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ABSTRACT

This paper presents the theories of L.S. Vygotsky as a conceptual framework for implementing instruction that supports concept development and promotes higher level thinking skills in students. Three major components (i.e., language, scientific and spontaneous concepts, and the zone of proximal development) of Vygotsky's socio-cultural-historical theories of learning are considered. The relationship of these components to the commonalities evidenced in the mathematics and science standards that suggest the efficacy of integrated curricular activity are then discussed. Next, the characteristics of computer-mediated communication (CMC) are presented, and the rationale for its use in an integrated mathematics and science curriculum is discussed. Finally, a current project is outlined that uses CMC as a facilitating technology for an integrated fifth-grade mathematics and science curriculum that is consistent with both a Vygotskian approach to learning and the mathematics and science standards. (Contains 41 references.) (MES)

INTEGRATING SCIENCE AND MATHEMATICS CURRICULA USING COMPUTER MEDIATED COMMUNICATIONS: A VYGOTSKIAN PERSPECTIVE

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Abstract

Computer -mediated communication technology provides a potential tool for facilitating an integrated science and mathematics curriculum consonant with current standards. This paper presents the sociocultural theories of L. S. Vygotsky as a conceptual framework for implementing instruction that supports concept development and promotes higher level thinking skills in students.

ED 436 144

Introduction

Mathematics is the language of science (Steen, 1994), and as such, mathematical understanding becomes a requisite for scientific literacy. The American Association for the Advancement of Science (AAAS) (1989) has identified the *scientific endeavor or* the *scientific enterprise* as a composite of the dynamic interrelationship of science, mathematics and technology. Each component involved in the scientific endeavor has its own character and history, yet each share relevant similarities, and each is dependent upon and reinforces the others. It is the similarities and interdependencies among the components of the scientific endeavor that suggest the efficacy of a blended or an integrated curriculum.

By extending the application of Vygotsky's theories to a technology facilitated model of an integrated mathematics and science curriculum, this paper will build on a previous work that examined the application of the sociocultural theories of L.S. Vygotsky in the implementation of technology in the mathematics curriculum (Harvey, & Charnitski, 1998). In this paper we will first consider three major components of Vygotsky's socio-cultural-historical theories of learning, and then discuss the relationship of these components to the commonalties evidenced in the mathematics and science standards that suggest the efficacy of integrated curricular activity. Next the characteristics of computer-mediated technology (CMC) will be presented and the rationale for its use in an integrated mathematics and science curriculum will be discussed. Finally, we will outline a current project that uses CMC as a facilitating technology for an integrated mathematics and science curriculum that is consonant with both a Vygotskian approach to learning and the mathematics and science standards.

Vygotsky's Theories of Sociocultural Learning

On a continuum of learning theory, Vygotsky's socio-cultural-historical theory lies between the poles of formalism and constructivism (Kozulin, 1990; Moll, 1990; Vygotsky, 1986; Wertsch, 1985). According to Vygotsky (1978, 1986,1997; Vygotsky & Luria, 1993) concept formation is an ongoing interaction between the concrete and the abstract dimensions that (contrary to constructivism) does not require that the child reinvent information, and (contrary to formalism) does not expect the child to form abstract conceptualizations without first having engaged in concrete activities that support the formation of mental models. Three foundational ideas of Vygotsky's theories are language, scientific and spontaneous concepts, and the zone of proximal development.

Language

Vygotsky (1986) contended that language is an indispensable requisite for all intellectual growth and that the attainment of real concepts is impossible without words. Concept formation is "...not an isolated, ossified, changeless formation but an active part of the intellectual process constantly engaged in serving communication, understanding and problem-solving." (p. 98)

He argued that the language of adults and others which surrounds the child is a major factor in the child's cultural and social environment. This immersion in language influences the content of the child's thoughts and determines how the child thinks (i.e., the interpretation or framing of information). Vygotsky did not isolate verbal interchanges with adults as a separate component in the process of a child's concept formation, but rather stressed the essential interrelationship between sensory material and words as mutual components of a child's concept development.

Two critical observations Vygotsky (1986,) made were that: (a) the role of a child's speech is equally as important as the role of action in attaining a solution to a problem; and (b) as situations demand more complex and indirect actions in finding a solution to a problem, speech plays a more important role in the solution process as a whole. Vygotsky considered conceptual thinking as arising from a need to solve problems, and judged words to be the tools or the means that direct mental operations and focus their attention toward the solution of a problem.

Spontaneous and Scientific Concepts

Vygotsky (1986, 1997) identified two types of concepts, *spontaneous* and *scientific*, that he distinguished by geneses. According to Vygotsky, spontaneous concepts are those concepts formed by the child through everyday exposure to the cultural environment in which he or she lives; as such, spontaneous concepts are typically unsystematic and highly contextualized. Scientific concepts, on the other hand, are mediated through formal instruction, are typically derived from the structured activity of classroom instruction, and are hierarchically and logically organized.

The essence of Vygotsky's approach to instruction is found in his contention that, while characteristically different, spontaneous and scientific concepts are mutually supporting structures. Spontaneous concepts give body and vitality to scientific concepts and scientific concepts raise spontaneous concepts to the level of conscious and deliberate use. Vygotsky (Davydov, 1990; Ratner, 1991; Schmittau, 1993, Vygotsky, 1986, 1997) maintained that formal concepts (scientific concepts) learned in school must be connected with the child's understandings (spontaneous concepts) that result form their everyday experiences.

Zone of Proximal Development

Contrary to tenets of traditional cognitivist thinking, Vygotsky (1978) argued that a child's developmental level should lead instruction. He maintained that a child's mental age should be viewed as a starting point for determining instruction, and that instruction should be configured in a manner that facilitates a child's movement forward through his or her *zone of proximal development* (ZPD). Vygotsky defined the ZPD as the area that lies between a child's actual mental age (i.e. his or her level of independent functioning) and the level of problem solving that the child is able to reach with assistance. Simply stated, with adult mediation the child can accomplish more than he or she would be able to accomplish independently.

The child's movement through his or her ZPD is supported by verbal communication and collaborative interchange with an adult or with a more competent peer. As the child becomes more capable of independent thinking, the child's state of development rises. As the child's developmental level increases, mediation can reach toward a higher instructional level, thus, instruction leads development.

Movement through the ZPD involves intelligent, conscious imitation, which requires that the child first understand the field structure and relationships between objects. Imitative behavior that is characteristic of movement through the ZPD should not be confused with automatic imitative behavior that shows no signs of conscious understanding.

Similarities Between Mathematics and Science

Mathematics and science are intellectual and social undertakings that share the underlying ideals of order; honesty and openness in reporting; peer review and outside validation of work. NAAS (1989) stated that proficiency in both the mathematics and science disciplines requires extensive student experience using relevant principles to solve problems, to communicate ideas, and to connect and generalize concepts. Participants in mathematical and scientific enterprises require imagination as they apply their human intelligence to figuring out the workings of the world and its myriad of connections.

The standards established by the National Council of Teachers of Mathematics (NCTM, 1989, 1991,1995) and the National Research Council (NRC, 1996) have given direction to the current reform efforts in the area of mathematics and science education. According to Steen (1994) the following are the similarities between the Standards for School Mathematics (NCTM, 1989) and the National Science Education Standards (NRC, 1996):

- both advocate a significant shift away from the "filter" model of education by raising expectations for all student learning
- both argue for more depth, understanding, and thinking and less memorization, mechanics, and mimicry
- both advocate active learning, increased collaboration, discussion, exploration, and "student talk" and less rote learning, decreased deference to teacher & text as sole authorities and sources of validation
- greater reliance on performance-based instruments that are coordinated with the curriculum and embedded in instruction and viewed as a recursive and reflective process
- both advocate full use of technology as a means and as a goal of instruction

Vygotsky's theories imply a multidimensional, holistic approach to learning; the same type of learning that is prescribed by both the mathematics and science standards, and required by the prerequisite skills for discipline involvement. Learning experiences consistent with a socio-cultural-historical approach are steeped in meaning-making colloquium, connectivity, and multi-layered or multi-tasked instruction (i.e., instruction that engages participants in subtasks at different cognitive levels, each of which contribute to a larger common task). Both sets of standards are aligned with Vygotsky in their imperative to position conceptual learning over memorization and automatic mimicry, situate content in leveled tasks, and engage students in support collaborative and cooperative enterprises. Agreement also exists in the proposition that the conceptual learning of the mathematics and science disciplines requires learners to be actively engaged in contextualized, authentic, problem-based learning that is facilitated and guided by the teacher. In this learning context, students are characterized by their participation in meaningful communication and, and interactive engagement with educational facilitators, with each other, and with their environment.

The Role of Computer-Mediated Communication

The very nature of our technologically driven society elevates the status of collaboration and connectivity in the processes of gathering, applying and sharing information in the learning process. The growing availability of computer mediated communications (CMC) in the school setting introduces new tools that provide extensive opportunity for curricular integration of authentic activities, engagement in outside collaboration, access to vast databases of information, and efficient and economical means of information dissemination, sharing, and validation.

The NSF issued a joint document with the U. S. Department of Education (1995) which stated that the appropriate use of technology has the potential to improve teaching and learning; expand and enrich opportunities for learning; link schools and learning sites to provide students access to the broader society; and provide equal access to educational opportunities.

Computer Mediated Communication (CMC) is an all-inclusive term that embodies technologies that mediate communication between and among individuals and groups of individuals. Subsets of CMC would include but not be limited to e-mail, the World Wide Web (WWW), listserves, and online searchable databases.

Riel (1996) asserted that computer-mediated communication (CMC) is a tool that can narrow the gap between collaborative and/or cooperative experiences and traditional formal instruction. Scott (as cited in Jonassen, 1996) evidenced that students working in groups through CMC participated more evenly, and accomplished more task objectives than students not using CMC.

The nature of asynchronous communications allows participants a delayed time frame that is generally not afforded in the traditional classroom setting. Romiszowski (1997) contended that this window of time may serve to enhance reflective thought and encourage participation. The author maintained that CMC is "...most promising for the development of the reflective thinking and creative planning skills that are required to close the gap between information and performance in knowledge work." (p. 33)

Kahn (1997b) characterized CMC as an interactive, open system that offers global accessibility that is distance and time independent. He further noted that CMC offers a high degree of learner control and environmental flexibility. CMC can support both formal and informal learning environments (McLellan, 1997), collaborative learning (Hiltz, 1994), and has the potential to extend cooperative and collaborative learning experiences to every classroom that is connected to the Internet (Relan, & Gillani, 1997).

Shneiderman, Alvai, Norman and Borkowski (1995) stated that " The low cost and flexibility of e-mail and Web usage means these technologies are likely to become universal..." (p.41) They liken e-mail to the personal automobile as a means of information transportation; most people will have it and use it daily. Listserves and Web sites they compare to commuter trains; large numbers of people will use it regularly to get to specific locations.

Sabelli (1995) stressed the need for the incorporation of advanced technology in the classroom environment. She asserted that as the affordability of powerful networked technologies increases, educators must assume responsibility for the profound pedagogical implications of change these technologies bring into the areas of science, mathematics and engineering. Sabelli contended that when technologies are properly used in the instructional process, they have the potential to make science and mathematics more understandable and attractive to an increasing number of students.

Computer technology has changed the way society thinks, works, studies and plays. Although Vygotsky died long before our current state of technological advancement was even dreamed of, he provided a theory in which the everyday experiences (i.e., spontaneous concepts) of the child weigh heavily. Computer technology is a part of the child's everyday experiences, from talking cash registers and digital scanners in grocery stores to video games and surfing the net. Accordingly, instruction should be tied to these everyday experiences.

The increasing access to CMC and its collaborative, flexible nature appear to make it a viable instructional tool for the implementation of activities that are consonant with both the curricular disposition and discourse promoted by the mathematics and science communities and with Vygotskian theory.

Curriculum Integration

While effective curriculum integration involves a great deal of time to plan and implement (Brant, 1991; Dressel, 1958; Jacobs, 1989; Palmer, 1991), the effects on student learning appear to make it well worth the invested effort (Levitan, 1991; MacIver, 1990). Lipson, Valencia, Wixson, and Peters (1993) asserted that the positive effects on students who engage in appropriately integrated curricula include: (a) more robust application of skills; (b) faster retrieval of information; and (c) increased depth and breadth of learning.

Palmer (1991) listed the essential elements of an integrated curriculum as: (a) core skills and processes; (b) curriculum strands and themes; (c) major themes; (e) questions; (f) unit development; and (f) evaluation. Mathematics and science emphasize the following common skills and processes that directly affect methodology in both disciplines (Berlin & White, 1994; Davidson, 1995; NCTM, 1989; AAAS, 1989):

- observing
- collecting, recording, and organizing data
- recognizing time/space relationships
- communicating
- interpreting data
- graphing
- predicting

While the literature is replete with examples of CMC's use, or potential use in classrooms across the world (e.g., Dede, 1996; Jonassen, 1996; Goldberg, & Richards, 1995; Kahn, 1997a; Morrison, & Goldberg, 1996), we will discuss the organization of a project in which we are currently involved as an example of how curriculum and methodology may be blended in mathematics and science.

The goal of this project is to have fifth grade middle-school students recognize and apply their existing and emerging mathematical repertoire to a science unit on weather. The students are heterogeneously grouped, and the project is structured to allow students to engage in collaborative ventures that contribute to a cohesive, communal product from multi- leveled and topic-divergent activities. Evaluation is formative and based on teacher-constructed, and teacher and class-constructed rubrics. This project is configured to incorporate Palmer's (1991) six essential components of integrated curricula.

In the beginning of the project, students engage in three concurrent activities: (a) learning basic weather concepts such as types of clouds, rain, snow, fog, windspeed through a variety of hands-on experiments; (b) exploring diverse geographical areas using the World Wide Web which includes recording each site's map location (including longitude and latitude), defining topographical features, seasonal cycles, and identifying characteristics, and (c) subscribing to relevant listserves.

While learning about basic weather concepts, students explore the situational measurements of latitude and longitude. They will then place various locations according to their latitude and longitude coordinates. Students may also relate latitude and longitude to things such as seasonal cycles, overall weather patterns, and time zones. *(recognizing time/space relationships)* After discussing and sharing the preliminary information collected, the students come to consensus on how this information should be categorized, and hierarchically organized. *(communicating; collecting, recording, and organizing data)*

During the next phase of the project, each students group will select a specific geographical area of interest and begin to collect previously agreed upon weather data (e.g., wind speed, temperature, precipitation, wind-chill, heat index) and other relevant information from one of the many weather sites found on the Internet (e.g., WeatherNet at http://cirrus.sprl.umich.edu/wxnet/), as well as from newspapers, periodicals, radio, and television (e.g., The Weather Channel). Students will also use other weather information tools easily found on the Internet such as weather-cams, (e.g., http://cirrus.sprl.umich.edu/wxnet/wxcam.html), related software (e.g., http://cirrus.sprl.umich.edu/wxnet/software.html), computer forecast models (e.g., http://cirrus.sprl.umich.edu/wxnet/model/model.html), weather satellite transmissions (e.g., http://www.intellicast.com/weather/mem/nexrad/), and weather-sites *(observing; collecting and recording data; interpreting data)*.

Group data on each geographical area will be entered into databases and/or spreadsheets. Graphs will be constructed as well as other visual representations that will help each group communicate their data to the other student researchers (*communication*; *graphing; interpreting data).* When sufficient background information has been collected on the different geographical locations, the students will bring their data to the whole class at which time the all of the student-researchers will discuss, compare and relate findings (e.g., Buffalo, New York and Grand Rapids, Michigan may be experiencing similar amounts of snowfall due to the lake effect) (*communication, interpreting data, make predictions*). During the final phase of instruction, students will follow major weather fronts and make weather predictions based on their accumulated knowledge and past observations.

Conclusions

There appears to be growing acceptance by educators of both the views of curricular content and student discourse promoted in the Mathematics and Science Standards (Chang-Wells, & Wells, 1993; Cobb, Wood, & Yakel, 1993), and of Vygotsky's theories of the socio-cultural nature of learning (Tharp & Gallimore, 1988). The American Psychological Association (1995) stated that environmental factors such as culture, technology, and instructional practices along with social interaction have substantial influence over learning. Bonk and Thomas (1997) asserted that there is increased agreement among educators that meaning is found in the process of negotiation and knowledge-building in a social context. Curtis and Reynolds (1997) stated, "The learner-centered movement has encouraged instructors to create challenging and novel environments that help learners link new information to old, seek meaningful knowledge, and think about their own thinking." (p. 167)

CMC is a tool that appears to hold significant promise for supporting teachers' efforts in this direction. The defining characteristics of CMC and its unique ability to extend and to enhance semiotic exchange make it a potential vehicle for supporting integrative classroom environments that are consonant with the mathematics and science standards and Vygotskian theory relative to language, spontaneous and scientific concepts, and the zone of proximal development.

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