King Fahd University of Petroleum & Minerals

DEPARTMENT OF MATHEMATICAL SCIENCES

Technical Report Series

TR 311

December 2003

Creativity and Computer in the Teaching and Learning of Mathematics

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> "The question of whether a child can learn and do more mathematics with a computer (or other forms of electronic technology, including calculator and various video systems) versus traditional media is moot, not worth proving. That computational aids overall do a better job of converting a child's intellectual power to mathematical achievement than do traditional static media is unquestionable. *The real questions needing investigation concern the circumstances where each is appropriate"* (Kaput 1992:518)

The advent of educational technology has been generally considered as major revolution in the educational system (see Ashby 1967). The impact is akin to the changes brought about by other educational revolutions such as: shifting the task of educating children from parent to teachers, or rather from home to school; the adoption of the written word as a tool of education; the invention and widespread of printing material such as books (The Fourth Revolution 1972). In the same vein, one can argue that the invention of computers and the

World Wide Web is another revolution inside the educational technological revolution. With this, the face of all educational systems has changed for ever.

Computers have been used in education for more than four decades, and they have now become an integral part of our entire educational system. This usage is increasing rapidly and has also generated new challenges. In this development, perhaps there is no subject that has benefited and is believed to have stronger intrinsic links with the computer than mathematics. Kaput (1992) noted that the role of computers in mathematics education is so significant that it is difficult to describe, and the changes so rapid that they are difficult to follow.

> anyone who presumes to describe the roles of technology in mathematics education faces challenges akin to describing a newly active volcano – the mathematical mountain is changing before our eyes, with myriad forces operating on it and within it simultaneously (Kaput 1992:515).

The purpose of using computers in the teaching and learning of mathematics is for the “enrichment and improvement of the conditions in which human beings learn and teach” (The Fourth Revolution 1972:89). In this sense, computers are subservient to the teaching and learning and not an end in itself. Although there is no consensus among mathematicians and mathematics educators on the educational merits of using computers in the teaching and learning of mathematics, much empirical research strongly supports the use of computers as a catalyst for improving and enriching the learning and teaching environment. For instance, out of several thousand studies reviewed, and many meta-analyses on this issue, the results mostly support the use of computers in the teaching and learning of mathematics (Kadiyala & Crynes

1998). According to Jeffries (1989), numerous meta-analyses of research in the computer aided learning (CAL) (some time refers to as computer aided instruction (CAI)) of mathematics have resulted in the following conclusions:

1. CAI is at least as effective as direct instruction when measured in terms of student achievement for students at all grade levels and in a wide variety of subject areas (Bangert-Drowns, Kullik, &Kullik, 1985;Chambers &Sprecher, 1980; Kulik, Bangert, & Williams, 1983: Kullik, Kullik, & Cohen, 1980).
2. CAI may be more effective for lower-ability students (Bangert-Drowns, Kullik, & Kullik, 1985; Chambers and Sprecher, 1980; Edwards, Norton, Tylor, Weiss, & Dusseldorp, 1975; Splittgerber, 1979).
3. Students demonstrated a more favorable attitude toward learning with computers than for direct instruction (Bangert-Drowns, Kullik, & Kullik, 1985; Chambers and Sprecher, 1980; Roblyer, 1988)
4. CAI is reported to have reduced learning time when compared to traditional instruction (Chambers &Sprecher, 1980; Jamison, Suppes, & Wells, 1983; Kullik, Kullik, & Cohen, 1980; Splittgerber, 1979)

Similarly, computers have been found to be cost-effective in the teaching and learning of mathematics (Levin, 1986; Niemiec & Walberg, 1987; Moonen, 1987; Cryer-Hittson, 1987). In another meta-analysis, the result revealed that the average effect of CAI was to raise student mathematics achievement by .33 to .45 standard deviations (Burns & Buzman, 1980; Kullik, Bangert & Williams, 1983). In addition, CAI improves students' attitude toward mathematics and computers (Bangert, Kullik, & Kullik, 1983), as well as toward academic conceptualization and perception of the quality of school life in general (Mevarech & Rich, 1985). From all the research findings on the use of computers in teaching and learning mathematics, it appears that it has a tremendous potential to improve mathematics education and consequently science and technological education.

For the enumeration of the benefits and advantages of using computers in education, one can for instance, see Kadiyala & Cryines (1998); The Fourth Revolution; Corcoran (2000); Dunham & Dick (1994); Roblyer (1989); and Setzer (2000).

In addition to all these benefits, we plan to show that, more importantly, if used effectively, computers can be a good instrument for fostering creativity in mathematics students, as well as instrumentally assisting teachers to effectively teach mathematics in a more successful manner.

WHAT IS CREATIVITY ?

> The creative act is often portrayed as a mysterious and even mystical process, more akin to divine inspiration than to mundane thought… However, with the advent of contemporary cognitive science, psychology has come much closer to appreciating the mental processes that must participate in the creative act (Simonton, 2000:152).

Creativity is a very complex phenomenon that is very difficult to define (Standler, 1998; Meissner, 2000). Consequently, many experts from different disciplines have resorted to a descriptive approach. Simonton (2000) described creativity as “one of the special ways that human beings display optimal functionality” (p.151). Quigley (1998) simply puts it as “…the ability to produce something effective and novel” (p.1). While Standler (1998) resorts to giving the difference between creativity and intelligence as that between a creative person and a intelligent person. According to him, intelligence is the ability to learn and to think, while a creative person does things that have never been done before. A tacit implication of this definition is that most creative people are intelligent but the converse is not always the case.

It has been argued (see Jacob, 1996) that creativity can be categorized into two distinct types, (1) a bolt out of the blue and (2) a process of incremental revisions. In a bolt out of the blue, creativity arrives in a sudden warm embrace, leaving one with a giddy sense of inspiration, vision, and purpose which results in a moment of clarity that is both inexplicable and undeniable (Jacob, 1996). In the ‘process of incremental revisions’ creativity is hard work, where one starts with a vague creative seed to spend countless hours of revision and rethinking to hammer out a work of blood, sweat, tears, but mostly frustration (Jacob, 1996). This is an experience also identified and explained by De Villiers (in press).

HOW DO WE PROMOTE CREATIVITY IN A MATHEMATICS CLASSROOM

The nature-nurture relationship forms a basis and circumstance that seem to influence the emergence of creative personalities. Embedded in this relationship are many other sub-factors. These include, according to Simonton (2000), the birth order, early parental loss, marginality, availability of mentors, and role models. Other developmental variables refer to an individual’s experience and performance in the school system (primary, secondary, and higher education). Simonton (2000) has pointed out that “…the acquisition of creative potential requires the simultaneous contribution of both nature and nurture" (p.154). As teachers we have very little or no control over the nature factors; however, a lot can be done in the mathematics classrooms that can nurture the creativity potential of our students. The good news is that studies have shown that creativity comes more from environmental factors than hereditary factors (Simonton, 2000). Research has also shown that creative people do not like to work in a conventional way. They have a desire to shake things up. They are dissatisfied with the status quo. They are restless, rebellious, courageous, diligent, arrogant and independent (Cangelosi, 1996; Meissner, 2000). In the mathematics classroom, Cangelosi (1996) has reported that mathematics creativity is displayed by students who think divergently. These are students who generate ideas, conjectures, algorithms, or problem solutions. In a study conducted in South Africa, Nakin (1993), for example, reported a link between creativity, divergent thinking and effective learning of geometry. Cangelosi (1996) describes divergent thinking as atypical reasoning that is different from the 'normal' way of thinking. It occurs in situations where 'unanticipated and unusual' responses are anticipated and accepted. Creativity thrives in an environment in which ideas are valued on their own merit, rather than on the basis of how they were produced or who produced them. This shows how relevant motivation, engagement, imagination, relative freedom, independence of thinking, relative originality and flexible thinking foster creative thinking (Cangelosi, 1996; Meissner, 2000). To enhance creativity, it is critical therefore that these qualities be encouraged and developed in the mathematics classroom. Although the creative process is not well understood, some recommendations have been proposed for teachers to help encourage creativity in their classrooms (Paul & Kathy, 1990; Cangelosi, 1996; & Meissner, 2000). These are:

1. Teach students to appreciate and be pleased with their own creative efforts.

2. Respect the unusual questions students ask, and the unusual ideas and solutions, for students will see many relationships that their parents and teachers miss.

3. Show students that their ideas have value by listening to their ideas and considering them. We can encourage students to test their ideas by using them and communicating them to others. We must give them credit for their ideas.

4. Provide opportunities and give credit for self-initiated learning. Overly detailed supervision, too much reliance on prescribed curricula, failure to appraise learning resulting from a student's own initiative, and attempts to cover too much material with no opportunity for reflection interfere seriously with such efforts.

5. Provide chances for students to learn, think, and discover without threats of immediate evaluation. Constant evaluation, especially during practice and initial learning, makes students afraid to use creative ways of learning. We must accept their honest errors as part of the creative process.

6. Establish creative relationships with students - encouraging creativity in the classroom while providing adequate guidance for the students.

7. Encourage curiosity, exploration, experimentation, fantasy, questioning, testing, and the development of creative talents. The students must develop important abilities. They must learn to explore and to visualize a problem, to invent own or to modify given techniques, to listen and argue, to define goals, to cooperate in teams.

8. Provide opportunities for creative expression, creative problem-solving, and constructive response to change and stress. We need "challenging problems". They must be fascinating, interesting, exciting, thrilling, important, and thought provoking. Often open-ended problems are welcome or challenging problems with surprising contexts and results. Challenging problems are provoking to students (or boring when there is no interest in the content or if they are too demanding). Therefore, the problem must be connected with the individual daily life experiences of the students. We must meet their fields of experiences and their interest areas. The students must be able to identify themselves with the problem and its possible solution(s). Challenging problems are the base for a non-conformist behavior and a threat to routines.

9. Prepare students for new experiences, and help develop creative ways of coping with them.

10. Students should be exposed to examples of creative production (for instance, through historical accounts of mathematical inventions and discoveries, and through teachers modeling divergent thinking in think-aloud sessions)

11. Heuristic activities such as brainstorming, open-ended question sessions, and discussions in which ideas for consideration are examined regarding purpose, structure, advantages, and disadvantages. Teachers should be aware of the natural curiosity of students, especially young children. We must let the children discover their environment. They themselves must describe and order or classify their observations, their activities, their questions, and their results. The teacher is only the guide through the jungle of "mathematics". Teachers must meet the interest fields of the students and interweave these

fields with relevant mathematical content. We must guide the intuitive, unconscious, global, spontaneous and visual approaches smoothly into teamwork discussions to further argument local logical thinking. On this path, guess and test procedures are necessary intermediate steps to gain a more conscious and systematic overview of the given problem

12. Metaphors and analogies can be used to lead students into an illogical state for situations where rational logic fails. The intention should be for the students to free themselves of "convergent thinking" and to develop empathy with ideas that conflict with their own

13. Teachers should create an environment that will further individual and social components of creativity, like motivation, curiosity, self-confidence, flexibility, engagement, humor, imagination, happiness, acceptance of self and others, satisfaction, success.

WHAT KILLS CREATIVITY?

An alarming fact for educators is the rate at which the enthusiasm of young children for mathematics disappears step by step as they get older (Meissner, 2000). It has been shown that children are generally highly creative, with vivid imaginations, learn by exploring, risking, manipulating, testing, and modifying ideas until they reach school going age (Paul & Kathy, 1990). However, as they enter school, their divergent thinking gradually develops into its antithesis: convergent thinking. Convergent thinking, according to Cangelosi (1996), is reasoning that produces predictable responses from most people. This type of thinking results in a steady decline in curiosity and creative activity during the school years. It appears therefore that, in order to enhance creative thinking, there is need for more curious students who challenge to ask *why?* rather than a submissive group who always says *yes I understand*. Teaching approaches that project mathematics as a rule-based subject (absolutist, discussed earlier) are not conducive to creative thinking. Typically, students' curiosity is stifled in such instances and the most creative minds are discouraged. For more creative students, such classrooms are 'torture zones' because they cannot express themselves. It should be remembered that creative people are unique in their ability to achieve anything. This means that they hardly function optimally under restricted conditions or when things have to be done in accordance with confining rules. It can be seen here that creativity is incompatible with mathematics teaching that does not allow students 'free expression' and exploration.

CREATIVITY AND COMPUTERS IN THE TEACHING AND LEARNING OF MATHEMATICS

It is common knowledge that people use and follow different ways of collecting and organizing information into useful knowledge. Some learn best through interaction with their peers, others accomplish this through lone study and contemplation. Certain individuals, on the other hand, prefer to learn a skill by manipulating concrete objects, watching, listening, or by reading an instruction manual (Cross, 1976). Issues such as time constraints, lack of abundant resources, teachers' experience and so on, make it extremely difficult for any teacher to cater for these individual differences. This situation sometimes results in learning difficulties for some students. To address these, some teachers resort to more or less prescriptive teaching, where rules and the mechanics of teaching are followed. On the other hand, other teachers follow creative teaching, which approaches situations in an unprecedented way.

Paul and Kathy (1990) distinguish between good learning and creative learning. They define creative learning as a natural healthy human process that occurs when people are curious and excited. Good learning, on the other hand, requires students to follow skills such as recognition, memory and logical reasoning, which are the abilities frequently assessed in tests of intelligence and scholastic aptitude (Paul & Kathy, 1990). However, creative thinking and learning involve the ability to sense problems, inconsistencies and missing elements, fluency, flexibility, originality, and elaboration and redefinition (Paul & Kathy, 1990). However, these are abilities that are rarely developed in mathematics classrooms despite "good" teaching intentions. To promote these, mathematics should be viewed differently - as a science of pattern rather than as a set of rules. In this regard students should be given control over what they learn. They should be actively involved in the learning process for knowledge to be meaningful. It has been shown that students prefer to learn in creative ways rather than just memorizing information provided by a teacher or parents and that they also learn better and sometimes faster (Paul & Kathy, 1990; Simonton, 2000). It is our submission that computer can assist teachers in developing a creative learning situation that takes cognizance of individual learning differences. Also, computers can empower and provide to students all the tools necessary for promoting creativity. There is no doubt that the greatest asset a teacher can have is to have access to computer because of its versatility. One of the most important things that preoccupy teachers' time is the preparation of presentable material for their classrooms. With the help of computers, the teacher can effectively address the challenge of organizing mathematics instruction in such a way that it attracts and develops the abilities of the greatest number of students possible (NCTM, 2000). With multimedia capabilities, computers have the capabilities of appealing to our eyes, ears, feeling and taste, and, therefore, can widen and enrich the content and scope of our educational experiences. With this, the individual differences in learning style can be taken care of in an unprecedented way. With computers, students can visualize mathematical concepts which are difficult to comprehend without computers. In a typical classroom, computers provide easier and clearer illustrations than those a teacher would make. As a matter of fact, there are relatively very few teachers that have the time or artistic talent to produce illustrations by "hand with chalk, overhead transparency pens, or marking pens that can compete with those generated with computer" (Cangelosi, 1996:202), or even a graphic calculator. This can be seen in a case of three-dimensional objects for instance. Such objects are difficult to draw on the chalkboard and difficult for students to visualize by the students. With the help of computers and graphic calculators, students themselves may creatively draw three dimensional objects, and also see different view of the object, thus saving teachers' precious and limited time as well as building concrete image of the of the object in students' minds.

Similarly, computers can give students a more self-reliant role in their own education, and make students become more active agents in their education, thus making students independent learners.

It has been shown that computers can simulate projects that teach students teamwork, problem solving, and critical thinking, as well as increasing their enthusiasm for learning. Also, computers give a student access to instructional programs designed with bigger resources, more expertise, and greater talent than can be found on a single campus. It can enrich and supplement classroom instruction that is already available. It can give a student alternative modes of instruction for the same subject.

It has been shown that working with the appropriate computer software can pack a large amount of graphing experience into a relatively short amount of time with the result that students deal with more graphs in class than students typically experience in an entire series of algebra courses (cf. Kaput, 1992, see also Yushau & Farhat, 2003). In a study on the influence of visualization, exploring patterns and drawing generalizations, Nixon (2003) reported that her students indicated visual representation on a computer screen as more beneficial to their understanding compared to diagrams in books.

Motivation is considered a driving force for most human endeavors. In fact motivation has been a major research topic in the area of the psychology of teaching and learning (Perry, Menec & Struthers, 1995). To that end, it has been shown that with the appropriate use of technology, teachers can motivate students to learn both extrinsically and intrinsically (see Cox, 1997). From the student's perspective, the creative potential seems to require "certain exposure to diversifying experiences that help weaken the constraints imposed by (a) conventional socialization and (b) challenging experiences that help strengthen a person's capacity to persevere in the face of an obstacle" (Simonton, 2000:153). There is no doubt that using a variety of technological tools, such as calculators, computers, and hands-on materials, under the guidance of a skillful teacher creates a rich mathematical learning environment. Such an environment helps in exposing and preparing students for diversified experiences (Beal, 1998). This is the exposure that is required and necessary to nurture creativity, a point supported by De Villiers (in press) and Nixon (2003).

One of the factors that limit student creativity in mathematics is the student's inability to recognize and connect mathematical structures and objects in different situations. In this respect, computers have the ability to help students uncover shared and unshared patterns of a class of mathematical objects. For instance, the multiple representation of a function (tabular, graphical, symbolic), is much easier using computers. This in a way exposes students to different sides of the 'mathematical coin' and allows them to see mathematics from different (and seemingly unrelated) angles. Such exposure helps them to visualize, explore and deeply understand mathematical concepts in a spectacular way (Cangelosi, 1996), invariably fostering their mathematical creativity. It is this exposure that informs students that mathematics is not a linear subject and that there are a variety of ways of tackling problems. It also removes pervasive beliefs that the only way of tackling mathematics is by following rules, which in fact kills creativity.

LEARNING MATHEMATICS AS AN ACTIVE (CREATIVE) PROCESS

Bell (1978) outlines four general reasons for people to be motivated to learn in and outside school. These are, "to create things, to make things work, to obtain recognition, and to find personal satisfaction" (p.33). If students are to be motivated and their enthusiasm enhanced, it is important that instruction be flexible enough to create room for creativity to prosper. Computers have the potential of making this a possibility and, as a consequence, develop high levels of motivation necessary for creativity (Cox, 1997). For instance, the intrinsic features of computers such as immediate feedback, animation, sound, active interactive, and individualization are more likely to motivate students to learn than any other media (Yang & Chin, 1996)

Learning is an active process; however, a lot of commonly used teaching strategies pace students in passive and receptive roles. That results in situations where students have very little control, if any, of the learning environment (Bell, 1978). Computers have the ability to enrich the content of students' learning experiences, provide greater flexibility, and give students a more self-reliant role in their own education. In that respect students become more active and involved participating agents in their education. Creativity is a more or less solitary business (Standler, 1998); similarly, learning is more effective and efficient when instruction can be tailored to unique needs of each learner. With the aid of technology, especially computers, instruction can be flexible and adaptable to individual needs. Also student-teacher interaction and learning are significantly more student-centered, thus, creating room for students' optimal functionality-creativity.

Today's students will live and work in the twenty-first century, in an era dominated by computers, by worldwide communication, and by a global economy. Jobs that contribute to this economy will require workers who are prepared to absorb new ideas, to perceive patterns, and to solve unconventional problems (Steen, 1989). Under this dispensation, there is no greater gift that a student can get from school than empowering him/her with the necessary tools to face this challenge. It has been established that good use of computers can empower students to be creative and critical thinkers, and better problem solvers (Kaput; 1992; Roblyer, 1989).

Thinking mathematically is considered (by many people) to be critical for everyday life skills. People use mathematics skills daily to identify problems, look for information that will help solve problems, consider a variety of solutions, and communicate the best solution to others. However, the connection between the mathematics learned at school and the mathematics used in daily life is more often than not missing. To bridge this gap, mathematics classrooms should provide practical experience in mathematical skills that are a bridge to the real world. Also they should allow explorations that develop an appreciation of the beauty and value of mathematics (Beal, 1998). Again the use of computers is a key in bridging this gap. This may be accomplished by providing students with a variety of challenging real life problems that are fascinating, interesting, exciting, thrilling, important, and thought-provoking – a wonderful asset for fostering creativity.

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