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DOMAIN SPECIFIC AND GENERAL EPISTEMOLOGICAL BELIEFS THEIR EFFECTS ON MATHEMATICS

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ABSTRACT

In order to understand how epistemological beliefs (beliefs about knowledge and learning) influence mathematical problem solving, over 700 college students completed a domain general and a domain specific (mathematical problem-solving) beliefs questionnaire. In addition, they completed two mathematical tasks, one that assessed cognitive depth and the other problem solving. Mathematical and general epistemological belief factors emerged from a single exploratory factor analysis. Furthermore, students with high mathematical background showed consistency between domain general and domain specific epistemological beliefs, whereas, students with less mathematical background were significantly different between the two levels of belief specificity. Comparisons among path analyses revealed indirect effects of general epistemological beliefs and direct effects of domain specific epistemological beliefs on mathematical performance.

Keywords: *epistemological beliefs, mathematical performance, knowledge and learning, problem solving.*

CREENCIAS EPISTEMOLÓGICAS DE DOMINIO ESPECÍFICO Y GENERAL. EFECTOS SOBRE LA HABILIDAD MATEMÁTICA

RESUMEN

Para entender cómo influyen las creencias epistemológicas (creencias acerca del conocimiento y del aprendizaje) sobre la resolución de problemas matemáticos, se aplicó un cuestionario sobre las

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creencias de ámbito general y ámbito específico (resolución de problemas matemáticos) a más de 700 estudiantes universitarios. Asimismo, los participantes llevaron a cabo dos tareas matemáticas: una que evaluaba la profundidad cognitiva, y otra sobre resolución de problemas. Con un solo análisis factorial exploratorio se extrajeron dos factores, uno sobre creencias epistemológicas y otro matemático. Además, aquellos estudiantes con altos conocimientos previos matemáticos mostraron consistencia entre las creencias epistemológicas de ámbito general y de ámbito específico. En cambio, los estudiantes con menos conocimientos previos matemáticos fueron significativamente diferentes en los dos niveles de especificidad de las creencias. Las comparaciones llevadas a cabo entre los path analyses mostraron efectos indirectos de las creencias epistemológicas generales y efectos directos de las creencias epistemológicas de ámbito específico sobre el rendimiento matemático.

Palabras clave: *Creencias epistemológicas, rendimiento matemático, conocimiento y aprendizaje, resolución de problemas.*

INTRODUCTION

Beliefs about the nature of knowledge and knowledge acquisition (epistemological beliefs) continue to be at the forefront of educational inquiry. In a major review of personal epistemology in mathematics, Muis (2004) called for an examination of the relationship between general epistemological beliefs and mathematical beliefs. This type of investigation could clarify the nature of epistemological beliefs. With that in mind, the purpose of this study is to examine college student's general epistemological beliefs and domain specific mathematical problem-solving beliefs and their relationship to students' academic performance.

Perry (1968) inspired others with his work on students' views of education. Interviews with Harvard undergraduates lead Perry to conclude that college students go through a transformation in their views of the nature of knowledge. They begin college thinking knowledge is simple, certain, and handed down by authority. By the time they reach graduation many students conclude that knowledge is complex, tentative, and derived through reason and evidence. For many years researchers studied epistemological beliefs with Perry's unidimensional paradigm as the underlying assumption (Baxter Magolda, 1992; Chandler, 1987; Kitchener & King, 1981).

Starting in 1990 a new paradigm for epistemological beliefs was introduced (Schommer, 1990). Schommer hypothesized that epistemological beliefs should be considered a system of more-or-less independent beliefs. By synthesizing the research that occurred earlier, she concluded that at a minimum there are five beliefs that compose the epistemological belief system. Initially she characterized each belief as a continuum. These included beliefs about the structure of knowledge (ranging from simple to complex), the stability of knowledge (certain to uncertain), the source of knowledge (omniscient authority to reason and evidence), the speed of learning (quick to gradual) and the ability to learn (fixed to improvable). By more-or-less independent Schommer meant that each belief may or may not develop at a different rate. The point being that one cannot assume that if individuals are mature in one belief then they are necessarily mature in all of their epistemological beliefs. Since this 1990 introduction, other researchers have carried out research that generated multi-dimensional models of epistemological beliefs (Buehl, Alexander, & Murphy, 2002; De Corte, Op't Eynde, & Verschaffel, 2002; Hofer & Pintrich, 2002; Muis, 2004; Schraw, Bendixen, & Dunkle, 2002; Wood & Kardash, 2002).

Epistemological belief research continues to grow because researchers continue to find many different links between epistemological beliefs and learning. For example, epistemological beliefs have been related to students' text comprehension (Kardash & Scholes, 1996; Schommer, 1993), students' cognitive engagement and achievement goals (Ravindran, Greene & DeBacker, 2005), students' search strategies for information in digital environments (Whitmire, 2004), and students' study strategies and communication styles (Schommer-Aikins & Easter, 2008, 2009).

Researchers are now emphasizing the need to study the effects of epistemological beliefs in combination with other variables. They hypothesize that the effects of epistemological beliefs are subtle, because more often than not, their influence on learning is mediated by other aspects of cognition and/or affect (Bendixen & Rule, 2004; Schommer-Aikins 2004).

Another issue that continues to be of concern in epistemological belief research is the level of domain specificity. Epistemological beliefs can be domain general which means they apply across all domains. Epistemological beliefs can domain specific which mean the can be applicable to specific academic domains such as mathematics, history, and social sciences.

For many years research has been conducted as if epistemological beliefs were domain general (Baxter Magolda, 1992; Kitchener & King, 1981; Perry, 1968; Schommer, 1990). More recently researchers have theorized that epistemological beliefs are both domain general and domain specific (Buehl et al., 2002; Hofer, 2000; Muis, Bendixen, & Haerle, 2006; Schommer-Aikins, 2002). Hence, the real question that needs to be considered is what is the nature of epistemological beliefs at different levels of specificity? For example, one can ask how do epistemological beliefs at different levels of specificity relate to each other? How do epistemological beliefs at different levels of specificity interact and ultimately affect other aspects of cognition and subsequently academic performance?

One study with middle school children has been conducted that investigates the relationship between epistemological beliefs at different levels of specificity and their effects on mathematical problem solving (Schommer-Aikins, Duell, & Hutter, 2005) Middle-school students completed questionnaires that assessed general epistemological beliefs (Schommer-Aikins, Mau, Brookhart, & Hutter, 2000), and domain specific mathematical problem-solving beliefs (Fennema & Sherman, 1976; Kloosterman & Stage, 1992). In a path analysis Schommer-Aikins et al. (2005) found that the domain general belief in quick/fixed learning had a direct effect on the domain specific belief in useful mathematics. Subsequently, belief in useful mathematics had a direct effect upon students' mathematical problem-solving performance. Although the domain-general belief in quick/fixed learning also had a direct effect on mathematical problem-solving performance, the path coefficients that had indirect effects via the mediating effect of belief in useful mathematics were stronger.

This study being reported continues this line of investigation using as a general model the study conducted by Schommer-Aikins et al. (2005). In the study being reported college students completed the domain general epistemological beliefs questionnaire and the domain specific mathematical problem-solving beliefs questionnaire as was used in the Schommer-Aikins et al. (2005) study. In addition, they completed two mathematical tasks, one that required identifying an underlying mathematical structure and the other that required solving mathematical problems. Four questions were addressed. Is there a distinction in levels of specificity as is evidenced in domain general and domain specific beliefs emerging as separate factors? Does having more academic knowledge relate to the nature of students' domain general and domain specific beliefs? How do those epistemological belief factors influence other aspects of cognition and actual mathematical performance? How do epistemological beliefs at different levels of specificity relate to each other?

METHOD

Participants

Seven hundred and one USA college students participated in the study. Their average age was 28.25 (*SD* = 7.89, *Range* = 17-62). Of the participants 259 were males, 442 were females, and one failed to report gender. One hundred fifty-seven were freshmen, 189 were sophomores, 126 were juniors, 109 were seniors, 117 were graduate students, and four did not report their educational level. When reporting their ethnic origin, 5.6% chose African-American, 6.6% Asian, 3.8% Hispanic, 2.4% Native American, 79.3% Euro-American, and 2.3% did not report their ethnic origin. When asked how many college mathematics courses they had completed, 152 (21.7%) reported none, 204 (29.1%) one, 251 (35.8%) two to three, 62 (8.8%) four or five, 32 (4.6%) six or more, while 1 (0.1%) did not mark a response. English was not the first language for 10.4%, English was the first language for 89.3%, and 0.3% did not report whether English was their first language. Students were recruited from classes in economics and education. They were asked to complete surveys as honestly as possible so that their responses would help educators understand students better. As an additional incentive, those students who completed the surveys were included in a drawing for $100 cash.

Measurements

General Epistemology. A 30 item epistemological belief questionnaire was used to assess general epistemological beliefs. The development of this instrument is described in detail in Schommer-Aikins et al., (2000). It consists of items to which students respond on a Likert scale from 1 (strongly disagree) to 5 (strongly agree). Statements assess students' beliefs about knowledge and learning (e.g., *If I can't understand something right away, I will keep on trying*). In this article we would like to emphasize that for each belief, one end of the spectrum supports higher order thinking (HOT). The other end of the continuum supports routine, everyday thinking or basic level thinking (BLT). To add clarity in our descriptions we will phrase results and discussion in terms of the end of the continuums. Furthermore, it is important to emphasize that students' belief scores represent preferences toward one end of the continuum as opposed to a total commitment toward one end of the continuum. Hence, for general epistemological beliefs, items were worded so that respondents who typically use BLT epistemological beliefs would agree with about half the items and disagree with the remaining items. The items were randomly ordered with about half of the items reversed scored so that the higher the score, the more respondents identified with BLT epistemological beliefs. When this questionnaire was administered to middle school students (Schommer-Aikins et al., 2005), exploratory factor analysis yielded four factors: (a) quick/fixed learning (CA = .77), (b) studying aimlessly (CA = .55), (c) omniscient authority (CA = .55), and (d) certain knowledge (CA = .36).

Mathematical Problem-Solving Beliefs. Students' beliefs about mathematical problem solving were assessed using a questionnaire consisting of the Indiana Mathematics Belief Scale (Kloosterman & Stage, 1992) and the Usefulness of Mathematics Scale (Fennema & Sherman, 1976). Both scales were developed for high school and college students. The development of these instruments is described in Kloosterman and Stage (1992). When this questionnaire was administered to middle school students in the Schommer-Aikins et al. (2005) study, exploratory factor analysis yielded seven factors: (a) effortful mathematics (CA = .80), (b) useful mathematics (CA = .80), (c) persistence in mathematics (CA = .62), (d) mathematics confidence (CA = .63), (e) understand mathematics concepts (CA = .70), (f) word problems (CA = .62), and (g) nonprescription mathematics (CA = .66).

Mathematical Cognitive Depth. To serve as one of the potential mediation variables, cognitive depth was assessed. In the current study cognitive depth is defined as being able to identify the structural feature of a mathematical problem. Modeling after the work of Silver (1981), students were given two target problems and six sample problems. For each target problem, their task was to determine which sample problem was mathematically most similar. Among the sample problems, one problem was structurally related to the target problem in that it required the same mathematical processes, e.g., both problems involve proportions (considered a deep response). Another sample problem shared surface details, e.g., both problems involve chickens and rabbits (considered a surface response). Four other sample problems shared neither the mathematics process nor the surface structure (considered irrelevant responses).

Four levels of cognitive depth were operationally defined. A score of zero was assigned to students who gave completely irrelevant responses (both responses were irrelevant or one response was irrelevant and the other was a surface response). A score of one was assigned to students were assumed to have used a simplistic, inappropriate strategy (both responses were surface responses). A score of two was assigned to students who were assumed to be at the initial stage of deep thinking (one surface response and one deep response). A score of three was assigned to students who were assumed to think deeply (both deep responses).

Mathematical Background. In order to assess students' mathematical background knowledge they responded to an item "How many mathematics courses have you completed?" They were able to select one of the following: (a) none, (b) one, (c) two to three, (d) four to five, or (e) six or more.

Mathematical Problem Solving. Students calculated the answers to the two target and six sample problems that were used to measure mathematical cognitive depth. The total number correct served as a measure of mathematical problem solving. Scores could range from 0 to 8.

Procedure

Both researchers distributed the experimental booklets during regularly scheduled classes. Each booklet contained instruments for general epistemological beliefs, demographic information, mathematical problem-solving beliefs, a filler task, and the mathematical problem-solving items. Participants were provided as much time as they needed to complete all tasks.

RESULTS

The first two questions addressed in these analyses were the following. Will domain general and domain specific beliefs emerge as separate factors? Does having more academic knowledge relate to the nature of students' domain general and domain specific beliefs? To answer these questions, we entered items from the domain general and domain specific beliefs into a single exploratory factor analysis. Although an eigenvalue cutoff of 1.00 occurred at 18 factors, sums of squared loadings and the scree plot indicated an eight factor solution. Based on this, the exploratory factor analysis was re-run forcing an eight factor solution. Sums of squared loadings and factors with items having notable factor loadings from this analysis indicated the first seven factors were the most meaningful. High loading items on the rotated factor matrix (.40 or higher) revealed that the mathematics beliefs and the general beliefs emerged as separate factors. There were four mathematics beliefs and three general epistemological beliefs.

The seven belief factors were titled and reliability was tested with Cronbach alpha (CA). This resulted in four mathematical factors labeled for the HOT end of their respective scale: (a) mathematics takes time and is useful (MTMUSE, *CA* = .90), (b) mathematics takes effort (MEFFORT, *CA* = .87), (c) conceptual understanding is important in mathematics (MCONCEPT, *CA* = .82), and (d) solving mathematical problems is more than simply following a step-by-step process (MBEYONDSTEP, *CA* = .57). This also resulted in the three general epistemological belief factors labeled for the BLT end of their respective scale: (a) the average person learns quickly or not at all (AVQUICK, *CA* = .64), (b) people are born smart (BSMART, *CA* = .47), and (c) experts can find the absolute truth (EXPTRUTH, *CA* = .69). Table 1 shows the descriptive statistics for all epistemological belief variables.

In order to examine the relationship of amount of background knowledge and the nature of levels of specificity, a comparison was made between the epistemological beliefs that were most comparable MTMUSE and AVQUICK. Both epistemological factors deal with the speed of learning and elements of natural ability. Three questions were addressed with a two way MANCOVA. The within subject dependent variables epistemological belief scores at different levels of specificity (domain general versus domain specific) and the between subject variable was mathematical background (low background of 0-3 courses versus high background 4 or more courses). These served as independent variables. School year and gender served as covariates.

TABLE 1
DESCRIPTIVE STATISTICS FOR VARIABLES USED IN THE ANALYSES

Variables	**Descriptive Statistics**		
	Mean	**SD**	**Range**
MTUSE	3.72	.73	1-5
MEFFORT	3.90	.76	1-5
MCONCEPT	4.01	.80	1-5
MBEYONDSTEP	2.90	.75	1-5
AVQUICK	1.84	.60	1-5
BSMART	3.84	1.04	1-5
EXPTRUTH	3.20	.95	1-5
MATHALL	6.93	4.16	0-13
COGSEMI	1.67	1.12	0-3
COLLMATH	1.46	1.06	0-4

Although results indicated that there was a significant main effect for mathematical background [F (1, 679) = 6.26, $p < .01$, eta squared = .01]. There was also a significant interaction effect [Wilk's Lambda F (1, 679) = 11.72, $p < .001$, eta squared = .02]. See Figure 1 for a graphic display of the interaction. Follow-up post hoc tests revealed

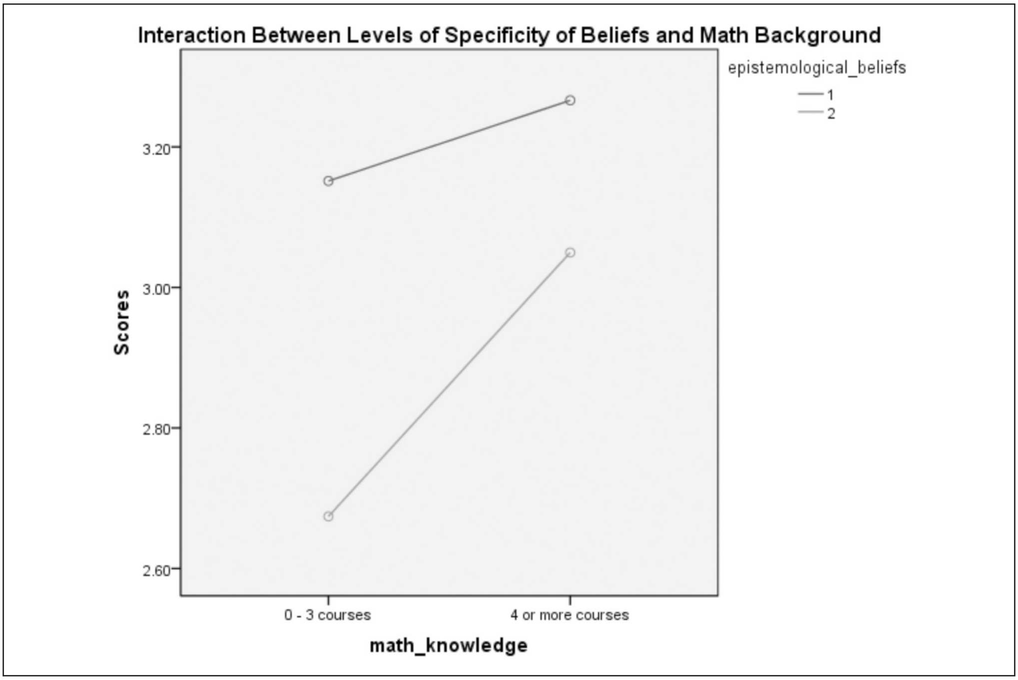

FIGURE 1
INTERACTION BETWEEN MATHEMATICAL KNOWLEDGE AND EPISTEMOLOGICAL BELIEF SCORES

that students with a high mathematical background were more likely to endorse HOT beliefs for both domain general and domain specific beliefs. However, students with low mathematical background did have a significantly higher score (more HOT) in their domain general beliefs compared to their domain specific beliefs [F (1, 588) = 18.35, p < .001)].

In the next set of analyses we addressed the following question. How do domain general and domain specific epistemological beliefs influence other aspects of cognition and actual mathematical performance? First we examined the zero order correlations among mathematical performance, mathematics problem-solving beliefs, and general epistemological beliefs. Table 2 reports the correlations among all relevant variables in the study. From these correlations we selected the mathematical belief and the epistemological belief that correlated the strongest with mathematical performance. These two beliefs would serve as measures of the most relevant mathematical problem-solving belief and general epistemological belief to predict mathematical performance in these path analyses.

TABLE 2
ZERO ORDER CORRELATIONS AMONG MATH PERFORMANCE, COGNITIVE DEPTH, MATH PROBLEM-SOLVING BELIEFS, AND GENERAL EPISTEMOLOGICAL BELIEFS

Variables	1	2	3	4	5	6	7	8	9
1. MATHALL		.62**	.39**	.12*	.18**	.18**	-.23**	.08	-.03
2. COGDEPTH			.31**	.11*	.16**	.17**	-.20**	-.03	.00
3. MTUSE				.48**	.58**	-.07	-.41**	-.19**	.10**
4. MEFFORT					.38**	-.16**	-.25**	-.10**	.20**
5. MCONCEPT						-.02	-.46**	-.19**	.11**
6. MBEYONDSTEP							-.06	.04	-.17**
7. AVQUICK								.30**	.01
8. BSMART									.01
9. EXPTRUTH									

*p < .05. **p < .01.

We compared three different path models. With each comparison we were first concerned that all designated paths be significant. Second, we were concerned that fit indices be in an acceptable range. What we varied among the models was the relationship of general beliefs to mathematical performance. In the first path analysis, the general epistemological belief was directly linked to mathematical performance. Path analysis revealed that the path coefficient was not significant. In the second path analysis the general epistemological belief was directly linked to cognitive depth. This path was also not significant. In the third analysis, the general epistemological beliefs were directly related to mathematical beliefs. All paths in the analysis were significant and all fit indices were in the acceptable range. In summary, these path analyses indicate the mathematical epistemological beliefs have both a direct and indirect on mathematical performance. On the other hand, domain general beliefs only have an indirect effect on mathematical performance. See Table 3 for the fit indices of each path analysis. See Figure 2 of graphic display of the best fitting path analysis.

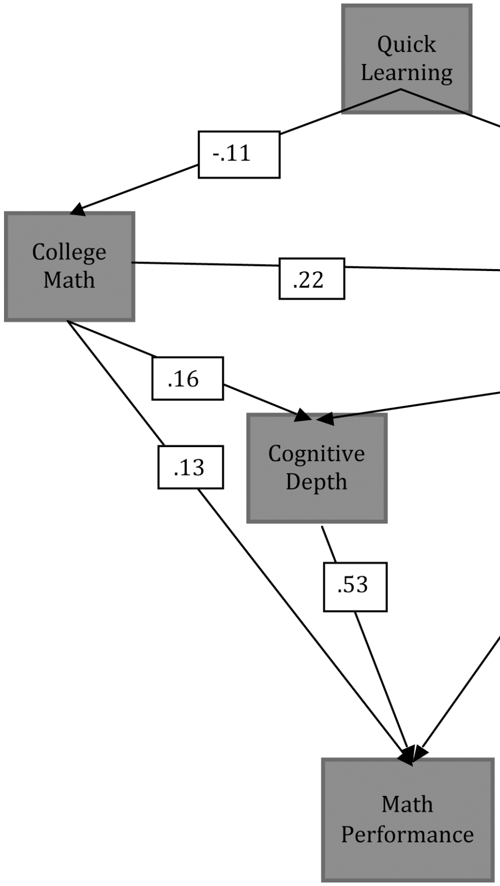

FIGURE 2
GRAPHIC DISPLAY OF THE BEST FITTING PATH ANALYSIS

Path analysis 3 showing the direct and indirect effects of epistemological beliefs on mathematical performance as mediated by mathematical cognitive depth. All paths are significant.

TABLE 3
FIT INDICES FOR PATH ANALYSES

Path 3	χ^2	df	paths ns	p	NFI	CFI	RMSEA
1	2.24	1	1	0.14	.99	.99	.06
2	0.78	1	1	0.38	.99	1.00	.01
3	3.02	2	0	0.22	.99	.99	.04

DISCUSSION

This study contributes to understanding the nature of level of specificity of epistemological beliefs. The first issue was to determine if these different systems of epistemological beliefs would emerge as separate factors. For example if one was testing a strong theory that epistemological beliefs are domain general, then the prediction would be that all items involving the speed of learning would merge as a single factor. This was not the case. Rather, two factors, one involving speed of learning in academics in general and one involving speed of learning in mathematics in particular, emerged from factor analysis. These results support the notion that these epistemological beliefs systems are distinct.

The domain specific beliefs were the psychometrically strongest factors in these analyses. This is apparent based on the fact that three out of the four mathematics factors were the first factors generated (earlier factors are stronger factors) and the Cronbach Alphas ranged from high to medium in strength. These results should not be surprising. It seems logical that students' beliefs about a specific domain which are grounded in particular experiences would more cohesive than are their beliefs that are applicable to all possible academic domains to which they have been exposed.

These results suggest that it is plausible that individuals hold both domain general and domain specific beliefs. This is evident in the emergence of separate factors for domain general beliefs and separate factors for domain specific beliefs. These results are consistent with other research that indicated the existence of both domain general and domain specific beliefs within individuals (Buehl et al., 2002; Hofer, 2000).

In the next set of analyses we delved into the nature of levels of specificity in relationship to students' mathematical background knowledge. As shown in Figure 1, when students have very little mathematical background, there is a significant difference in that their mathematical beliefs tend to support basic level thinking, whereas their general epistemological beliefs are beginning to support higher order thinking. In contrast, when students have more mathematical background, both domain general and domain specific beliefs have a propensity to support high order thinking. In other words, once students obtain an advanced level of mathematical knowledge, their epistemological systems appear to become indistinguishable or more domain general.

These results are consistent with earlier work. In their within subject study, Schommer-Aikins, Duell, and Barker (2003) compared students' epistemological beliefs in mathematics, social sciences, and business. For each paired comparison, when students had either high knowledge in both domains or low knowledge in both domains, their epistemological beliefs correlated substantially and appeared domain general. When students had high knowledge in one domain and low knowledge in the other domain, results were highly mixed. Some comparisons suggested domain general and some comparisons suggested domain specific beliefs. The results from this study being reported and the Schommer-Aikins et al. (2003) study clearly show that the amount of background knowledge should be taken into consideration when studying level of specificity of epistemological beliefs.

The next question to ponder is how do these two systems interact to influence other aspects of cognition and actual performance? In this study cognitive depth was defined as being able to recognize the underlying mathematical structure of mathematics problems. Correlations and path analyses indicated a strong relationship between students identifying the mathematical structure and their ability to solve mathematics problems. This is consistent with previous research which indicates that poor problem solvers lack the ability to identify structure before they attempt to solve a problem, when they are solving a problem, or when the solution to the problem has been presented (Krutetskii, 1976; Silver, 1981).

The path analysis indicated that the domain general epistemological belief AVQUICK had indirect effects on cognitive depth and mathematical performance. The indirect effects were mediated by students' mathematical background and by their domain specific mathematical problem solving belief of MTUSE. In other words, the more students believed that the average person learns quickly or not-at-all, the fewer mathematics courses they had taken and the less likely they were to believe that mathematics requires substantial time and is useful. We did not find evidence that domain general epistemological beliefs have direct effects on cognitive depth and mathematical performance because these path coefficients were not significant.

However, the domain specific mathematical problem solving belief of MTUSE had direct effects on cognitive depth and mathematical problem solving. That is, the more students believed that mathematics takes time and is useful, the greater their cognitive depth and the better their mathematical problem solving. MTUSE also had an indirect effect on mathematical problem solving as it was mediated via cognitive depth because cognitive depth had a subsequent direct effect on mathematics performance. It is logical that the beliefs which are more specific to a domain would have a stronger effect on performance in that domain.

These findings are consistent with findings for middle school students (Schommer-Aikins et al., 2005) with one important difference. In that study path analyses revealed belief in the usefulness of mathematics had a direct effect on mathematics problem solving. In contrast to the study being reported, the domain general belief in quick/fixed learning had direct effects on belief in the usefulness of mathematics and on mathematics problem solving. Hence, belief in quick/fixed learning not only had a direct effect on mathematics problem solving, but also a mediated effect via the domain specific mathematical belief. This difference is consistent with Muis et al's (2006) framework in which they hypothesize that domain general beliefs may play a lesser role in academic performance as individuals grow in their expertise.

The fact that speed of learning played an important role in both studies is consistent with earlier works that consistently indicate that beliefs about the speed have a powerful influence over a learners' performance. Speed of learning has been shown to predict comprehension, metacognition, mathematical problem solving, and grade point average (Schoenfeld, 1983; Schommer, 1990; Schommer, Calvert, Gariglietti, & Bajaj, 1997; Schommer & Dunnell, 1997; Wood & Kardash, 2002).

Like all studies, this work has limitations and these limitations serve as an impetus for future research. Results are generalizable to a limited demographic group. The study of culturally diverse populations has the potential to add new insight into the study of epistemological beliefs. Understanding the nature of each epistemological belief as well as the addition of beliefs not yet considered will likely to result from cross cultural investigations. Only two levels of specificity were examined in this study. Highly specific levels may add precision to predictions. At the same time the more specific the epistemological belief, e.g. epistemological beliefs in a particular classroom, the more the epistemological belief measure will be entangled with situation-specific factors.

The research evidence is accumulating that suggests that personal epistemology has many influences on learning, yet that does not necessarily make it obvious in the instructional setting. The current finding, that domain general beliefs have indirect effects, is consistent with the theory that the effects of epistemological beliefs are subtle (Schommer-Aikins, 2004). An instructor will struggle to try to understand why students may resist explicit directions to take their time and to look for the mathematical structure of the problem while problem solving. The obstacles may be both domain general and domain specific epistemological beliefs. Therefore, instructors should consider assessing both domain general and domain specific epistemological beliefs. Finally, when students mysteriously resist thinking deeply, searching for complex understanding, and questioning the world around them, instructors may need to go beyond teaching content knowledge and begin to explicitly address epistemological issues.

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