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Technical Report

University of Colorado, Boulder

EXPERT BLIND SPOT AMONG PRE-SERVICE TEACHERS

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Running Head: Expert Blind Spot

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Abstract

Subject-matter expertise is critical for effective teaching. However, examinations of the drawbacks that may be ascribed to highly developed content knowledge are rare. This study (N = 48) examined the relationship between preservice teachers' subject-matter expertise in mathematics and the nature of the developmental models they appear to have about algebra learning. As predicted by the *expert blind spot hypothesis*, participants with more advanced mathematics education, regardless of their program affiliation or teaching plans, were more likely to view symbolic reasoning and mastery of equations as a necessary prerequisite for word problem solving. This expectation is in contrast to students' actual performance patterns. An examination across several subject-matter areas, including mathematics, science and language arts, suggested a common pattern: Absent well-developed pedagogical content knowledge, educators with advanced content knowledge within a subject area tend to draw upon the powerful organizing principles, formalisms, and methods of analysis that serve as the foundation of that discipline as guiding principles about student development and instruction. We consider how teachers' developmental views may influence classroom practice and professional development, and call into question policies that seek to streamline the licensure process of new teachers because of their subject matter expertise.

Expert Blind Spot Among Preservice Teachers

Prior knowledge is essential for subsequent learning. It has been identified as critical for directing the subsequent learning of others (Borko, Eisenhart, Brown, Underhill, Jones, & Agard, 1992; Ma, 1999; Shulman, 1986; Vygotsky, 1978). It has also been widely accepted that subject-matter expertise is critical for effective teaching, especially in secondary and post-secondary education. Yet, there have been few examinations of the potential pitfalls for instruction that may be ascribed to expert subject-matter knowledge. One concern is teachers' subject-matter expertise overshadowing their pedagogical knowledge about how their novice students learn and develop intellectually within the domain of interest.

In this work we investigate the *expert blind spot hypothesis*–the claim that educators with advanced content knowledge within a scholarly discipline tend to use the powerful organizing principles, formalisms, and methods of analysis that serve as the foundation of that discipline as the principles governing student development and instruction, rather than the learning needs and developmental profiles of novices (Koedinger & Nathan, 1997; Nathan, Koedinger & Alibali, 2001). The existence of expert blind spot (EBS) would raise the concern that expertise in a content area may make educators blind to the learning processes and instructional needs of novice students.

We first review prior work examining the connections between expert content knowledge and pedagogical content knowledge. We then present data on the expectations about beginning algebra students' mathematical reasoning and development held by preservice mathematics and science teachers with greater and lesser mathematics education. In exploring this construct we do not contend nor imply that highly developed content knowledge is bad for teaching – on the contrary, it is clearly essential (e.g., Ingersoll, 1999). Rather, we present evidence suggesting that those educators with advanced subject-matter knowledge but without concomitant knowledge of how novices actually learn within a content area tend toward views of students' development that align more closely with the organization of the discipline than the learning processes of students. Documenting this phenomenon is vital to understanding how teachers' implicit theories of student development influence curricular decision making and instructional practice. This work also has practical implications for teacher education and professional development. It also calls into question policies that seek to streamline the licensure process of new teachers because of their subject matter expertise. These issues are discussed in the final section.

Theoretical Framework

The Nature of Expertise

This research draws on and extends the expert-novice paradigm in cognitive science (Chi, Feltovich & Glaser, 1981; Simon & Chase, 1973), which shows that experts and novices exhibit very different knowledge organization, perception, and problem-solving processes, despite a common cognitive architecture. Studies of expert performance have shown that it is based on vast amounts of well-organized, domain-specific knowledge, or schemas; intense, long-term practice within a narrow field; psychological and physiological adaptations; and the exploitation of regularities found in familiar tasks (Simon & Chase, 1973; Ericsson & Lehmann 1996).

Expertise is not without its shortcomings, however. Studies have shown that people with a large amount of domain knowledge may actually be at a disadvantage when compared to novices on certain tasks. One area may be teaching, where domain experts can forget what students find easy and difficult to learn (Bransford, Brown, & Cocking, 2000). Experts can also show impaired performance relative to novices on search-intensive tasks such as forming remote associations among disparate concepts (Wiley, 1998). Wiley argued that this is because expert knowledge tends to be highly schema-based, so things like improbable events or disparately related concepts may elude them. In other words, expert subject-matter knowledge can act as a mental set, fixating experts on unproductive solution paths during creative problem-solving tasks while novices may behave more flexibly. Verbal "think aloud" reports have shown that experts are less likely than novices to have access to memory traces of their cognitive processes when engaged in tasks within their area of expertise. This is because these highly practiced cognitive and perceptual processes have become automatized so there is nothing in memory for experts to "replay," verbalize, and reflect upon. (Ericsson & Simon, 1984).

Expertise in Teaching

Expert teaching is a complex phenomenon comprised of expertise in multiple domains, including knowledge of the curriculum content area, student behavior and development, and pedagogy (Shulman, 1987a). Expert teaching also appears to substantiate many of the general claims made about experts in general (e.g., Berliner, 1986; Borko & Livingston, 1989; Chi, et al., 1981; Ericsson & Lehmann, 1996; Leinhardt & Greeno, 1986). Expert teachers differ from novices along several dimensions: (a) They notice different things about the classroom environment, (b) they do more planning and plan differently than novices, and (c) they more deeply organize their knowledge of content, students, and pedagogy in ways that readily facilitate lesson planning and teaching (Borko & Livingston, 1989).

Content Knowledge and Pedagogical Content Knowledge in Teaching

As with expertise generally, expert teaching behavior is highly dependent upon efficient access to vast, well-managed knowledge structures, including domain-specific content area knowledge. Behaviors associated with teaching expertise, as with expertise in general, have also been shown to be quite fragile, and generally limited to familiar and well-practiced teaching situations (Borko & Livingston, 1989). For example, the case studies from Shulman's (1987b) *Knowledge Growth in Teaching Project*, described the practices of a beginning English teacher, Colleen, whose content knowledge of literature was far better developed than her knowledge of grammar.

> In teaching literature, she conducted open-ended discussions, welcoming student questions and alternative interpretations of the text. When teaching a grammar lesson, Colleen looked like a very different teacher. She raced through a homework check at the speed of light, avoiding eye contact, and later admitted that she didn't want to give students the chance to ask questions she couldn't answer. (Shulman, 1987b, p. 15).

While the importance of content knowledge for teaching has long been acknowledged, only in the past 15 years has the educational community become concerned with the specific knowledge effective teachers possess of how to teach content to novices. Shulman (1987a) introduced the term "pedagogical content knowledge" to describe the "blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented and adapted to the diverse interests and abilities of learners for instruction" (p. 8). An example of pedagogical content knowledge is knowledge of specific algebra story problem-solving tasks that serve as effective scaffolds for learners. This is contrasted with content knowledge (e.g., how to solve a story problem) on the one hand, and general pedagogical knowledge (e.g., it is helpful to get the attention of every student) on the other.

In many cases, teachers with high content knowledge also have high pedagogical content knowledge. However, content knowledge can be viewed as developing independently from pedagogical content knowledge (e.g., Borko & Livingston, 1989). This was evident in a study in which people of varying levels of teaching experience openly analyzed a video of classroom events (Copeland, Birmingham, DeMeulle, DeMidiocaston, & Natal, 1994). Regardless of their level of content knowledge, noneducators focused on surface-level characteristics of teaching behaviors, while educators with varying degrees of classroom experience tended to focus on the central purposes of the instruction and the connections between the teacher's actions, goals and student responses.

All teachers with high content knowledge do not necessarily have high pedagogical content knowledge. As suggested in one study of science teaching, content knowledge appears to be a prerequisite for well-developed pedagogical content knowledge; however, pedagogical content knowledge appears to develop out of classroom teaching experiences that also draw on content area knowledge (van Driel, Verloop, & de Voss, 1998). Readily accessible pedagogical content knowledge is a principal component for effective teaching.

With this background on expertise and the role of knowledge in teaching, we now introduce the expert blind spot (EBS) hypothesis – the claim that well-developed subject matter knowledge can lead people to assume that learning should follow the structure of the subject-matter domain rather than the learning needs and developmental profiles of novices. This certainly has some face validity, as many college students who have sat through impenetrable lectures can attest. The EBS hypothesis has particular relevance to the pedagogical decisions made by K-12 teachers. We review findings about the knowledge and beliefs of mathematics teachers, prior to presenting our study. In the final section we explore competing hypotheses that may explain our findings. We then address the general nature of EBS in domains other than mathematics, and discuss its implications for teacher education, and for recent state and national policies that seek out professionals with advanced content knowledge to address the educational needs of communities.

Prior Work and Expert Blind Spot Hypothesis

Prior research (Koedinger & Nathan, in press; Nathan & Koedinger, 2000a) has demonstrated that high school mathematics teachers expected to promote algebraic development by emphasizing symbolic reasoning and notation prior to the use of verbal reasoning and representations. Of note here is not only high school teachers' experiences with student learning, but also their relatively high level of content knowledge; all high school teachers who participated in the study were mathematics majors or received the equivalent training. High school teachers defended this pedagogical approach because they viewed symbolic reasoning as "pure mathematics," and a necessary prerequisite for more advanced verbal "applications." This has been termed the *symbol precedence view* (SPV).

Contrary to the SPV of development, a *verbal precedence view* of development has been found to be statistically more consistent with the performance of most students (Koedinger, Alibali & Nathan, 2000; Koedinger & Nathan, in press; Nathan & Koedinger, 2000b; Nathan Stephens, Masarik, Alibali, & Koedinger, 2002). Students in a number of studies at different grade levels solved verbally presented story and word-equation problems more readily than matched symbolic problems. An advantage of about 20-percentage points was evident for ninth grade students (based on two samples of urban 9th graders who completed a year of algebra, $n_1=76$, $n_2=171$; Koedinger & Nathan, in press). This verbal advantage has been replicated with middle school students (Nathan et al., 2002), and high- and low-performing college students (Koedinger, Alibali & Nathan, 2000). In contrast with the high school teachers, middle school teachers who participated in the study had substantially less formal mathematics education (all had elementary licensure, none had been mathematics majors) and gave greater homage to students' verbal reasoning abilities. The middle school teachers' predictions of students' difficulties were statistically more accurate for predicting student problem-solving performance than the predictions made by high school teachers.

Markedly different expectations provided by the middle and high school teachers of varying mathematics educational backgrounds led Koedinger and Nathan (1997) to hypothesize that high school teachers' expertise in the area of mathematics may influence their views and lead them to think about their algebra students through a math-centric lens. They proposed the EBS hypothesis, speculating that teachers with greater mathematics content knowledge will expect students to follow a normative process of development that mirrored the structure of the domain of mathematics. This domain structure places formal representations (e.g., algebraic equations) as primary, and verbal forms of mathematics as extensions and applications (cf. Kline, 1973). Reasoning about verbally presented problems, in this SPV, depends directly on one's abilities to translate the linguistic information into a formal symbolic equation (typically an equation or set of equations), and then to manipulate the resulting formalisms.

Prior research established the tendency for teachers at the high school level with high content knowledge to favor a SPV of algebraic development, in contrast to student performance data. However, these results may be attributed to influences within schools, such as the structure of textbooks used by teachers (Nathan, Long, & Alibali, 2002), and the demands placed on teachers by school districts and mathematics departments. Furthermore, the prior study of high school and middle school teachers confounded grade level of instruction with mathematics education of the teachers studied. Thus, teaching affiliation and prior mathematics education could not be separated out as influential factors. In this current investigation we set out to study the expectations of preservice teachers with advanced and basic levels of mathematics education, who are selecting to teach within or outside of secondary mathematics.

Method

Participants

All participants were preservice teachers (PSTs) enrolled in a nationally acclaimed teacher education program at a Big-12 college. For these PSTs general subject matter knowledge in mathematics was rated as high if they completed calculus or above, or low if they did not complete pre-calculus. Ratings were based on participants' responses to an accompanying survey. The mathematics education criterion was based on prior research on retention of mathematics knowledge that showed that students' knowledge and retention of a given level of mathematics is most highly developed after they go on to subsequent levels of mathematical study (Bahrick & Hall, 1991). Sixteen PSTs were in a specialized program for mathematics and science majors (the MathSci condition in this study) seeking secondary licensure in mathematics or science education. The remaining PSTs were from the general population of teacher education students and were not seeking secondary mathematics or science licensure. Using the pre-established criterion, they were divided into two groups: high mathematics knowledge (HiMathK, $n = 19$), or basic mathematics knowledge (BasicMath, $n = 3$).

Materials and Procedure

All participants (N = 48) performed a ranking task that compared problems with the same underlying mathematical relations (Table 1). Participants were asked to rank-order six problems in accordance with their expectations of the ease/difficulty that beginning algebra-level students would experience when solving them. We believed that this would be more effective at eliciting participants' true beliefs about curriculum and student learning than asking them directly. Implicit in the task is the 2 X 3 structure shown in Table 2. Participants decided whether algebra students would find problems more accessible if they were in symbolic forms (such as algebra equations) or verbal forms (such as story problems or word equations) along one dimension, and whether performance was higher for arithmetic or algebraic problems. However, they were not made aware of the underlying structure of the six ranking items (see Table 2).

Place Tables 1 and 2 about here

After completing the ranking task, participants rated the degree to which they disagreed or agreed with each of 47 statements by selecting the appropriate number along a 6-point Lickert scale, with 6 representing *strongly disagree* and 1 representing *strongly agree*. Examples of each construct are presented in Table 3. Each construct presented items that were worded both positively (affirming the construct) or negatively (negating the construct). The survey instrument included items that broadly addressed current reform-based issues of pedagogical practice, mathematical learning and development, problem solving, student prior knowledge, the implications of invented strategy use about student knowledge, and the role of algebra in complex problem solving. Included were statements supporting or challenging the SPV of algebra knowledge development.

Hypotheses

Following the EBS hypothesis, we expected that PSTs with high-content knowledge (MathSci and HiMathK) would tend to base their expectations of student performance difficulty on their knowledge and familiarity of algebraic formalisms. From this, we predicted that their rankings would correlate better with the SPV than the rankings provided by BasicMath PSTs. Operationally, the SPV is exhibited by this problem ranking (following the notation provided in Table 2), 1 2 3 4 5 6, which predicts that arithmetic problems are easiest within each level of representational format (symbolic or verbal), and the ability to solve symbolic forms strictly precedes story and word problem solving.

We also predicted that all PSTs would generally agree with reform-based views of student-centered learning and instruction in the survey because of their enrollment in a reform-oriented teacher education program. Thus, it was expected that PSTs would tend to reject views that emphasize getting the correct answer (product) over the specific solution methods used (process), and those views that disregard the importance of students' invented methods as a basis for subsequent learning. We further predicted that, regardless of their specific teacher education program affiliation, HiMathK participants would tend to agree most strongly with statements that specifically reflect SPV of algebraic development, while exhibiting reform-based views of learning and pedagogy more generally.

Results and Conclusions

Problem Difficulty Ranking

We first look at the expectations provided by participants with high mathematics knowledge who were seeking licensure in secondary mathematics and science education. The average ranking across all MathSci PSTs (n=16), ordered from easiest to solve to most difficult, 1 2 4 3 5 6, was virtually indistinguishable from the ranking predicted by SPV, $r=.94$, $p < .005$. Analyses of individual rankings of each PST showed an average correlation with SPV of 0.72, SE = .18. To correct the distribution, a Fisher transformation was applied to each participant's rank correlation. Mean transformed scores had a 95% confidence interval that included 1.0 ($1.19 <= X <= .64$), making this statistically indistinguishable from a perfect correlation with the SPV ranking (Figure 1). A t-test failed to reject the null hypothesis that the correlation was equal to 1.0, $t(14) < 1.0$. Thus, difficulty rankings of those students majoring in mathematics and science who intended to go into mathematics or science teaching at the secondary-level paralleled the hypothetical ranking predicted from the SPV.

Place Figure 1 about here

PSTs who were not pursuing certification as secondary mathematics or science teachers, but reported advanced mathematics education (n = 19) also exhibited an average ranking of 1 2 4 3 5 6, which strongly correlated with SPV, $r = .94$, $p < .005$. The average Pearson's correlation was 0.81. Mean Fisher transformed rank correlations were statistically indistinguishable from $r=1.0$ (Figure 1).

PSTs with relatively limited mathematics education ($n = 13$) showed an average ranking of {1 2 4} as tied for easiest, {3 5} as middle difficulty, and 6 as most difficult. This correlated only moderately with the SPV ranking, $r = .48$. The average individual Pearson's correlation was 0.48. BasicMath PSTs' average ranking had structural similarities with HiMathK PSTs. For example, all three participant groups expected algebra story problems (P6) to be most difficult for students. However, individually Fisher-transformed ranking correlations with SPV for BasicMath PSTs produced a 95% confidence interval that did not include 1.0 ($0.71 <= X <= .35$), indicating this was significantly different from the SPV ranking (Figure 1). A t test showed that the similarity measure with SPV was reliably less than 1.0, $t(12) = 5.3$, $p < .001$.

Pair-wise comparisons of the transformed correlations showed that the idealized SPV ranking was significantly more dissimilar to the ranking generated by BasicMath PSTs than the rankings of MathSci ($p < 0.01$) and HiMathK ($p < .0001$) PSTs. MathSci and HiMathK did not differ statistically.

The ranking data support the hypothesis that PSTs with more advanced mathematics education (i.e., those in the MathSci and HiMathK groups) are far more likely to follow the SPV of algebra development than are other PSTs in our sample. This holds equally well for teachers studying to be secondary-level mathematics and science teachers (where algebra is typically taught and applied) as it does for those with high mathematics knowledge pursuing teaching careers in other areas, such as elementary education.

Several MathSci and HiMathK PSTs defended their rankings with comments that underscored their notions of the primacy of symbolic reasoning in mathematical development. One PST proclaimed "[The arithmetic equation] sets up the problem exactly as they need to do it, in familiar notation… [the arithmetic story problem] provides a scenario that seems more likely to distract or confuse students, who tend to fear word problems." Fear of word problems was typical in justifying the SPV ranking: "Words scare students, and they will struggle. And [algebra] problems where the variable is not isolated are harder still." Others focused on the greater demands of solving problems presented first with words, suggesting that they believed algebraic equations were necessary for finding solutions to these problems: "Word problems require the students to set it up themselves, and the scenario might make it even more difficult to interpret." "Word problems confuse me… [symbolic problems] are easiest because they're just straight forward." Only one MathSci participant explained why symbolic problems might be more difficult: "[The algebra equation] has notation they may be unfamiliar with."

This pattern of results is consistent with the EBS hypothesis that contends that advanced mathematics knowledge per se, rather than algebra teaching, which mediates educators' views of algebra development. Highly developed content knowledge appears to make fledgling teachers blind to the actual developmental processes of beginning algebra students, a finding that parallels earlier data on practicing teachers.

Responses to Beliefs Survey

In addition to the difficulty ranking data and comments, participants responded to a 47-item beliefs instrument on a number of topics related to mathematics instruction and learning. The rating data obtained from the survey showed that the six hypothesized constructs (summarized in Table 3) were well formed (Cronbach's *alpha* between .54 and .89, with 6 items removed based on the reliability analyses). Thus, when we consider participants' levels of agreement, we have high certainty that agreement with specific items is reflective of each construct in general.

Place Table 3 about here

Many of participants' views were in line with current mathematics reform. However, there were also significant differences between participants at the 5% level of certainty that parallel divisions in their level of mathematics education. The percentage of participants in each group who agreed with each construct is shown in Figure 2. All the differences reported in the following discussion are significant.

Place Figure 2 about here

A greater percentage of HiMathK and MathSci PSTs believed using algebraic formalisms is best for solving complex problems (an average of 51% agreed) compared to BasicMath PSTs (38%). BasicMath participants were more likely to agree (82%) that learning is fostered through discovery (*Learning and intuitions*) than HiMathK (64%) and MathSci (56%) PSTs. BasicMath PSTs were also more inclined to believe that instruction should build on students' intuitions and invented methods (*Student-centered pedagogy*; 66%) than PSTs with more mathematics education (38%). Furthermore, consistent with the EBS hypothesis, both groups of PSTs with greater mathematics education were in significantly greater agreement (average of 83% across the two groups) than BasicMath PSTs (66%) with the SPV that students' symbolic reasoning precedes and serves as a necessary pre-requisite to their verbal reasoning and story problem-solving abilities. However, it must be noted that this view was still widely held among the PSTs in this sample generally. Members of all three groups also responded consistently to the remaining two constructs, and rejected both the primacy of students' answers over their solution methods (*Product over process*; 5% agreed), and the notion that alternative problem-solving approaches signal knowledge gaps in students (30% agreed).

Discussion

On the basis of these findings, it appears that budding educators who view student development through a domain-centric lens tend to make judgments about student problem-solving performance and mathematical development that differ with actual student performance patterns in predictable ways. While preservice teachers with more advanced mathematics education expected algebra students early in their education to be best at solving equations, and worst at solving story problems with the same underlying mathematical relations, students exhibit the opposite pattern. This set of findings replicates earlier results shown with practicing mathematics teachers with different levels of mathematics education and so provides further support for the EBS hypothesis. This work extends those prior results by showing that the tendency for educators with high mathematics knowledge to conceptualize mathematics development as following a symbol-precedence trajectory is evident among preservice teachers, regardless of their plans to teach secondary mathematics and science. The SPV evident among PSTs is not simply due to affiliation as a math teacher, professional teaching plans, influences from within the school settings or curriculum materials used by teachers.

It is important in evaluating the contribution of this work to consider alternative explanations to those suggested by EBS that could account for this pattern of findings. One competing hypothesis is that domain-centric views of development such as the SPV are strongly entrenched societally and this is merely reflected by our participants. Though the broader societal influences cannot be ignored, if this were the dominant influence on educators' expectations, we would not expect to see such marked differences along the lines of mathematics education in PSTs as reported here, or among teachers in different grade levels as reported by Nathan and Koedinger (2000b). On the basis of this investigation it does seem that teachers' levels of mathematics knowledge and notions of students' mathematical reasoning and development are related.

A second hypothesis to consider is that those who tend toward a SPV of algebra development do not have impaired judgment but have less well-developed pedagogical content knowledge. At some level this must be true, since educators with a SPV are making some inaccurate predictions of student problem-solving performance. But this, too, does not seem to tell the whole story, since PSTs in all three groups did show strong agreement with widely-held reform views of learning and instruction in the survey, as reflected in the *Product over process* and *Alternative solutions* constructs, as well as others (Table 3). We also note that the middle and high school teachers studied by Nathan & Koedinger (2000b) accurately predicted student performance differences attributable to arithmetic versus algebraic problem structure, even though they differed in their views of the impact of symbolic and verbal format.

Expert Blind Spot More Broadly Considered

Our position regarding teacher preparation is that well-developed subject matter knowledge is vital for effective instruction. However, these findings and others that we now review suggest that subject matter expertise in many disciplines can, if unchecked, lead teachers to be blind to certain developmental needs of novice learners. In medical training, for example, it is customary for expert nurse clinicians, rather than professional medical school educators, to fill faculty positions, and these expert nurse practitioners typically demonstrate a notable lack of awareness of the learning needs of their students (Krisman-Scott, Kershbaumer, & Thompson, 1997). In physics education, there is a recognized tension between those advocating teaching physics in a "top down" fashion, starting from scientific principles and moving to technological application, and those who prefer a "bottom up" approach that uses technology as a basis to induce general scientific principles (Nathan, 2003). Indeed, one author of a textbook designed for undergraduates whose majors lie outside of the natural sciences, clearly articulated this dichotomy.

> While this book starts with objects and looks inside them for scientific principles, most physics texts instead choose to develop the principles of physics first and to delay the search for real-life examples until later.... While a methodological and logical development of scientific principles can be very satisfying to the seasoned physicist, it can appear alien to an individual who isn't familiar with the language being used (Bloomfield, 1998, vii).

This pattern is also evident in language arts. In a case study of a beginning reading teacher, Holt-Reynolds (1999) described how an expert in literature had no awareness of her own reading process or its early development. The teacher was unable to transform her own, highly developed disciplinary knowledge about language and literature into a form that novice learners could understand and apply. This contributed to a rather lackluster year of teaching.

Additional evidence for the EBS hypothesis comes from Pamela Grossman's (1990) comparative case study of six beginning secondary English teachers, all of whom were strong in content area knowledge but differed in their teacher preparation. Three teachers were graduates of a professional teacher education program and three received their degrees through academic programs such as literature. This study has provided a valuable comparison of teachers' pedagogical content knowledge and instructional views while holding content area knowledge constant at a relatively high level.

The case studies of English teachers who had no formal English teacher education have revealed how they tended to promote a *text-centered* view of English instruction that followed the "formal criticism" and "new criticism" approaches, which emphasize detailed textual analysis (*explication de texte*) as the means to understand literature (Kessey, 1987; Rosenblatt, 1991). Although this perspective offers a great deal of depth to the study of language arts, pedagogically it was a poor match for most high school students. The lessons developed from this critical view were often too analytical, insufficiently engaging, and quite disconnected from students' own personal experiences and their pre-conceptions of reading. For example, Teacher Jake "... did not distinguish between his conception of English as a discipline and his conception of English in secondary school" (Grossman, 1990, p. 25). Similarly, Teacher Lance used themes with roots in his understanding of literature, rather than any specific understanding of ninth graders. Grossman noted that, although Lance tried to rethink his teaching "to make it more accessible to ninth graders, his disciplinary knowledge and interests seemed to overwhelm his emerging pedagogical instincts" (p. 39).

In contrast to text-centered views prevalent among language arts teachers who had not received professional teacher training, those who graduated from a formal teacher education program (and who had a similarly high level of content area knowledge) emphasized student-centered approaches in their instruction. Their lessons demonstrated much greater sensitivity to their students' prior knowledge, interests and pre-conceptions toward their English classes, even though literary analysis and grammar still played a central role in these classrooms (Grossman, 1990).

In our view, the English teachers from the academic program found themselves in the same predicament as many of the high school mathematics teachers that have been studied. Their well-developed content knowledge, based in this case on formal principals from linguistics and literary analysis, served as valuable organizing principles for themselves, and served to dominate their instructional approaches, irrespective of the developmental needs of their students.

Within mathematics education EBS takes the form of the SPV of development because of the primacy and enormous utility of symbolic formalisms within the field of mathematics. Although we share the goal to advance learners' understanding of and facility with formal, symbolic representations, previous findings have shown that students do not necessarily develop these formal representations first. Symbolic reasoning may trail and even depend upon the prior development of verbally based representations and procedures (Kalchman, Moss, & Case, 1999). Thus, the pedagogical efforts of inservice and preservice teachers who hold symbol-precedence expectations for these beginning algebra students appears to be misdirected.

Implications For Educational Research and Teacher Education

The present study does not report directly on classroom instruction or its impact on students. However, we claim that these data provide insights into the developmental models that educators have about students, and how those developmental models may influence educators' judgments about student performance and learning.

The existence of EBS should be a central concern to teacher educators because teachers' beliefs about the goals for teaching their subject areas act as a "conceptual map for instructional decision making, serving as the basis for judgments about textbooks, classroom objectives, assignments, and evaluation of students" (Grossman, 1990, p. 86). As such, this work provides a foundation against which instructional practices and curricular designs may be interpreted as researchers try to understand the relationship of teacher knowledge, beliefs and practice, and how these lead to successes and failures within classrooms.

This body of research highlights the need to understand better the pre-existing views and expectations that preservice and practicing teachers have about student learning, the origins of these views, and how these views may interact with empirically based theories of student development that educators will encounter in their professional development. Just as notions of the interrelationships between prior understanding and learning have evolved as the educational experiences of students are re-examined, researchers must be willing to re-examine the role of prior conceptions in the learning processes of teachers.

There is no doubt, in our view, about the essential role of well-developed content knowledge for effective teaching (e.g., Ma, 1999). However, the existence of EBS also underscores the need to balance content knowledge with well-developed pedagogical content knowledge and an understanding of how students' subject-matter specific knowledge develops. The research we have reviewed suggests that advancements in content knowledge without concomitant advances in pedagogical content knowledge can lead educators to adopt domain-centered views of curricula that can shape their pedagogical practices leading to neglect of and sometimes even conflict with students' actual learning processes.

A teacher's subject-matter expertise can operate outside of the practitioner's awareness, and can instill the rigidity of behavior that accompanies all automated processes. In many cases, expertise develops through the deliberate practice of routinized problems that are meant to be solved using schema-based approaches (Ericsson & Smith, 1991). In contrast to routinized expertise, *adaptive expertise* is aimed at how people deal effectively with unfamiliar situations in dynamic and unpredictable environments (Hatano & Inagaki, 1986), such as becoming a life-long learner or teaching in authentic settings. Whether one becomes a routine or adaptive expert depends on the nature of the extended practice. If practice is oriented exclusively toward skillfully but repeatedly solving a fixed class of problems, people tend to become experts characterized by fast, accurate performance and automatic procedures (Hatano & Inagaki, 2000). They become efficient problem solvers, but also become rigid and relatively non-reflective (cf., Wiley, 1998).

This distinction between routine expertise and adaptive expertise is related to the distinction between "knowing that" and "knowing how" (e.g., Bransford & Schwartz, 1999; Broudy, 1977). Well-developed content knowledge (knowing that) is certainly essential for the development of routine or adaptive expertise. However, in isolation, a focus on content knowledge tends to emphasize routinization. If teachers are to develop a flexible and responsive base of pedagogical content knowledge, subject matter education must be coupled with experiences that focus on teaching for student understanding, rather than exclusively on rapidly generating correct answers to stereotypical problems, or covering the curriculum (Berliner, 1986). Teachers in settings where understanding students is valued equally with understanding subject matter tend to become more reflective about their instructional practices, more sensitive to their own intellectual processes and obstacles to students' learning, and more aware of how they know what they know and do what they do (i.e., Broudy's knowing how). Consequently, these teachers also become more attuned to what students actually understand about new material and how that understanding comes about (Zech & Davies, 2000).

Recent Policies on Teacher Licensure Based on Subject-Matter Expertise

In the current *zeitgeist* of educational reform, many see subject-matter preparation as paramount, and put the focus on pedagogical knowledge in a distant second place (e.g., The Holmes Group, 1986). This view has been echoed in much of the rhetoric of the current "math wars" between proponents of calculation-centered (or "back to basics") curricula and those emphasizing the social construction and situated nature of mathematical knowledge. It has led at least one educationally oriented foundation president to push for higher standards for teachers' content knowledge, and to recommend that the American mathematics research community ("Number one in the world") lead the reform of our national mathematics curricula (Goldman, 1997).

This expert-centered approach of mathematics curriculum development echoes the so-called "New Math" movement of the 1950s and 1960s; the content that formed the basis of that curriculum was designed by mathematicians to highlight the organization of the formal structure of mathematics, particularly set theory and number theory, with little regard to how that content was to be learned by children, understood by teachers, or taught in classrooms by non-mathematicians (Loveless, 1997). Opponents (e.g., Kline, 1973; National Council of Teachers of Mathematics, 1970), criticized what they saw as an over-emphasis on formal structure and notation at the expense of good instructional practices, meaning making, and connections to areas of application.

Current research on learning and teaching and policies regarding teacher preparation must include the drawbacks as well as the merits of teachers' subject matter knowledge. Recent reports have made much of the deficits in teacher content knowledge and its apparent impact on student learning and performance on high-stakes assessments (e.g., Educational Trust, 2002; Gonzalez, et al., 2000). Some (e.g., U. S. Department of Education, 2001) have used these findings to argue that teacher education and professional development programs spend too much time on pedagogy and on understanding students' prior knowledge and experiences, and too little time on improving teachers' content-area knowledge. EBS research suggests that teacher education and professional development must steer clear of either extreme. Teacher education must keep sight of the importance of pedagogical content knowledge in teaching, and this emphasis must not be traded off against excessive attention to subject-matter preparation that can contribute to inaccurate models of students' intellectual development.

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Table 1. Ranking task given to participants.

A SURVEY

Below are 6 problems that are representative of a broader set of problems that are typically given to public school students at the end of an Algebra 1 course -- usually 8^{th} or 9^{th} grade students. My colleagues and I would like you to help us by answering this brief (10 min) survey. We will have an opportunity to discuss these problems later.

What we would like you to do:

Rank these problems starting with the ones you think will be easiest for students to solve to the ones you think will be hardest for them to solve. You can have ties if you like. For example, if you think the fourth problem (#4) was the easiest, the 3rd was the most difficult, and the rest were about the same, you would write:

4 (easiest)
2 1 5 6
3 (hardest)

Please provide an explanation and any assumptions you made in the space below.

Problems:

1) (68.36 – 25) / 4 = P

2) Starting with 68.36, if I subtract 25 and then divide by 4, I get a number. What is it?

3) After buying a basketball with her four daughters, Ms. Jordan took the $68.36 they all paid and subtracted out the $25 she contributed. She then divided the remaining amount by 4 to see how much each daughter contributed. How much did each daughter pay?

4) Solve for D: D x 4 + 25 = 68.36

5) Starting with some number, if I multiply it by 4 and then add 25, I get 68.36. What number did I start with?

6) After buying a basketball with her daughters, Ms. Jordan multiplied the amount each daughter had paid by 4 (because all 4 sisters paid the same amount). Then Ms. Jordan added the $25 she contributed and found the total cost of the ball to be $68.36. How much did each daughter pay?

Please include any explanations and assumptions:

Table 2. Hidden structure of the problem difficulty-ranking task given to participants.

Presentation type →	**Verbal**		**Symbolic**
Unknown value ↓	**Story**	**Word**	**Equation**
Result-unknown (Arithmetic)	P3	P2	P1
Start-unknown (Algebra)	P6	P5	P4

Table 3. Percentages that participants (n=48) agree with each construct when presented on a 6-point Lickert-scale survey (6=Strongly Disagree).

Construct (no. of items)	Description	Alpha	MathSci (n=16)	HiMathK (n=19)	BasicMath (n=13)
Algebra is best (12)	Algebraic procedures are the singularly most effective solution method.	.79	54.2	47.8	37.8*
Student-centered pedagogy (7)	Teachers can effectively build on students' invented methods.	.89	36.1	39.8	65.8*
Symbol Precedence View (4)	Symbolic reasoning precedes story problem solving.	.54	79.7	85.5	66.2*
Learning and intuitions (8)	Students enter the classroom with intuitive methods for reasoning algebraically.	.85	56.3	64.5	81.7*
Product over process (4)	Correct answers are more important than the method used.	.71	4.7	8	2
Alternate solutions (6)	Students' alternate solution methods indicate knowledge gaps.	.76	34	32.3	27.5

* $p < .05$.

List of Figures

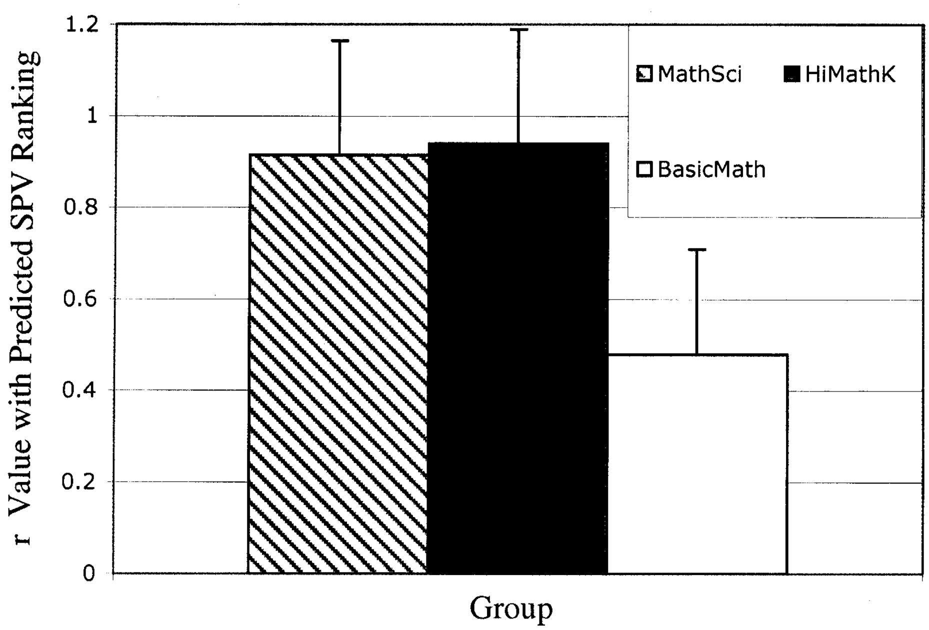

Figure 1. Mean correlation (using adjusted Fisher transformation) of participants' ranking (by group) with predicted symbol precedence view ranking.

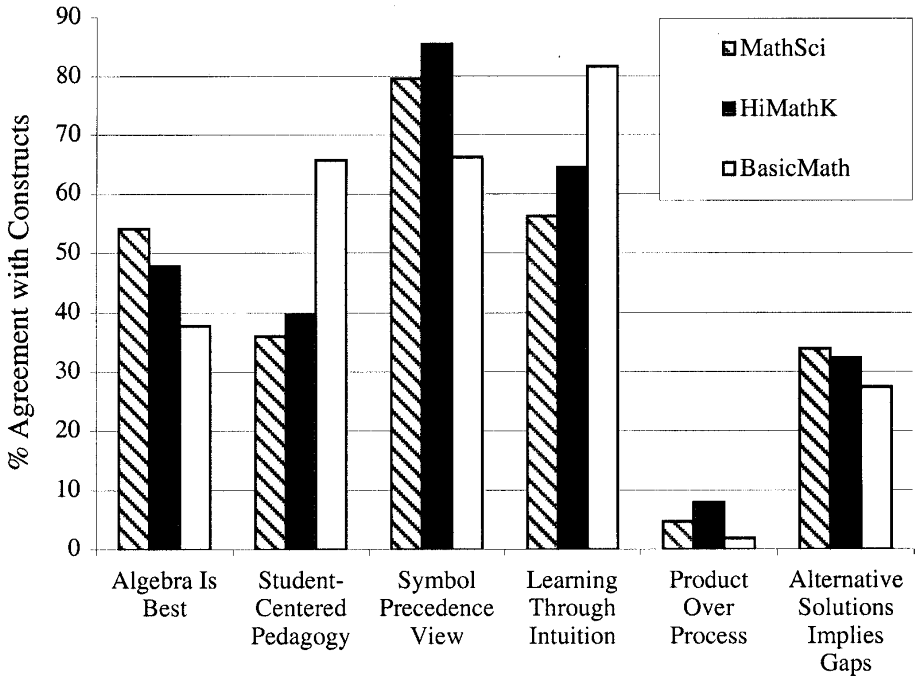

Figure 2. Percentage agreement with belief constructs by condition.