The Ideal Science Student and Problem Solving

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Abstract: We examined the nature of students' social mental models of the ideal science student, whether or not these models vary with student ethnicity, and the relationship of these models to problem solving strategies used, and problem solving ability in a robotics challenge. Participants were twenty-six, academically advanced, eleven and twelve year olds. Two social mental models were identified, a traits-based model and a robust model. While models do not appear to vary with ethnicity, a significant association was found between model group and strategy usage ($p = .032$). In addition, the robust group achieved higher scores on their final solution than the traits-based group ($p = .03$). The robust group made excellent use of the tools in the environment to solve the problem. The traits-based group did not. The robust group evidenced an environmental view of learning. The traits-based group displayed a mental representations view of learning.

Problem solving has been identified as an important aspect of student learning in science and technology and in the development of scientific literacy (National Research Council, 1996). Social factors, such as student beliefs about what it means to be an ideal student and their implicit theories of personality appear to influence student academic activity, problem solving approaches, and achievement (Dweck & Leggett, 1988; Hogan, 1998; Lunenberg & Vollman, 1999). However, these social factors have not been a focus of science education research (Patrick & Yoon, 2004). Indeed, many investigations of student problem-solving in science focus on either cognitive factors (e.g., Chang, C.Y., 2002; Dhillon, 1998; Reid, N. 2002;), or on students' science epistemological beliefs (e.g., Hammer, 1995; Lin & Chiu, 2004). Consequently, we know little about the specific relationship of social factors to student problem solving activity and achievement in science. The purpose of this study is to address this lack of knowledge by examining the relationship of middle school students' social mental models of the ideal science student to their problem solving activity and achievement in a robotics environment.

Social Mental Models

A social mental model is defined as an individual's understanding of the functioning of society and societal entities. For most children in the developed world, school is the dominant societal entity in their lives. Students' social mental models of school are developed by participation in school (Hatano & Wertsch, 2001), and they appear to be influenced, in part, by teachers (McRobbie & Tobin, 1996), other students (Cashmore & Goodnow, 1985), the classroom environment (Ames & Archer, 1988), the school environment (Buchanan-Barrow & Barrett, 1996), and parents (Smith, 1982). Students create a social mental model of the school as a dynamic system that includes not only individuals, but also rules, roles and distributions of power and authority that govern the relationships of the individuals in the school system (Buchanan-Barrow & Barrett, 1998). Researchers have investigated student social mental models from two perspectives, the ideal student construct and implicit theories of personality research.

The Ideal Student

What is meant by the term "ideal student?" According to Durkheim (1972/1922), "…every society sets up a certain ideal of man" (p. 203); he argues that members of the society come to share this ideal, to a certain degree, through the mechanism of schooling. Durkheim (1972/1922) argues that one of the purposes of education is to instill in the members of a society the ideals of that society. Further, he reasons that the values of varying societal groupings will affect the ideals held by members of these groups. Therefore, while a general societal ideal exists, variations in the ideal develop as a function of specific positional differences in societal groupings.

Ideal student research has been limited and it has primarily focused on identifying variations in social mental models of the ideal student (Cashmore & Goodnow, 1985; Lin & Schwartz, 2003; Ten Dam, 1995). As Durkheim (/19721922) predicted, the "ideal" is not defined singularly or even similarly by individuals residing in the same society. Indeed, researchers have found that student social mental models of the ideal student appear to differ based on age, country of origin, gender, and school type (Cashmore & Goodnow, 1985; Lin & Schwartz, 2003; Lunenberg & Volman, 1999; Ten Dam, 1995). Lunenberg and Volman (1999) also investigated the relationship of students' social mental model to their classroom activity. The researchers found that students who viewed the ideal student as a passive receiver of knowledge from the teacher, behaved in just this fashion in class.

Given the small number of existing studies, it is not possible to draw strong conclusions about the variation in and effect of student social mental models of the ideal student on learning activities. However, there is evidence that models vary based on societal positioning and that social mental models may be aligned with subsequent learning activities. Therefore, we hypothesize that students with varying societal positioning will have varying social mental models of the ideal science student and these variations in models will be associated with variations in learning activities.

Implicit Theories of Personality

The second perspective from which students' social mental models have been investigated is through their implicit theories of personality. Implicit theories of personality are naïve theories that each of us develop as a result of everyday lived experience; we use these theories to explain the behavior of self and other (Bennet, 1993; Moscovici, 1981). A students' social mental model of the ideal student may be considered a specific instance of their implicit theory of personality (Dweck & Leggett, 1988). In other words, the ideal student construct is related to the notion of an implicit theory of personality inasmuch as it represents the student's model, shaped by everyday societal experience, of a specific personage and the behavior governing attributes this personage will possess.

Dweck & Leggett (1988) present a research based social-cognitive model of motivation and personality that is offered as an approach to understanding the relationship of students' implicit theories and motivation to problem solving and achievement. The model posits students' implicit beliefs about the nature of intelligence as related to their subsequent learning goal orientation, problem solving strategy use, and achievement in the classroom. In this model, Dweck & Leggett (1988) have defined two beliefs that students might hold: the belief that intelligence is a fixed trait (entity theorists), and the belief that intelligence can be increased through effort (incremental theorists). Researchers have investigated Dweck and Leggett's model and it has garnered empirical support (Ablard, 2002; Leonardi and Gialamas, 2002). For instance, Stipek & Gralinski (1996) found that students who endorse entity beliefs are more likely to adopt performance goals and to use "superficial learning strategies that undermine their achievement" (p. 404), than their incrementalist counterparts.

Domain Specificity

Dweck & Leggett (1988) reasoned that their model might be useful in understanding behavior in domains other than intelligence. Subsequent research has produced mixed results regarding the cross-domain generality of beliefs (Bempechat, London, & Dweck 1991; and Stipek & Gralinski, 1996). For instance, Bempechat, et al., (1991) report that fourth and fifth graders held different beliefs in the different domains of intelligence, sociability, physical skills, and physical appearance. For example, an individual may hold an entity view about intelligence but an incremental view about sociability. Meanwhile, Stipek and Gralinski (1996) found that elementary school students in their study did not hold differentiated beliefs about the nature of intelligence in regards to the academic domains of math and social studies. Based on these studies, it remains unclear as to whether or not students' implicit theories about intelligence vary by domain.

Much research regarding students' beliefs about intelligence has been conducted using forced choice questionnaires. There are two problems with this approach. First, when using forced choice questionnaires the student-generated viewpoint is left out (Quihuis, Bempechat, Jimenez & Boulay, 2002). Second, forced choice questionnaires present hypothetical situations that a student might face. Presenting decontextualized, hypothetical situations to students may not indicate their actual beliefs or reveal the actual actions they would undertake when confronted with a real problem-solving activity (Schunk, 1995). There is a need for more field-based research into students' beliefs and behaviors that focus on actual problem-solving activity, not self-reports of what one might do in a given situation. Additionally, this research should occur in a more diverse learning environment as much of the present data has been collected from white, middle class students (Quihuis, et al., 2002).

The research undertaken in this study addresses these issues by investigating the domain specificity of student social mental models of the ideal science student using an open-ended questionnaire. Furthermore, it examines the relationship of these social mental models to problem-solving activity and achievement in a more ethnically diverse, authentic robotics problem-solving environment. This study advances our understanding of the relationship of social factors to problem solving in science.

Methods

Three over-arching research questions are investigated in this study: 1) what are student social mental models of the ideal science student? 2) Is there a relationship between varying social mental models and student ethnicity? And 3) How are students' social mental models of the ideal science student related to student problem solving and achievement in the robotics environment?

The data for this study was collected at one of the Center for Talented Youth's summer camp programs. The students in the study are considered academically advanced based on their scores on standardized tests. Participants attended either of two three-week long, intensive summer robotics sessions. Twenty-six eleven and twelve year-old students participated, 22 boys and four girls. Fourteen of the participants were white (12 boys and two girls), nine were Asian American (eight boys and one girl), and three were bi-cultural students (two white and Middle Eastern – one boy and one girl), and (one white and Native American boy). Socio-economic status was not available; however, the camp was expensive and none of the students were receiving scholarship assistance.

The research design was correlational and observational. Students completed two questionnaires on the first day of class, a demographic survey and the Ideal Science Student survey. This survey asked students to write five qualities the ideal science student would have. In the last week of both sessions, each student individually engaged in a robotics problem-solving activity that was videotaped. Students were instructed to think-aloud during the problem solving session. The robotics challenge was as follows: The robot must follow a black line on the track provided. When it bumps into an object, it will back up six inches, make a complete 360-degree turn and stop.

Robotics, in this study, refers to the RCX microprocessor created at MIT, the Robolab software program created at Tufts University, and the Lego Mindstorms kit. The use of specific tools is an important aspect of problem solving in robotics. In this study, the students had available in the task environment a paper track (with a ruler inscribed on it), the microprocessor, input sensors, various structural resources (i.e. different sized wheels, different Lego pieces, etc.) and the Robolab program itself.

Results

Social Mental Models

Quantitative content analysis (Chi, 1997) was used to analyze the responses on the ideal science student survey. Two graduate students were trained on the use of the codes with the data and interrater reliability was achieved at k = .86. All coding disagreements were resolved through discussion. Four categories of response were identified: 1) learning strategies and performance; 2) classroom order and discipline; 3) motivation, interest and effort; and 4) personal traits. Learning strategies and performance refers to responses that focus on external and outcome oriented academic aspects of classroom behavior. Classroom order and discipline refers to responses that focus on external, non-academic, orderly student behavior in the classroom. Motivation, interest, and effort refer to responses related to student internal motivation and interest in science, and their external effort in the science classroom. Personal traits refer to internal personality traits that a student may possess.

Two primary social mental models of the ideal student emerged from the analysis of the category responses, a traits-based social mental model group with responses falling primarily in the traits category and a group with a richer social mental model whose conception of the ideal science student included not only personal traits, but also motivational, behavioral, and learning strategy and performance aspects. Students with this fuller and richer view of the ideal science student are termed the robust social mental model group. The traits and robust categories are similar to those reported by Bempechat et al., (1991). They found that students categorized as entity theorists were likely to use trait terms as evidence to support their attributional judgments, and fifth grade students categorized as incremental theorists were likely to use action or process terms as evidence to support their attributional judgments of behavior. Therefore, our categorization aligns with the findings of previous researchers.

We systematized the classification of the students into one of these two groups by developing a metric that could be applied to each case. The metric developed for determining classification in the traits-based social mental model group is as follows: 1) the majority of responses to the ideal science student survey (at least 60%) must be categorized as a personal trait response; and 2) all responses must fit into just two categories overall, the personal traits category and one other category. Using these criteria, ten students were classified as having a traits-based model. The metric developed for classifying students as having a robust social mental model of the ideal science student is as follows: the responses are categorized in at least three of the four response categories. Therefore, none of the categories receive a majority of responses. Fourteen students were classified as having a robust social mental model. Using these metrics, two students of the 26 students fit into neither classification. Both of these students were male; one is Asian American, the other white. Of these two students, one had primarily motivation, interest and effort responses, and the other student had mostly classroom order and discipline based responses. These two students were dropped from further analysis.

Social Mental Models and Ethnicity

Of the 24 students who remained in the study, eight of the students are of Asian American descent, 13 of the students are white, and three of the students have bi-cultural backgrounds (two are middle-eastern and white and one is Native American and white). Chi square analysis of student ethnicity and social mental model group membership revealed no association, x^2 (2, n =24) = 2.479, p = .290.

Social Mental Models and Problem Solving

Descriptive written logs of student activity during problem solving were created through multiple viewing of the videotapes. The unit of analysis was shift in activity (Jordan & Henderson, 1995). A shift in activity refers to an attentional shift from one element or task in the challenge to another element or task. The transcripts were analyzed to identify the problem solving strategies students used to solve the challenge. Five domain specific strategies and four domain general strategies were derived from the viewing of the videotapes.

Domain specific strategies are ones that derive from the domain itself. As previously mentioned, robotics is a tool-intensive activity. Therefore, most of the domain specific strategies deployed in a robotics environment regard use of the available tools. The strategies thus identified were: 1) measure with ruler on map; 2) take light readings with the light sensor; 3) simulate the movement of the robot; 4) use the Robolab context-sensitive help; and 5) make structural adjustments with Lego pieces. Four of these five strategies are self-explanatory. Simulate the movement of the robot refers to the observed student activity of reading the challenge, picking up the RCX and affixing a light sensor, manually moving the RCX over the black line on the paper track, and reasoning aloud about the factors involved in programming the robot to follow the black line. Domain general strategies are those that may be used in any domain. Such strategies used by students in this study were: 1) guess and check; 2) sub-goal analysis; 3) ask questions; and 4) take notes. These nine strategies were used to code each student log. A graduate student was trained on the use of the codes; interrater reliability was established at k = .94. All disagreements were resolved through discussion. The ratio of domain specific to domain general strategies used by each student was calculated and used to designate students as using primarily domain specific or domain general strategies.

A chi square test of independence was conducted to examine the association of social mental model group and strategy type primarily used. A significant association was found, x^2 (1, n=24) = 4.608, p = .032. Students with a robust social mental model are more likely to use domain specific strategies than students with a traits-based social mental model.

Students' scores on their final problem solutions serve as a measure of problem solving ability. These final solutions were scored using a conceptual rubric. The computer science concepts inherent in the problem were input/process/output, procedural flow, and iteration. Possible scores ranged from zero to seven points. Points were allocated based on judgment of difficulty and complexity of each concept as embodied in the challenge. For example, the line following task engaged the input/process/output concept and was considered to have a high level of difficulty and complexity because students had to take into account a number of factors to solve it correctly, including how many light sensors to use, where to place the light sensors, and the variations in light reflection due to sensor placement and/or temporal fluctuations in the quality of light in the room. Content validity of the rubric was achieved when two Robolab experts independently reviewed the rubric and agreed that it accurately reflected the difficulty and complexity of each concept as embodied in the challenge. Students' final problem solution scores were tabulated using the conceptual rubric. A one-way ANOVA (see Table 1) was conducted to test the significance of differences in the group mean scores.

Table 1. Solution Score by Social Mental Model Group ANOVA

Source	SS	df	MS	F	p
Between Groups	18.31	1	18.31	5.367	.030
Within Groups	75.03	22	3.41		
Total		23			

The test was significant, $F = 5.367$, $p = .030$, the effect size was $\eta^2 = .196$, and the observed power was .601. Students with a robust social mental model obtained significantly higher solution scores ($M = 3.07$, $SD = 2.06$) than the traits-based students ($M = 1.30$, $SD = 1.49$).

Discussion

The results of the study indicate that while students have varying social mental models of the ideal science student, these models do not vary based on ethnicity. However, variations in social mental models are associated with variations in problem solving activity. These differences may be attributed to students' use of the distributed intelligence inscribed in the tools found in the task environment (Pea, 1991). The traits group relied largely on their mental representations to solve the robotics problem; they did not take advantage of the affordances for solving the problem offered by the tools as evidenced by their strategy usage. Students in the robust group made excellent use of the provided tools and, by extension, the distributed intelligence in the tools themselves. This is exhibited by the robust groups greater use of domain specific strategies to solve the problem.

To what may we attribute the relationship of a specific social mental model to the decision to use or not use the distributed intelligence in the task environment to help solve the problem? We conjecture that students' social mental model of the ideal science student may be related to their beliefs about learning and cognition. Greeno (1991) distinguishes two views of learning and cognition, a mental representations view and an environmental view. The former view relies on internal representations to reason about problems. The latter view relies not only on internal representations, but also on physical and social resources in the environment to reason about problems. It is possible that the traits group has a mental representations view of learning and cognition, hence they relied on their internal representations and well-known domain general strategies to reason about the robotics challenge. Whereas, the robust group may have an environmental view of learning and cognition that relies not only on mental representations and known strategies, but also employs the domain specific strategies made possible by the available tools in the task environment to reason about and solve the problem. In this study, the students with an environmental view displayed greater problem-solving ability. These students, by virtue of their tool use, continued to construct their knowledge of robotics as they solved the challenge. The learning space of these students was expanded by their active engagement with the resources available to them.

Implications and Conclusions

This study has important implications for educational policy and classroom teaching. These results suggest that standardized assessments that rely on mental representations may be an inadequate form of assessment. Students who utilize the affordances of physical and social resources to solve problems may be at a disadvantage when such resources are not available to them. In essence, students may be capable of much more than what these tests are able to discern. Therefore, expanding methods of assessment beyond tests of mental representations will provide a better picture of both what students have already learned and what they are capable of learning. Regarding classroom teaching, If a teacher has a social mental model of the ideal science student that is traits-based, and a mental representations view of learning and cognition, this teacher may not provide a classroom environment that includes the physical and social learning resources utilized by environmental learners. This type of classroom may put these learners at a distinct disadvantage. Indeed, Thomas, Pederson, and Finson (2001) find teachers' beliefs about themselves as science teachers influence the type of classroom environment they create. Furthermore, the use of tools in science is an important element of developing scientific understanding (Roth, 2001). The NRC (1996) emphasizes tool use as an important aspect of scientific literacy.

This study offers thought provoking results to those interested in social factors related to student problem solving in science. It is presented as a first foray into the thicket of such factors and their relationship to learning. The generalizability of these findings are limited due to the small number of participants, and the lack of academic and socio-economic diversity of the participants. Therefore, future research should address these issues.

References

Ablard, K.E. (2002). Achievement goals and implicit theories of intelligence among academically talented students. *Journal for the Education of the Gifted*, 25(3), 215-232.

Ames, C., & Archer, J. (1988). Achievement goals in the classroom: Sudents' learning strategies and motivation processes. *Journal of Educational Psychology*, 80(3), 260-267.

Bempechat, J., London, P., & Dweck, C.S. (1991). Children's conceptions of ability in major domains: An interview and experimental study. *Child Study Journal*, 21(1), 11-35.

Bennett, M. (1993). Introduction. In Mark Bennett (Ed.) *The development of social cognition*. New York: The Guilford Press.

Buchanan-Barrow, E., & Barrett, M. (1998). Individual differences in children's understanding of the school. *Social Development*, 7(2), 250-268.

Buchanan-Barrow, E., & Barrett, M. (1996). Primary school children's understanding of the school. *British Journal of Educational Psychology*, 66, 33-46.

Cashmore, J.A., & Goodnow, J.J. (1985). Agreement between generations: A two-process approach. *Child Development*, 56, 493-501.

Chang, C.Y., (2002). An exploratory study on students' problem-solving ability in earth science. *International Journal of Science Education*. 24(5), 441-451.

Chi, M.T.H., (1997). Quantifying qualitative analyses of verbal data: A practical guide. *Journal of the Learning Sciences*, 6(3), pp. 271-315.

Dhillon, A.S. (1998). Individual differences within problem-solving strategies used in physics. *Science Education*, 82, 379-405.

Durkheim, E. (1972). *Education and society*. (A. Giddens, Trans.). Cambridge: Cambridge University Press. (Original work published 1922).

Dweck, C.S., & Leggett, E.L. (1988). A social-cognitive approach to motivation and personality. *Psychological Review*, 95(2), 256-273.

Greeno, J. (1991). Number sense as situated knowing in a conceptual domain. *Journal of Research in Mathematics Education,* 22(3), 170-218.

Hammer, D. (1995). Epistemological considerations in teaching introductory physics. *Science Education*, 79(4) 393-413.

Hatano, G. & Wertsch, J.V. (2001). Sociocultural approaches of cognitive development: The constitutions of culture in mind. *Human Development*, 44(2/3), 77-83.

Hogan, K., (1998). Relating students' personal frameworks for science learning to their cognition in collaborative contexts. *Science Education*, 83(1), 1-32.

Jordan, B., & Henderson, A., (1995). Interaction analysis: Foundations and practice. *Journal of the Learning Sciences*. 4(1), 39-103.

Leonardi, A., & Gialamas, V. (2002). Implicit theories, goal orientations, and perceived competence: Impact on students' achievement behavior. *Psychology in the Schools*, 39(3), 279-291.

Lin, H.S., & Chiu, H.L., (2004). Student understanding of the nature of science and their problem-solving strategies. *International Journal of Science Education*, 26(1), 101-112.

Lin, X.D., & Schwartz, D.L. (2003). Reflections at the crossroads of culture. *Mind, Activity and Culture*, 10(1), 9-26.

Lunenberg, M.L., & Volman, M. (1999). Active learning: views and actions of students and teachers in basic education. *Teaching and Teacher Education*, 15, 431-445.

McRobbie, C., & Tobin, K. (1995). Restraints to reform: The congruence of teacher and student actions in a chemistry classroom. *Journal of Research in Science Teaching*, 32(4) 373-385.

Moscovici, S. (1981). On social representations. In Forgas, J.P., (Ed). *Social cognition: Perspectives on everyday understanding*, (pp. 181-209). London: Academic Press.

National Research Council, 1996. The national science standards. Retrieved April 5, 2005 from the World Wide Web: http://www.nap.edu/readingroom/books/nses.

Patrick, H. & Yoon, C., (2004). Early adolescents' motivation during science investigation. *Journal of Educational Research*, 97(6), 319-328.

Pea, R.D., (1991). Practices of distributed intelligence and designs for education. In Gavriel Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 56-67) Cambridge: Cambridge University Press.

Quihuis, G., Bempechat, J., Jimenez, N.V., & Boulay, B.A. (2002). Implicit theories of intelligence across academic domains: A study of meaning making in adolescents of Mexican descent, *New Directions for Child and Adolescent Development*, 96, 87-99.

Reid, N., (2002). Open-ended problem solving in school chemistry: a preliminary investigation. *International Journal of Science Education*, 24(12), 1313-1332.

Roth, W.M., (2001). Learning science through technological design. *Journal of Research in Science Teaching*, 38(7), 768-790.

Schunk, D.H. (1995). Implicit theories and achievement behavior. *Psychological Inquiry*, 6(4) 311-314.

Smith, T. E. (1982). The case for parental transmission of educational goals: The importance of accurate offspring perception. *Journal of Marriage and the Family*, 44, 661-664.

Stipek, D., & Gralinski, J.H. (1996). Children's beliefs about intelligence and school performance. *Journal of Educational Psychology*, 88(3), 397-407.

Ten Dam, G.T.M. (1995). Drop out from adult education: social environment, school culture and perceptions. *International Journal of Lifelong Education*, 14(1), 51-63.

Thomas, J.A., Pedersen, J.E. & Finson, K., (2001). Validating the draw-a-science-teacher-test checklist (DASST-C): Exploring mental models and teacher beliefs. *Journal of Science Teacher Education*, 12(3), 295-310.