of PCs, especially the growth of numbers of internet hosts and WWW servers is phenomenal (Flake, 1996). The classroom is not an exception.

However, we still do not observe many mathematics classrooms where technology is used for teaching and learning of mathematics. Inservice teachers pointed several reasons: a) first of all, there is no enough time to finish the expected amount of contents with technology within the limited time; b) although there are a computer connected to internet and a large TV, but it is still small for about 40 students to watch materials on TV at the same time; c) materials on internet are not perfectly appropriate for the class and it takes too long to prepare a class that is helpful to students with other works to do; d) it is hard to control classrooms, etc. from interviews with a teach who participated in this study. It sounds that we do not get benefits as much as we invested for the use of technology in mathematics classrooms.

This paper investigated the feasible way to introduce technology into mathematics classrooms so that it can really play a role to help students to understand mathematics better. Simply having fine technology may not mean anything to us. We admit that there are some barriers that we have to overcome for the full advantage of technology as for now, for example, the reform of current curriculum, to secure financial support, to retrain inservice teachers, etc., which are huge tasks that cannot be easily solved. But, through this study, we would like to explore the feasible way to use a technology, especially network services, i.e., cyber space with a computer, without requiring so much change of the present situation where our teachers and students are situated.

II. Review of Literature

The World Wide Web, called WWW, is "a network of networks that has a body of software and a set of protocols and conventions in common" (Flake, 1996, p. 89). It uses hypertext and multimedia techniques and became user-friendly with the development of hyperlinking systems, which makes the web easy for anyone to browse, roam, and make contributions.

The Internet began in 1969 through the Department of Defense with four universities: the University of California at Los Angeles, the Stanford Research Institute, the University of California at Santa Barbara, and the University of Utah. In 1972, E-mail was first invented to send a mail through a network and in 1973, transatlantic connections were established to England and Norway. In 1982, the first definition of an "internet" was instituted as a linked set of networks. By 1984, there were about 1,000 hosts and by 1991, 100,000 hosts. This shows an evidence of the rapid growth in the number of WWW servers. The potential of WWW has been recognized as a major force in our society. Perhaps the biggest question that we need to consider seriously is "How do we want it to grow and help become a major contributor to our educational system?" (p. 91).

Flake summarized several very important educational opportunities that the World Wide Web provides us. First, students have access to a wide range of knowledge and information. But because those knowledge and information may be out of date or irrelevant, students need to learn to develop skills in gaining knowledge. Second, students can develop in socially relevant ways. The WWW can become a social environment for learning because students not only can learn knowledge and information from others, but also can gain ideas and insights by looking at other reports on understandings and investigations beyond the boundary of theirs. Third, the WWW provides a vehicle for the path to the newly developed high technology. As the technology is greater, people need to be in touch with other people. Fourth, as people explore the WWW, expectations will continue to rise, and the materials on the WWW will continue to get better and better.

Starr (1997) claimed that there are three keys to the educational value of the World Wide Web that are important to the instructional designer:

> The first of three keys to the educational value of the Web is hyperlinking that allows user control of information, the most basic level of interactivity. The designer can create links independent of a rigid hierarchy to allow, for example, the user to seek elaboration of the hyperlinked word(s), choose which topic to view, or follow different pathways through the program.
> The second key is delivery of multimedia with graphical browsers, perhaps the most important feature of the Web for instruction, enabling the widespread and inexpensive distribution of excellent images.
> The third key is the support for high levels of interactivity, with program response to the user to implement features such as searches, scoring of test answers, and simulations based on user input. The cross-platform nature of the Web assures facile widespread distribution of programs and enables seamless integration of lessons from widely dispersed sites. Worldwide programs can be updated or expanded by simply revising or adding files to a single computer. (p. 11)

On the other hand, Flake mentioned several concerns about the WWW although she acknowledged the great potentials of the WWW. First, there is no censorship. Students can access

some inappropriate materials which might cause to waste their time and energy. Those also can hurt students psychologically and mentally. A second concern is that there is no systematic information system. Too much information can bring confusion. Hence, it becomes a major challenge to locate appropriate materials within a reasonable time. The last potential problem that she recognizes is that because WWW provides a dynamic process of updating and modifying materials, an active address one week may lead to a blind alley the next. In addition, different browsers may display the screen differently for the same information or the speed may vary browser to browser as well as designers may have difficulty in locating appropriate materials due to the copyright issues (Starr, 1997). Flake (1996) added that WWW provides "a very open approach to education where students no longer are dependent upon their teacher or a textbook as their sole source of information. Students may learn a variety of topics in a number of ways .... WWW also holds the potential of raising the standards of education" (p. 100).

It is good to have enough information. But teachers in reality have to redesign the class with materials gotten from browsing through internet. This whole process forces teachers to be naturally away from using technology because there are too many things to do. Kim and Noh (2000) found that there are many useful websites related with teaching and learning of mathematics but, contents-based websites that teachers can use right away are very rare. In addition, because some useful sites are written in English, this is also another barrier that pushes teachers whose first language is not English into the wall. They also pointed out that the biggest barrier is the restricted mind toward the use of networks and lack of knowledge about computers of inservice teachers in using the cyber space for teaching and learning mathematics.

III. Research Methodology

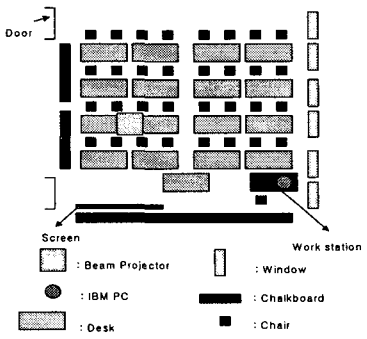
Considering the purpose of this study and research questions proposed above, a qualitative methodology study is the most appropriate for this study. In particular, the case study method was used. The case study provides some of the most useful methods available in educational research due to its flexibility and adaptability to a range of contexts, processes, people, and foci (Macmillan & Schumacher, 1993). "Case studies are differentiated from other types of qualitative research in that they are intensive descriptions and analyses of a single unit or bounded system (Smith, 1978) such as an individual, program, event, group, intervention or community" (Merriam, 1998, p. 19). As Stake (1995) explained, "it is the case we are trying to understand" (p. 78). The participants were above average in their mathematics performances and were 12 eighth graders.

Also, Goetz and LeCompte (1984) claim that case study is the powerful and appropriate research method "for intensive, in-depth exami-

nation of one or a few instances of some phenomena" (p. 46). Thus, case study is a particularly useful methodology for exploring an area of a field of practice not well researched or conceptualized. In-depth describing and understanding of a phenomenon are needed before generalizations can be made and tested. Case study, which has as its purpose the description and interpretations of a unit of interest, can result in abstractions and conceptualizations of the phenomenon that will guide subsequent studies (Merriam & Simpson, 1995, p. 112). This study intensively focuses on teaching and learning the concept of centroid. This special case will be analyzed in detail and is expected to find a clue to spread the possibility to use cyber space for teaching and learning mathematics more efficiently with what we have now.

1. Procedures

We created the website[2] that contains the concept of a centroid of a triangle in order to use it for this investigation. This concept is taught in the eighth grade in Korea. It took about almost four weeks to create this very special site. Twelve students were finally selected by the inservice teacher, who knows our investigation, on voluntary basis. Since the secondary school did not have the facilities (Figure Ⅲ-1) that we wanted, we invited all participants to university and one of researcher assistant who participated in this investigation taught the lesson to them. He was an inservice teacher at one middle school at the time of this study. The participants did not learn the concept of centroid as well as related geometrical properties as yet.



[Figure Ⅲ-1. Structure of classroom]

In the first day, we gave out pre-survey and pre-test. Then the instructor taught the related concepts for learning the concept of centroid such as the concept of similar triangles and their properties, and the properties of parallelograms which are necessary for proving that three medians meet at one point, and midpoint connection theorem. In the second day, the instructor taught the concept of centroid for 45 minutes which is the same amount of time in a normal classroom, but did using a different method in the different environments. He used cyber space about 32 minutes, which is 2/3 of the whole class. After the class, we gave out another survey and post test. Then, we interviewed students by breaking them into two groups with the same guiding questions, six in each group.

As for data collection methods, there were pre & post survey, pre & post test, classroom

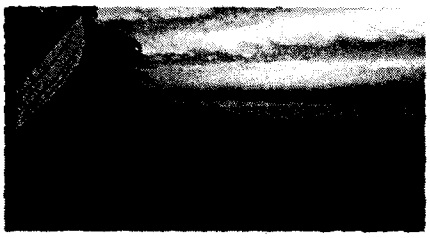
2) http://math.kongju.ac.kr/ktme/math_contents/08-na/centroid/teaching/teaching.htm

observation & video taping, and interviews used. All those collected data were analyzed with constant comparison method based on analytical induction.

IV. Findings and reports

1) Students intensively concentrated on the introduction of the concept of centroid for two minutes in the beginning of the class.

Teacher began the class with the site[3] by giving the problem situation to students, named raft activity, that is, Suppose that you are in an uninhabited island in the middle of the ocean where there is nobody. Luckily, there is a triangular raft which you can use in order to get out of that island. However, the raft can move forward only when you put the sail in the place where the raft is balanced. You have only one chance to try. Where would you put the sail in the raft? How would you find that place? If the sail is put in the place that is wanted, the raft would move forward with the beautiful sound of wave of the sea, but if not, it was designed that the raft sink under the sea with the sound that something is going down into water (Figure IV-1).



[Figure IV-1. Raft in uninhabited island]

After he introduced the situation, about 30 seconds passed without any noise. He let any student try out but, it did not work out very well. Three students did try by grabbing the sail and putting down it somewhere in the middle of the raft. Unfortunately, all failed, which means the raft sank down, and so students could not get out of the island. In about one minute and 40 seconds, teacher tried and it worked out well, which means the raft was well balanced and could be used to go to land. Students did not know why the teacher showed this raft in the beginning of the class and what this is for relating to learning mathematics at the moment. But, they did know that it was mathematics class and would learn something about mathematics. The raft activity worked well in stimulating students interest.

(S : Student & R : Researcher)
R : What was the most interesting in todays lesson?
S : Umm ... Ah, the raft! That was so cool.
R : In what sense did you like that most?
S : I just could not do anything else. My eyes were stuck to the screen in front. It was very curious to see how my friends are doing. They failed but, it was fun. I have never seen such an activity in the mathematics class.

(T : Teacher & R : Researcher)
R : Sir, you started the class with the raft activity. How would you evaluate your class, especially the beginning of the class?
T : I think it was very successful. Especially, I am very much satisfied with the introduction. I could tell very easily that students were focusing

3) http://math.kongju.ac.kr/ktme/math_contents/08-na/centroid/teaching/intro.htm

on whats going on. This is my seventh year as a math teacher. I have never seen the moment that students concentrated so hard like today.

R : What do you think the raft activity played a role for the class?

T : I used that activity in order to induce students concentration on today's lesson. I did not expect too much other than their showing interest about what they would learn today. I think it worked out perfect as introduction. They really focused.

The raft activity was highlighted more than anything else in the sense that the amount of time for the activity was appropriate, it was simple and easy enough so that anybody could understand the task, and students themselves did voluntarily participate in the activity. Teacher and students were one at least for the first two minutes. After the introduction, teacher was very busy in delivering properties relating to the concept of centroid throughout the class. But, he kept reminding students of the raft activity as the class went along. Thus, the raft activity played a role not only to trigger students interest toward the class but also to be consistent throughout the class so that students fully understand the concept of centroid. In other words, the first two minutes made a teacher and students be one, and guided the whole class period.

2) *Some students preferred the mathematics class with blackboard and some did with cyber space with technology.*

Four students preferred the class with blackboard, seven students with cyber space with technology, and one student liked both. We posed a question to ask if they had any experience to study any subject using any type of technology. Only a few students had such an experience, but the subjects were social studies and arts. There was nobody who studied mathematics with any type of technology, which is not very much surprising to us because we knew that technology is only used in the special program for the limited amount of time such as education for gifted students. At the same time, we were so surprised at the fact that nobody had an experience with mathematics because it has been a decade since Department of Education of Korea

<Table Ⅳ-1. Students responses for selected questions of post-survey>

Items		Number of Students
1. The mathematics class with cyber space using technology was	a) very interesting b) interesting c) not interesting	6 4 2
2. The mathematics class with cyber space using technology was _____ in understanding the concept of centroid.	a) very helpful b) a little helpful c) not helpful	5 6 1
3. I prefer mathematics class with _____.	a) blackboard b) cyber space using technology	4 7
4. I understood the concept of centroid about _____.	a) 100 % b) 70 % c) 50 % d) 30 % e) 0 %	5 6 1 1 1

has emphasized the use of technology for learning and teaching at school. For some reason, it did not work out well for mathematics. The teacher who lead the class of this study admitted that I am very much interested in using technology for mathematics class. But, I could not use it. The situation in the field does not allow me to do so.

We learned that they were not used to the learning environments relied on technology from interviews with students. But, students pointed out several advantages as well as obstacles that technology-based mathematics classroom could bring. First, students preferred mathematics class with blackboard because

a) they are used to learning mathematic on blackboard;
b) they feel more comfortable with blackboard;
c) contents are introduced in a normal speed as fast as they can follow;
d) it is easier to understand because teacher draws or writes as he explains;
e) it is easier to correct and add (or delete) when there is something wrong;
f) it is easier to use.

The main reason and background why they preferred the traditional classroom was that they were not ready to accept the new style yet or did not want to change their learning style that they have done so far or were not sure how the new style would impact on them. But, they were partially agreed to the use of cyber space using technology for learning mathematics. Although they preferred mathematics class with blackboard, they admitted that there are some advantages for learning mathematics using technology because it is much easier to recognize the figures or graphs due to exact construction and various colors.

On the other hand, students preferred mathematics class with cyber space using technology because

a) they can try over and over as many as they want by themselves;
b) they can try new things that they cannot before;
c) they had enough of mathematics class with blackboard;
d) it is more interesting to learn mathematics using cyber space with technology;
e) it is easier to understand because figures and graphs are more clear and exact;
f) blackboard is so dark, thus they cannot see things provided on it well;
g) classes are more active and vivid.

These students pointed out several things that did not exist in traditional mathematics classes. They wanted changes and the change that they experienced was fresh and provided new expectations that the mathematics class with blackboard could not. Although they preferred mathematics class with cyber space using technology, they suggested that sometimes explanations with blackboard were more effective, especially for proofs.

3) Teacher believes that we can really use cyber space in mathematics classroom without changing current curriculum and textbooks.

While the teacher was teaching the class, about 70% of the class period was spent relying on the cyber space using a computer. Before the class,

we did not ask him to teach the class with a specific method. We simply provided, the teacher was one of assistant researchers who created the materials, the materials and had him decide teaching style. As briefly mentioned earlier, he has been interested in using technology for teaching mathematics and actively participated in the regular meeting that the group of those types teachers held. Further, he was awarded at the nationwide contest to create the homepage for teaching mathematics. He evaluated his teaching in the following way:

R : What do you think about the class with cyber space?
T : I think about 70% was successful.
R : Would you explain some more?
T : I think the use of technology is appropriate especially for introduction in the beginning and arrangement at the end of the class. In the practical sense, it is not helpful for proving properties or theorems to students. Of course, I can show them quickly with well constructed figures done by a computer, but from the students perspectives, we have to consider if they understood or not. Students logical thinking is not well developed or trained yet. In my experience, they had a hard time even with simple proof.
R : Have you ever used technology in your classroom before?
T : Yes. It did not go well. They could not follow as I intended. I think about less than 20% of the class period is appropriate for using technology. Students cannot concentrate on cyber space appeared in front so long. But, as you could tell, they liked the introduction, raft activity, and the arrangement with cyber space at the end.

The teacher was confident of the use of cyber space. After he taught students, he recognized some problems with the materials provided on internet. He wanted to show the process step by step after raft activity. He learned that the automated process was too long. For example, he explained the concept of medians with the materials[4] created by Flash 5.0. Everybody felt too long while the process was going on. He tried to explain what is going on. But, the repetition of the same thing was not very much attractive to students. Finally, teacher admitted that it is too long and told students that he should fix this later, which might have students mind turn away from this type of mathematics class. The other problem that he recognized was that he had to go back and forth in front during the class. The computer was on the right corner, a huge screen on the left side of the front wall, and blackboard was on the wall located in the left side of the classroom (Figure Ⅲ-1.) from teachers side. Due to the location of computer, screen, and blackboard, he could not help but move around continually throughout the class. But, if a computer was located on the left corner or teacher used the cyber space in the beginning and at the end, we could see different responses from students and teachers.

R : Do you think that the class was lead as you intended?
T : Yes and no. Almost all the students showed their interests to the use of cyber space and they said it was helpful, but I was not fully ready to mix traditional and new teaching styles appropria-

4) http://math.kongju.ac.kr/ktme/math_contents/08-na/centroid/development/centroid_dev_1.swf

tely. I wish I spent less time with cyber space.

R : Will you use cyber space in your class?

T : Definitely, of course. It was such a precious experience even to me. I tried teaching mathematics with technology once or twice before. But, it did not go really well. Since then, I always thought of how I could use it effectively. I learned many things from this experience.

R : Could you say more specifically?

T : For some reason, I heavily relied on the use of cyber space. I see many good things of it, but I think it is very important to consider which style is better for each concept and different group of students. That is, when and how to use is the main thing that I should consider for the most effective results. I cannot give stake to new born baby although I know it is delicious.

V. Discussion and Implications

It is an ironical situation to see that technology is not used in mathematics classroom considering so many studies relating to the use of technology. Many of those (Ayersman, 1996; Hannafin, 1992; Jung, 2002; Kwon, Kim, & Kim, 2002) confirmed positive effects that technology could bring to the educational field in learning and teaching of mathematics. However, Hwang and Cha (2002) suggested followings for the use of technology to be practically available and to contribute to the learning and teaching of mathematics with dynamic software: 1) a teachers role is important. The success of the class with technology is on teachers hand for many parts; 2) School environments should be reformed, i.e., the classroom should be equipped with technology up to the decent level so that each or group of students can really use it whenever they need; 3) Curriculum should be reformed so that textbook goes along with new type of teaching and learning of mathematics; 4) Teaching and learning mathematics with technology is the first, not the colorful figures or fancy sound from machines.

In this study, we learned that first, students intensively concentrated on the introduction of the concept of centroid, which is the raft activity, in beginning of the class. This was the moment that the teacher and students were one throughout the class. Everybody was quiet and everybody was looking at the raft and tried to figure out what was going on. It was the moment that everybody liked most. We saw the possibility to induce students to the interesting part of mathematics by showing them mathematical concepts from different perspectives, which is the cyber space using a computer. It was simple but powerful enough to make everybody focus on one thing.

Second, some students preferred the class with blackboard, but some with cyber space using technology. This is an interesting part we should carefully consider. Students who participated in this study have never used any type of technology for learning mathematics. But, many students thought that learning mathematics with cyber space would be helpful for better understanding of mathematics. Even those students who preferred the class with blackboard said that they liked the introduction activity and some features that they can take advantages from using computers. If we could arrange the amount of time when cyber space should be used and create

good harmony between the use of technology and blackboard, we could expect more positive effects on students understanding of mathematical concepts. The teacher agreed that he just tried to use cyber space and computer too much. This suggests that we can find a way to use cyber space for teaching and learning of mathematics with current curriculum and textbooks.

Third, the teacher was confident of the use of cyber space in mathematics classrooms. He recognized that it was not effective to depend on cyber space too much, rather it distracted students focus on study materials. He felt that the introduction using cyber space was very successful because everybody fixed their eyes on the activity appeared on screen, and the arrangement at the end of the class because they were able to see the whole picture of what was done during the class. But, he would avoid using cyber space in the middle of explanation of mathematics properties. He decided to use it less in the middle of the class. He thought that is better with the current curriculum and textbook, especially for those students who are not used to the use of cyber space in mathematics classroom and have to pass high school or college entrance examinations.

We also learned that there are several things that we should seriously consider before we introduce new types of teaching and learning of mathematics. To bring new tools into classrooms requires changes from many aspects such as the structure of classroom and curriculum, students and teachers attitude toward mathematics class, parents and administrators expectations, etc. The harmony of these factors along with effective use of cyber space with computers can make the vision suggested *by Curriculum and evaluation standards for school mathematics* (NCTM, 1989) come true: The thoughtful and creative use of technology can greatly improve both the quality of the curriculum and the quality of children's learning. (p. 19) Although we do not have textbooks or curriculum which is most appropriate for the use of cyber space with computers, the use of cyber space can lead us the way to embrace the technology into the mathematics classroom for what textbooks and curriculum should be like in the future as NCTM(2000) stated, Technology not only influences how mathematics is taught and learned but also affects what is taught and when a topic appears in the curriculum. (p. 26).

From this study, we learned several issues about when to use what types of tools including cyber space and the amount of time of a specific technology while teaching and learning mathematical concepts. We suggest the harmony between the new tool such as cyber space with computers and the current curriculum rather than the radical reformation of it. Although many people emphasized the use of technology in mathematics classroom for a while, it is still a long way to observe mathematics classroom where technology plays the roles that we expect and the use of technology goes with the vision provided by NCTM. However, the appropriate and flexible use of technology for the limited time with the current curriculum, textbook, and facility can give us new faces of teaching and learning of mathematics for more efficient understanding.

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가상학습체계를 통한 중학교 수학의 교수 및 학습

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본 연구는 실질적인 의미에서 학생들로 하여금 수학을 더 잘 이해할 수 있도록 돕기 위해 테크놀로지를 학교 교실에서 직접 활용하는 방안에 대한 연구이다. 특히 여기서는 수학을 가르치고 배우는 과정에서 가상학습체계가 주요한 도구로서 적용되었다. 내용은 무게중심을 택했고 12명의 중학생을 대상으로 현직교사가 직접 지도하였다. 학생들은 수업초기에 교사에 의해 소개되는 학생중심 학습활동에 강한 관심과 호기심을 보였고 집중력이 아주 강했다. 전통적인 수업방식과는 달리 학생들이 참여하였고 테크놀로지를 이용하여 전통적인 방식의 교실에서 할 수 없었던 수업의 시작은 학생들의 호기심을 자극하는데 충분하였다. 전반적으로 테크놀로지 환경에서의 수업을 선호하였지만 아직 전통적인 방식인 칠판과 분필을 이용한 수업을 선호한 학생들도 있었다. 새로운 변화도 좋지만 새로운 환경에 친화적이지 않거나 테크놀로지를 이용한 수업의 빠른 진행이 학생을 오히려 혼란하게 만들기도 하였다. 마지막으로 교사는 가상학습체계를 교실에서 활용함에 있어서 현 교육과정과 교과서를 크게 개혁하지 않아도 잘 준비되고 계획된 테크놀로지의 활용에 대한 잠재력을 확인할 수 있었다. 우리는 현재 테크놀로지의 보급에 비해 그 활용도가 낮다는 것을 잘 알고 있고 기타 입학시험이라는 현실이 교육과정과 학습방법의 개혁을 현실적으로 추진하는 것이 어려운 일임을 잘 알고 있다. 그래서 현 상황에서 테크놀로지의 사용을 가능하게 할 수 있는 방법을 모색하였다. 이미 보급된 테크놀로지와 교사와 학생의 테크놀로지에 대한 이해가 앞으로 그 잠재력을 갖고 있다고 확인하였다.

* key words : technology, mathematical teaching and learning, cyber learning system, geometry, understanding