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Early Algebra with Graphics Software as a Type II Application of Technology

SUMMARY. This paper describes the use of Kid Pix–graphics software for creative activities of young children–in the context of early algebra as determined by the mathematics core curriculum of New York state. It shows how grade-two appropriate pedagogy makes it possible to bring about a qualitative change in the learning process of those commonly struggling with mathematics by substituting computer-mediated tasks for algebraic tasks. The pedagogy is analyzed along the lines of Vygotsky's theory of using tools and signs in the internalization of higher psychological functions. *[Article copies available for a fee from The Haworth Document Delivery Service: 1-800-HAWORTH. E-mail address: <docdelivery@haworthpress.com> Website: <http://www.HaworthPress.com> © 2005 by The Haworth Press, Inc. All rights reserved.]*

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The teacher must orient his work not on yesterday's development in the child but on tomorrow's.

–L. S. Vygotsky

One of the major themes of today's mathematics education research is the impact of computer technology on K-12 classrooms. This impact was recognized more than a decade ago in an ambitious agenda for teaching mathematics in North American schools presented in the National Council of Teachers of Mathematics' *Curriculum and Evaluation Standards for School Mathematics* (National Council of Teachers of Mathematics, 1989). The *Standards* called for students "to use the computer as a tool for processing information and performing calculations to investigate and solve problems" (p. 8). The position of the 1989 document was advanced in its more recent version *Principles and Standards for School Mathematics* (National Council of Teachers of Mathematics, 2000)–by elevating technology to the status of being a principle: "Technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning" (p. 24). These statements clearly point to the fact that technology brings about significant changes in K-12 mathematics education by raising students' intellectual abilities to higher ground.

One may note that, in a more general context, Maddux (1994) had made a distinction between ways technology can be used in educational applications and advocated for "new and better methods of teaching and learning . . . that would not be available without technology" (p. 31). Maddux argued that bringing technology into education is so expensive in terms of time, effort, and enthusiasm, that the expenditure can only be justified if it brings about a qualitative change in how we teach and learn. Hence the term *Type II applications of technology* was coined. The main feature of Type II applications is that of giving students control of almost everything that happens on the screen, including student-computer interaction. It is through such an interaction that tools of technology can serve as "intellectual partners . . . in order to engage and facilitate critical thinking and higher-order learning" (Jonassen, 1996, p. 9). Through Type II applications of technology, students' cognitive processes and their development can become more visible to the teacher so that the potential for providing help in a social milieu of the classroom can be realized. By the same token, students can assist one another, when appropriate, working in a collaborative learning environment of a computerized classroom (Means, 1994).

This paper describes the use of graphics software with second-graders of a rural school in upstate New York in a highly sophisticated (for that grade level) problem-solving context. Maddux, Johnson, and Willis (1997) defined graphics software as a program that enables one to draw pictures on the computer screen. These authors argued that graphics software can be considered as Type II if its instructional uses stimulate one's active intellectual involvement into technology-enabled tasks and provide opportunities for spontaneous and open-ended interaction with the software. Regardless of grade level, solving nonroutine problems in mathematics is a clear-cut example of such an intellectual activity. Therefore, using graphics software in support of nonroutine mathematical problem solving is a Type II application of technology. This paper shows how one can adapt versatile features of Kid Pix (Broderbund Software, Inc., 2001) for fostering young children's informal mathematical reasoning skills in the context of what may be construed as an early application-oriented algebra. The context was artificially developed through recognizing that various seemingly unrelated, applied problem-solving tasks across the K-12 mathematics core curriculum of New York state are structurally identical and thus can be embedded into a single, grade-two appropriate context. The use of the software by young children is analyzed through Vygotsky's (1978) construct of using tools and signs in the internalization of higher psychological functions.

RECURRING MATHEMATICAL STRUCTURE IN NEW YORK STATE CORE CURRICULUM

Dienes (1960), one of the early advocates for continuity in teaching mathematics, argued that any mathematical structure once introduced is used later in other parts of the curriculum. More recently, Connell (2001) suggested that mathematical thinking of young children in developmentally appropriate (e.g., action-oriented) environments may parallel higher level lines of thought of developmentally more advanced learners. These pedagogical positions are reflected, though implicitly, in a resource guide (New York State Education Department, 1998) that provides guidance to districts and schools in New York state for structuring local mathematics curricula and instruction. Problems 1 through 3 that follow are applied algebra problems found in the guide. Pertaining to the elementary, middle, and secondary levels, respectively, the problems illustrate how the same mathematical structure hidden in diverse contextual situations reoccurs in different parts of the curriculum across grades. Appropriate use of technology can bridge pedagogy of different grade levels. It should be noted that, while teachers are encouraged to use technology in all parts of the curricula, no specific recommendations are provided in the guide in connection with the problems. As will be shown below, the use of graphics software could play a major role in mathematical development of young children, preparing them for participating in more advanced activities as they grow older.

Problem 1 (recommended for grade 2). *A pet store sold only birds and cats. One day the store's owner asked his clerk to count how many animals there were in the store. The clerk counted 18 legs. How many cats and birds might there have been?*

Problem 2 (recommended for middle school). *Julie sold 125 frozen juice bars and 150 ice cream cones on Saturday. She made a total of $500. Julie sold each ice cream cone for $2.25. Write an equation you can use to find the cost of each frozen juice bar. Solve the equation you wrote to find the cost of one frozen juice bar.*

Problem 3 (recommended for high school). *Mary purchased 12 pens and 14 notebooks for $20. Carlos bought 7 pens and 4 notebooks for $7.50. Find the price of one pen and the price of one notebook algebraically.*

Analyzing the three problems, one can recognize that, regardless of context, a similar structure is recurring across grades. It is based on linear combinations of contextually related objects put in two groups according to their specific properties. More specifically, such objects are cats and birds, frozen juice bars and ice cream cones, and finally, pens and notebooks. Three main didactical differences among the three problems can be recognized: the context, the magnitude of the numbers involved, and a number system used at each grade level. This implies that all three problems can be introduced at the primary level provided that the context, magnitude, and number system are grade appropriate. To this end, the following two problems were designed as the conversion of the middle and secondary school problems, respectively, into primary school problems. Artificial names *trimp* and *grimp* given to the creatures are vicarious variables (or informal unknowns–the number of legs that each creature has) to be used at an early elementary level.

Problem 2.1. *Julie, a pet store's owner, sold two types of animals on Saturday; two of them were cats and three of them were some other type of animal. She counted 23 legs. How many legs did the other animal have?*

Problem 3.1. *Mary, a pet store clerk, sold five trimps and two grimps which have the total of 18 legs. Carlos, another clerk, sold four trimps and three grimps which have the total of 20 legs. How many legs does a trimp have and how many legs does a grimp have?*

KID PIX AS A PROBLEM-SOLVING TOOL

Kid Pix is graphics software for enabling creative activities of young children. Used for more than a decade in educational applications (Chan, 1993), it has been recognized as a tool with potential to support curricula in such areas relatively distant from mathematics as language, geography, and art (Ballenger, 1992). Even an overview of multimedia environments for children that is strongly oriented toward mathematics (Druin & Solomon, 1996) does not mention any mathematical activities with the use of the software. More recently, Brown (1998) argued that the software has potential to be applied across the whole spectrum of the curriculum, yet no specific recommendations were provided in support of the statement.

While many Web sites are available that show mathematical activities for young children that can be enhanced by the use of Kid Pix, traditional print publications on this topic are scarce. Lifter and Adams (1997) recommended using Kid Pix in developing basic counting skills (e.g., counting by twos). Clements (1999) suggested that openness and closeness–the fundamental notions of geometry–can be illustrated through the graphics of Kid Pix. Rosaen, Hobson, and Khan (2003) reported on the use of Kid Pix as an environment for visualizing numbers at the kindergarten level. These uses of the software, though meaningful and important for the mathematical development of young children, fall short of a sophisticated problem-solving context and thus do not reach the level of Type II applications of technology.

In the course of preparing technology-rich materials for a field-based elementary mathematics methods course, I found (Abramovich, 2001) that the use of Kid Pix in the context of Problem 1 by young children has potential to reach the Type II level. Based on this earlier finding, the use of Kid Pix was then extended to include mathematical activities presented through Problems 2.1 and 3.1. To this end, by "editing" custom tools of the software a new set of rubber stamps was created. The new stamps (referred to as *trimps* and *grimps*) represented artificial creatures with a number of legs varying in the one through nine range. Four elementary education students familiar with possible mathematical applications of Kid Pix through the above-mentioned course work were assigned to administer these activities as part of their field work at a small school in rural upstate New York with a group of second-graders chosen from a remedial classroom.

Two 60-minute sessions were conducted in a computer lab. The children were familiar with Kid Pix. However, specific skills such as those related to the use of *trimps* and *grimps* were taught as the activities went along. Two children were paired at the computer, the other two worked individually. In both instances, the children worked on a computer under the tutelage of the pre-teachers and were assisted if they could not perform independently. During the first session, this included guidance in reading and interpreting problems, support in keeping the children's frustration from incorrect guessing at a minimum, help in comprehending the notion of a problem with more than one correct answer (Problem 1), and assistance in recalling conditions of a particular problem when the solution created on a computer screen did not satisfy these conditions.

For the second session, a new set of three problems with different numerical data was created. The goal of the second session was to assure that tutoring during the first session, in which children's problem-solving activities were strongly guided, would not result in dependence on the tutor (Bruner, 1964). Thus, assistance in problem solving during the second session was reduced to a minimum. For example, a need for assistance that occurred during the second session dealt with the children's constructing a solution that was based upon data of a problem from the first session. During both sessions, all children demonstrated nontrivial, on-task behavior that can be ascribed to both the enjoyable context of "pet store mathematics" and the user-friendly environment of Kid Pix.

DEVELOPING A SYSTEM IN RESOLVING INDETERMINATE PROBLEMATIC SITUATIONS

How do young children solve problems with more than one correct answer using graphics software? How can problem-solving performance at the elementary level and that at the higher level be connected? What role can graphics software like Kid Pix play in providing young children with "*objects of thought* [that] become the basis upon which later mathematical thinking occurs" (Connell, 2001, p. 160, italics in the original)? In analyzing the children's informal problem-solving strategies in an indeterminate problematic situation (i.e., a situation in which there is more than one correct response), these questions are of particular interest.

During the second session, it was observed that after initial confusion with Problem 1 (in which 18 was replaced by 16), the first (correct) combination of animals that the pair of children working in collaboration had constructed included only cats. In developing the combination on the screen of a computer using Kid Pix, a child was counting the cats' legs one by one. Because of the visible sloppiness in counting, he was advised by the partner to count by twos–an earlier known strategy that perhaps was never perceived as a problem-solving tool by the children. When he successfully completed counting, the partner uttered, "Good boy!" and, taking her turn, affirmed, "I'll use birds this time." Apparently, this intuitive strategy was prompted by the image of the cats on the computer screen and it resulted from the use of Kid Pix as a recording medium. The strategy was not taught during the first session, and it emerged due to the children's intellectual growth that occurred through problem-solving activities.

The analysis of this strategy indicates the presence of rudiments of advanced mathematical thinking in the children's intuitive approach to finding solutions to what in formal terms is a linear indeterminate equation in two variables. Indeed, this approach parallels a formal (geometric) method of solving such an equation in whole numbers that begins with finding two specific points that belong to its graph; namely, the points of concurrency of the graph with the coordinate axes (points with no birds belong to the cats' axis, points with no cats belong to the birds' axis). To complete the solution, one has to find all lattice points that reside on the segment connecting the two points. Such a search for the lattice points can be recognized in the children's suggestions to each other: "Use more cats!" or "Use more birds!" As a result, all combinations of animals (five in the case of the total of 16 legs) were constructed.

This example shows how the emergence of systematic thinking can be found in young children's intuitive strategies and how those strategies can be identified with more advanced lines of reasoning in a formalized context of solving indeterminate equations. It confirms observations by many researchers that young children are capable of powerful mathematical reasoning manifested through their seemingly naive actions upon developmentally appropriate objects of thought (Connell, 2001). Encouraging young children's informal mathematics in a problem-solving situation can help their intuitive thoughts to develop into a formal realization at the secondary level. Yet, revealing these mathematically rich manifestations of intuitive thinking by the children is not an easy task for elementary pre-teachers. Thus, in the context of teacher education, this study can be used to help pre-teachers understand mathematical thinking of young children.

Another episode worth noting is an attempt to advance the strategy of counting by twos to a higher cognitive plane. More specifically, an apparent success in using this strategy as a tool was a turning point. The child developed an insight that led him to inquire: "*How do we count by fours?*" It is clear that counting by fours represents an operation that second-graders were not familiar with; however, such an operation, when mediated by enjoyable context and tools that encourage playful thinking, was developmentally appropriate. In other words, the concept of counting by fours belonged to the child's "zone of proximal development" (Vygotsky, 1978)–a dynamic characteristic of cognition that, in a problem-solving situation, measures the distance between two levels of the child's development as determined by independent and assisted performances. The ability to ask questions indicates one's readiness to go beyond the actual level of development based on earlier experiences with the help of another, more knowledgeable person. Apparently, "[b]y asking a question, the child indicates that he has, in fact, formulated a plan to solve the task before him, but is unable to perform all the necessary operations" (Vygotsky, p. 29). Although assistance in counting by fours was not provided at that point, had it occurred, it could have been described as assisted performance at those points of the zone where assistance is required. Note that such an assistance is what Tharp and Gallimore (1988) have conceptualized as teaching. Overall, this episode shows how learning to perform higher cognitive functions can be motivated by Type II applications of technology.

DEVELOPING SKILLS IN USING ALGEBRAIC SYMBOLISM

Another interesting finding that resulted from this study is the ability of second-graders to move with relative ease from representing a problematic situation through graphics (iconic representation) to its representation through written symbols. The traditional approach to applied algebra problem solving is to start with writing equations (mathematical models) and continue with solving these equations using strictly defined rules of mathematics. Such an approach is not possible until higher grades. Furthermore, the grasp of the deductive structure of moving from general to specific (i.e., from an algebraic equation to its numeric solution) is often extremely difficult for learners to follow because of the technical complexity of the correct application of mathematical rules. In the context of Problems 2.1 and 3.1, children were moving in the opposite direction by being led into the use of symbolism through drawing. A question to be answered in this section is: How was that achieved?

To this end, note that one can distinguish, using Vygotsky's (1978) terminology, the introduction of "first-order symbols . . . directly denoting objects of actions, . . . [from] . . . second-order symbolism, which involves the creation of written signs for the spoken symbols of words . . . [and] develops [by] shifting from drawing of things to drawing of words" (p. 115). Indeed, whereas variables were introduced to children as first-order symbols–a notation that reflects quantity associated with objects of their actions, equations that relate these variables to each other were introduced as second-order symbols–a notation that reflects relationships among the quantified objects. Kid Pix, or any graphics software, provides young children with tools capable of making a shift from using first-order symbols to acquiring second-order symbolism. It is through meaningful play that children can move from creating graphics-based solutions of problematic situations to writing true algebraic equations (mathematical sentences) that rigorously model the situations. A practical implication of the approach of teaching second-order symbolism through play is that it can be done earlier than usual–a recommendation by Vygotsky (1978) for the teaching of writing. Such a recommendation can be extended to other school subjects, including algebra. Indeed, the construction of equations as symbolic representations of concrete situations can be introduced early in mathematics education provided that appropriate computer tools, like graphics software, can accommodate children's move from drawing objects of actions to drawing symbolic relations that quantitatively describe these objects.

The use of Kid Pix enables young children to develop functions of both first- and second-order symbolism by using "talking" letters and numerals as elements in a support system. The success in developing these functions by the children using Kid Pix can be explained in terms of the "method of double stimulation" (Vygotsky, 1962, p. 56). Indeed, one can note that in the course of moving from icons to symbols, two sets of stimuli were involved: The first set included rubber stamps of letters/numerals as objects of the children's activity, and the second set included verbal representations of the stamps that were employed to mediate the activity. "Talking" letters/numerals represent a sign system that served as an enhancement of young children's internal speech.

Thus, in the mediated process of writing mathematical sentences, "the child is able to include stimuli that do not lie within the immediate visual field" (Vygotsky, 1978, p. 26). In this, Vygotsky insisted on the importance of semiotic mediation (i.e., mediation by artifacts) in the development of human consciousness.

As an illustration, consider the problem-solving context of Problem 3.1. It was found that a second-grader from a remedial classroom was capable of implicitly solving a system of simultaneous equations "via actions upon developmentally appropriate objects" (Connell, 2001, p. 161) and then explicitly representing this system through the use of meaningful (to her) symbols *T* and *G* associated with artificial creatures *trimps* and *grimps*. The trial-and-error approach, which was not directly taught to the children but rather emerged as an intuitive problem-solving strategy, enabled the child, in fact, to solve the system of equations as a physical activity by partitioning 18 objects into five groups with one cardinality and two groups with another cardinality and then, using the same grouping principle, partitioning 20 objects into four and three such groups. This partitioning perspective may be considered a method of solving systems of two simultaneous equations in whole numbers, something that is not commonly taught even at the secondary level. In such a way, a partitioning problem-solving strategy developed with the help of graphics software can be adapted as a formal method for solving high school algebra problems.

To conclude this section, note that, despite overall success in resolving the partitioning brainteaser, a challenge for the child was to recognize the fact that, if the first partition is a correct one, then the second partition should not involve trial and error but rather a check-in strategy. More specifically, if from the pictorial representation of the partitioning of 18 legs, it follows that a *trimp* has two legs and a *grimp* has four legs, one may develop the second combination of creatures by testing whether four and three such *trimps* and *grimps*, respectively, give the total of 20 legs. This kind of reasoning, however, has not been observed; apparently it was beyond the ability of the child.

CONCLUSION

The use of graphics software in the context of activities described in this paper enabled multiple pedagogical ideas to be used. One such idea was to demonstrate that graphics software is an appropriate tool for enhancing early algebra curriculum. In the last two decades, many authors focused on the role that *graphing* software could play in the teaching and learning of algebra. In particular, Kaput (1989) anticipated significant changes in what it means to solve an equation as a result of using such technology. As this paper has described, a meaningful change can emerge from the appropriate use of *graphics* software also. While computers could not and should not replace students' abilities to solve algebraic equations in a traditional way (i.e., through the use of formal rules of algebra), exploring "new ways of thinking about actions on equations" (Kaput, p. 181) at the elementary level has potential to raise cognitive abilities of young children to higher ground. Furthermore, through the use of graphics software, several informal problem-solving skills that can be adapted at the secondary level can naturally develop.

Another pedagogical idea behind the activities was to show pre-service teachers (participating as tutors) how to orient computer-mediated instruction to enhance the development of residual mental power (i.e., something that remains in the mind when a support system is removed) in young children that can be used in the absence of a tutor. In general, the goal of such pedagogy is to ensure that today's collaboration with a more knowledgeable other could result in a zone of proximal development and thus would facilitate an independent performance tomorrow (Vygotsky, 1987). As Berg (1970) noted, although Vygotsky did not make clear how instruction could use the zone of proximal development, "he would perhaps recommend that teachers and pupils work together to solve problems and to do activities that pupils couldn't do by themselves. The teachers' job would be to provide cues and clues to help the pupil over hurdles he couldn't get over himself" (p. 385). It is precisely this kind of pedagogy that was learned first hand by preteachers through their practicum.

It should be noted that the described use of graphics software as a tool for doing mathematics made it possible to substitute computer-mediated tasks for algebraic tasks so that for those commonly struggling with mathematics, the unity of content and pedagogy was particularly advantageous. This pedagogical approach brings about a qualitative change in a learning process through the use of computers, and thus it represents a clear-cut example of a Type II application of technology. As this paper has demonstrated, by using various tools and features included in an expanded software repertoire, young children were able to represent mathematical situations at different levels of sophistication and grow intellectually as activities went along. The fact that the children were able to self-structure and–most importantly–goal-organize their problem-solving activities while mediating them by tools and signs of the software, is a testimony to their intellectual growth (Berg, 1970). I believe that such growth is due to pedagogy that introduces early algebra into a mathematics classroom, and thus enhances tomorrow's development of these young children.

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