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Assessing Goodness-of-Fit Measures for Multidimensional Personal Epistemology Survey Instruments: An Alternate Approach Using Multitrait-Multimethod Confirmatory Factor Analysis

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Abstract

Survey instruments measuring multidimensional attributes of individuals' personal epistemology beliefs have not demonstrated strong goodness-of-fit between the hypothesized model and collected data. Despite this, the growing body of research in personal epistemology suggests the existence of multiple dimensions of epistemic beliefs. To date, previous surveys have been examined using confirmatory factor analysis (CFA) in which the dimensions of beliefs have been the levels of a single factor examined. The dimensional structure explored in this study includes certainty, structure, authority, innate ability and acquisition speed. Alternatively, the multitrait-multimethod (MTMM) CFA introduces a second factor into the model. In this context, the second factor was a "method" effect introduced by the philosophical classification of the questions/items in the survey. This project demonstrated that the MTMM CFA is the better statistical tool to confirm the presence of five distinct dimensions in a traditional epistemic belief survey. This was accomplished by modelling the influence of the epistemic belief dimensions crossed with the philosophical nature of the items in the survey. Data were collected over two academic terms in various levels of mathematics courses in a community college in the Pacific Northwest region of the USA. Items in the survey were selected to measure the five epistemic dimensions listed above. Items were then classified as axiomatic, ontologic, deontologic or procedural in nature (deontological items were excluded). Results statistically indicated that the MTMM CFA model was the strongest model compared to standard (single factor) CFA models or alternate conceptualizations of the (dual factor) MTMM CFA model. In addition, results indicate very strong goodness-of-fit measures for the MTMM CFA model (CFI = 0.94; RMSEA = 0.038). Epistemic belief profiles for students are various levels of mathematics instruction in the tertiary environment were also explored.

Key Words

Personal Epistemology, Multitrait-Multimethod CFA, Tertiary Students, Mathematics

Introduction

Beliefs about knowledge can influence how students choose to engage in learning. This has been demonstrated in mathematics classrooms (Lampert, 1990; Schoenfeld, 1988). Here are a few examples that demonstrate how beliefs about knowledge and learning have the potential to influence student engagement. (a) A belief that mathematics is composed of simple facts may result in a student memorizing formulas and rules instead of looking for underlying patterns connecting those very formulas and rules. (b) A belief that all mathematics problems can be answered quickly may result in a student abandoning effort on a problem after a few moments of thought and struggle. (c) A belief that speed is necessary to demonstrate aptitude in mathematics may cause the slower—but thoughtful—student to lose interest in mathematics under the mistaken assumption that they have no innate talent in mathematics.

Most researchers would acknowledge that it is necessary to understand these possible relationships if we are to support our students as they learn mathematics (and other disciplines). As such, it would be necessary to measure (at least) the five aspects of beliefs about knowledge and learning suggested above. Yet, this is the nature of the current problem: measurement of these beliefs about knowledge and learning has been problematic. Current statistical methods suggest that there are possible psychometric flaws with the surveys used to measure students' beliefs about knowledge and learning. This paper examines the effectiveness of an alternate statistical tool to extract psychometric information from the survey instruments in current use.

Personal Epistemology

The study of knowledge, epistemology, is the field of philosophy in which researchers explore the nature of knowledge, truth and the process of justification. For example, one proposed definition of knowledge is a true and justified belief (BonJour, 2002). In this realm, knowledge is generally understood to relate to a cognitive process, but it is explored as a concept that may (or may not) be separate from the knowing agent. However, as individuals are involved in the construction of their beliefs, it is also possible to explore the process of knowing in the psychological realm. The study of the beliefs that a person holds about knowledge, knowing, learning and the process of justification have come to be termed as personal epistemology (Pintrich & Hofer, 1997).

The origins of personal epistemology began with Perry's (1970/1998) work with Harvard undergraduates. Other researchers proposed additional models for the development of beliefs about knowledge and the process of justification (Belenky, Clinchy, Goldberger, & Tarule, 1986; Baxter Magolda, 1992; King & Kitchener, 1994; Kuhn, 1991). Common features among all of these proposed models included the existence of stages of development and the generally linear progression through the stages. In their extensive review, Hofer and Pintrich (1997) suggested similarities in the stages of these models. One time-consuming aspect of these research protocols was the interview process used to assess a person's epistemic beliefs[1]. As research in the field progressed, surveys were used to obtain data from people in a more efficient manner (Moore, 1989; Schommer, 1990).

One of the earliest surveys to explore epistemic beliefs was Schommer's (1990) Epistemological Questionnaire. This was a 63-item survey. The innovative element of this new tool was that it conceptualized epistemic beliefs along multiple dimensions. It was hypothesized that five relatively independent dimensions underlie students' epistemic beliefs. These dimensions were (a) the structure of knowledge (collections of simple facts vs. a web of interrelated ideas), (b) the certainty of knowledge (answers are either right or wrong vs. assessment is relative to context), (c) speed of acquisition (i.e., knowledge is learnt quickly or not at all), (d) innate ability (fixed vs. malleable intelligence), and (e) authoritarian justification (i.e., knowledge is justified by a more knowledge authority figure). While Schommer's (1990) original analysis confirmed only four of the

[1] Epistemic beliefs will be understood to encompass all the beliefs an individual holds regarding knowledge, learning and justification.

five dimensions (authority was omitted), researchers have since found support for a five-dimensional model (Bendixen, Schraw, & Dunkle, 1998; Jehng, Johnson, & Anderson, 1993).

Along with demonstrating multiple dimensions of epistemic beliefs, it was also demonstrated that students in different academic disciplines held different levels of beliefs (Jehng et al., 1993). However, this interpretation of epistemic beliefs has since been challenged. It has alternatively been suggested that epistemic beliefs are discipline specific and not simply general beliefs about knowledge (Hofer, 2000; Buehl & Alexander, 2002; Schommer & Walker, 1995). Consequentially, to avoid issues of cross-disciplinary interpretation, the survey used in this research was designed to measure five dimensions of epistemic beliefs solely in the discipline of mathematics.

Survey Instruments & Epistemic Beliefs

While the use of survey instruments to measure epistemic beliefs may be a more efficient process to obtain data from larger groups of people quickly, it is necessary to demonstrate that the desired psychometric properties of the tools are present. These, at a minimum, include validity of the measures, internal reliability among the items, and strong fit between the proposed multidimensional model of beliefs and obtained data. To date, there have been issues with (at least) the last two items of this list.

One of the issues raised in their seminal review (Hofer & Pintrich, 1997) was the need to distinguish between epistemic beliefs that examine the nature of knowledge and knowing and those beliefs that examine the nature of instruction and learning (including beliefs about intelligence). This is partially addressed in the multidimensional model. However, it is possible that an item may straddle these philosophical vs. educational distinctions. Take for example: “I will do well in this course if the instructor can explain things well.” This item would generally be classified as an authoritarian belief item. Yet, it suggests a learning element (doing well in the course) and a knowing element (justification provided by well explained examples). Even within multidimensional models, most consisting of 3 to 5 dimensions, this issue has yet to be further explored.

Another issue associated with these survey tools is the choice of items used. As is the case when attempting to measure a latent construct, a single item may be insufficient at directly obtaining a manifest response. As such, collections of related items are provided with the hope that the underlying construct will emerge in a set of consistent and related responses. As exploratory and confirmatory factory analysis (EFA & CFA) have been the statistical tools to assess the presence of multiple dimensions in these surveys, this strategy is appropriate. However, some items have been conspicuous. Reasons for this concern involve nebulous wording, multiple interpretations beyond the academic realm, or cross-discipline interpretations. “Most things worth knowing are easy to understand,” is an example of a nebulously worded item. The word choice “most” may cause students to interpret the item differently. “Scientists can ultimately get to the truth,” is an example of an item that may be interpreted in a religious sense (truth) as opposed to an academic sense (factual). “You can believe most things you read,” is an example of an item that may be interpreted differently across disciplines. A student in a math class may provide a different response from a student in a history class. As the use of such items is acceptable for a latent variable analysis, these issues may be unavoidable, but they still should be carefully considered.

In the process of determining which items are associated with which epistemic belief dimension, researchers have used EFA (Bendixen et al., 1998; Hofer, 2000; Jehng et al., 1993; Schommer, 1990) and CFA (DeBacker, Crowson, Beesley, Thoma, & Hestevold, 2008). While it is ideal to propose a model delineating the number of dimensions with associated items and then test the fit between model and collected data using CFA, initial studies used an EFA approach to ascertain how many latent dimensions might be present. As a result, research has been reported in support of a range between two and five dimensions (see DeBacker et al. [2008] for a summary review). Additionally, EFA is better suited to explore the dimensional structure of uncorrelated or orthogonal latent variables. As it is reasonable to expect multiple dimensions of epistemic beliefs to be correlated in some manner, the CFA strategy is more appropriate as the correlational structure of multiple dimensions can be incorporated into the model. In their exploratory study with multiple survey instruments (DeBacker et al., 2008), it was found that a five dimensional model may be appropriate, but there were issues with goodness-of-fit indices associated with the CFAs, and internal reliabilities among sets of items associated with specific dimensions were low. As data has accumulated over the past two decades, there is adequate (if inconsistent) support of multiple dimensions. At this stage, it would be appropriate to focus on CFA to determine the fit of a proposed model (specifying a fixed number of dimensions) with collected data.

Past research of multidimensional models has had a number of methodological issues. The principal concern was the use of factor analysis applied to subsets of items (Schommer, 1990) as opposed to an analysis of the actual items. The potential problem is that, in the aggregate, correlational affects may be exaggerated (an issue of great concern to factor analysis as the statistical analysis focuses on the variance-covariance relationships). While researchers have since addressed this concern (see DeBacker et al. [2008] for a review), a subsequent issue has arisen regarding poor to weak measures of goodness-of-fit (a measure of how well the model fits the correlational structure of the collected data). The standard for goodness-of-fit is a goodness-of-fit index (GFI) above 0.9; the stronger gold standard is a GFI at or above 0.95 (Byrne, 2006). As might be expected with smaller samples, these goodness-of-fit measures have not been achieved. In their large-sample study of three instruments (DeBacker et al., 2008), reasonable fit indices were obtained for one survey, but even then the measures were not consistently above 0.90. The survey that produced consistent measures above 0.90 was an analysis conducted on subsets of items, thus the model did not assess the goodness-of-fit between the model and the individual survey items. The dimensional structure will best be established when a CFA is tested on a model relating items to a predetermined number of dimensions and fit indices are consistently above 0.90.

Another concern with the current survey instruments is the relatively weak internal consistency measures among subsets of items related to specific dimensions. For example, Bråten & Olaussen (2005) reported internal reliability coefficients between $\alpha = .46$ and .67. This is an issue that appears frequently in this body of research. Some researchers report using the subsets of items with weaker reliability. Other researchers acknowledge the dimensional structure, but only conduct additional analyses on those dimensions with adequate reliability measures. While the use of the personal epistemology surveys is increasing, this is an issue that has yet to be resolved.

Multitrait-Multimethod Confirmatory Factor Analysis

Confirmatory factor analysis (CFA) is the means by which a model of latent variables is proposed to predict the observed relationships between a set of measured variables. From a measurement perspective, this model generally consists of a number of factors (the latent variables) that may or may not be correlated with each other. In turn, these factors predict the measured variables up to an error term. The vocabulary term of "factor" may not be ideal, as in the analysis of variance (ANOVA) conceptualization, a factor is a categorical variable of potential influence; the different categories comprising this variable are labelled levels. Thus, in a two-way ANOVA, one factor may have three levels and another factor may have five. In the CFA terminology, factor refers to each latent variable. In a multidimensional model, this may not be an issue. However, if there are two (or more) collections of dimensions that may influence the observed variables, the terminology becomes convoluted. As such, to mirror the ANOVA formulation, the term factor will be used to describe the collection of dimensions, and the levels will be termed latent dimensions or latent categories.

The multitrait-multimethod (MTMM) CFA (Byrne, 2006) proposes two factors that may influence the observed variables. From the multitrait perspective, there might be a number of latent traits; in the multimethod perspective, the observed variables may be measured by different methods. It is not unreasonable to expect the observed variables to be effected by the trait of influence and the method of measurement. This is comparable to a two-way ANOVA where the first factor is the trait and the second factor is the method of measurement. The latent variables of the model would be the different traits (latent levels under the first factor) and different method influences (latent levels under the second factor). It is proposed that a second factor (comparable to a method effect) is present in the personal epistemology survey instruments currently in use.

Proposal for a Second Factor in the Multidimensional Model

As noted earlier, when studying epistemic beliefs, it is necessary to distinguish between beliefs related to knowledge, knowing or justification and beliefs related to learning or teaching (Hofer & Pintrich, 1997, 2002). Additionally, it is necessary to recognize that the wording of some items may arouse conceptions of knowledge different from that intended by the researcher. For example, religious views (Lodewyk, 2007) may be instantiated when survey items refer to "truth." Researchers have alluded to the possible distinctions between attributes of epistemic beliefs (Kuhn & Weinstock, 2002; Hofer & Pintrich, 1997). What follows is an attempt to distinguish the possible influence of subtle differences that appear in epistemic survey items.

To capture a quasi-method effect (an effect beyond that of the multiple dimensions), the following classification for items appearing in personal epistemology surveys is proposed. Philosophers—particularly epistemologists—study knowledge with the goal of axiomatically classifying beliefs as true, justified, etc. One common example of an axiomatic definition of knowledge is the "true and justified belief" (BonJour, 2002). While the nature of justification may suggest a process, the concern is more on the end result. As such, I propose that items that suggest a formal or inferred definition of knowledge be classified as *axiomatic*. Items suggesting the process of justification—which may be viewed as knowledge creation—alternatively should be classified as *ontological* (as ontology is the study of existence, this term suggests the process of how knowledge might come to exist). Items that may be interpreted in a religious lens should be classified as *deontological* (the study of duty, morality and ethics). Finally, items that refer to the application or use of knowledge should be termed *procedural*.

To illustrate, a few examples from common personal epistemology instruments are classified. The statement, "Absolute moral truth does not exist," would be classified as deontological because it suggests morality and can be construed as a statement of religious or spiritual belief (from the Epistemic Beliefs Inventory [Schraw, Bendixen, & Dunkle, 2002]). "How much a person gets out of school mostly depends on the quality of the teacher," would be classified as ontological because it suggests how students become knowledgeable—how knowledge comes into existence for an individual student (from the Schommer Epistemological Questionnaire [1998]). "It's a waste of time to work on problems that have no possibility of coming out with a clear-cut answer," would be classified as procedural because it suggests a use of knowledge—the application of knowledge would not provide the desired result (Wood & Kardash, 2002). Finally, from her discipline-specific survey (Hofer, 2000), "Principles in this field are unchanging," would be classified as axiomatic because it provides axiomatic information by which knowledge (the principles in the field) can be classified as knowledge (the unchanging nature).

Using this additional classification scheme, items in the survey used in this research will be classified accordingly and will be aligned with an epistemic dimension. As such, the classification scheme will serve the role of a quasi-multimethod (the factor of classification with latent levels of axiomatic, ontologic, deontologic, and procedural). Additionally, the multiple dimensions of epistemic beliefs will serve the role of the multitrait (the factor of dimension with latent levels of certainty, structure, authority, innate ability and speed of acquisition).

As suggested by Byrne (2006), when testing a MTMM CFA model, it is necessary to compare the more complicated model (with essentially two factors of multiple latent levels) with alternate models. The standard models used to compare the MTMM model against are (a) a model with correlated error terms in place of the quasi-method effect, (b) a model with freely correlated dimensions but no quasi-method effect, (c) a model with perfectly correlated quasi-method effects and freely correlated dimensions, and (d) a model with freely correlated dimensions but uncorrelated quasi-method effects. If the MTMM CFA model is found to statistically fit the data better, there is ample evidence to suggest the presence of a quasi-method effect (in this case, a classification effect amongst the items).

Research Questions and Hypotheses

To date, no personal epistemology surveys have been analysed using a MTMM CFA. This is mainly due to the fact that even with surveys intended to measure multiple dimensions, it has not been hypothesized that an additional source of variation might be accounted for among the survey items. This research attempts to explore whether an additional factor of latent levels, a quasi-method effect associated with item classification, should be included in the survey analysis. As such, the hypotheses to be explored in this project are: (1) The MTMM CFA analysis of a multidimensional personal epistemology survey that incorporates a quasi-method effect associated with item classification will produce high goodness-of-fit measures supporting the existence of five distinct (but potentially correlated) epistemic belief dimensions. (2) The MTMM CFA will consistently produce higher goodness-of-fit measures compared to those observed to date using CFA on items (not subsets of items) aligned with multiple dimensions. (3) The MTMM CFA will be the superior model regarding goodness-of-fit between model and data when compared to alternate models associated with the introduction of a potential quasi-method effect.

Method

Participants and Procedures

Data was collected from one community college district containing three schools located in a greater metropolitan area in the Pacific Northwest region of the USA. Data was collected over two terms (Autumn 2008 and Winter 2009). Participants were recruited from a variety of mathematics classes ranging from Pre-Algebra to Introduction to Differential Equations. For the first term, there were 381 respondents to the pre-survey and 351 respondents to the post-survey with 276 responding to both surveys (unique $n = 456$). For the second term, there were 359 respondents to the pre-survey and 333 respondents to the post-survey with 249 responding to both surveys (unique $n = 443$).

Across the two terms, the mean age was $M = 24.1$ years ($SD = 6.7$), with ages ranging from 16 to 61, and 84.8% of the students were 18 to 29 years old[2]. The sample consisted of 48.7% male respondents and 51.1% female respondents; a total of 41 students did not report a gender, and 2 participants were trans-identifying individuals. In the two terms, 1291 students indicated race in a clearly discernable manner (9.1% of the participants did not provide information on race or ethnicity). Of the self-identified group of respondents, 46.9% where white, 36.9% were Asian, 7.2% were black, 3.4% were Latin@, 2.2% were Arab, 1.2% were Native American, and 2.2% indicated mixed race. These proportions of represented ethnicities and races were not disproportionate from the district as a whole (47% students of colour).

All students participating were invited to take the survey twice each term, once near the start of the term and once near the end. Surveys were completed online, and in most cases, students received a minimal amount of course credit for participating. Additionally, participation was encouraged via a random drawing for 2 $50-gift cards and an iPod Shuffler that was conducted each term.

Measures

Participants completed an online survey intended to measure motivation, epistemic beliefs, affect and demographic information. All items, as appropriate, were written in a manner appropriate to the discipline of mathematics. While the data collection was part of a larger study, only the epistemic beliefs are examined here. The portion of the survey measuring epistemic beliefs consisted of 25 items that were chosen—and revised as necessary—from a large collection

[2] Four students reported ages under 18; these students were excluded because parental consent was not obtained.

of previously published survey items (Schraw et al., 2002; Schommer, 1998; Wood & Kardash, 2002; Hofer, 2000; Hofer & Pintrich, 2002).

Epistemic dimensions.

In line with the original multidimensional framework proposed by Schommer (1990), items were chosen to measure five distinct dimensions of epistemic beliefs. Students were asked to indicate their level of agreement with a list of statements using a Likert scale (strongly disagree, disagree, neutral, agree, strongly agree). For each dimension, five items were chosen for their lack of ambiguity and consistent association with the proposed dimension in earlier research. Items were coded so that a higher score (agree and strongly agree) would indicate a less sophisticated epistemic belief. The certainty dimension measures beliefs about answers being right or wrong compared with the belief that the accuracy of an answer may be more context-dependent. An example for this dimension is, "The best thing about math courses is that most problems have only one right answer." The simple dimension measures beliefs that knowledge is a collection of simple and distinct facts compared with the belief that knowledge is an interconnected web of ideas. An example for this dimension is, "I try my best to combine information from math class with knowledge I have about other topics" (this item was reverse coded). The authority dimension measures beliefs that knowledge is given and confirmed by an omniscient authority compared with a belief that knowledge is justified by appropriate arguments of the knower. An example for this dimension is, "How much math a student learns mostly depends on the quality of the teacher." The innate ability dimension measures beliefs that intelligence is an attribute fixed at birth compared with the more malleable belief that individuals can learn how to learn. An example from this dimension is, "How well you do in math class depends on how smart you are." The final dimension is the speed of acquisition; this dimension measures beliefs that learning occurs quickly or not at all compared with beliefs that some learning requires diligent persistence. An example from this dimension is, "If a person spends too much time trying to understand a problem, they will most likely just end up being confused." The complete list of 25 items of the survey (5 items grouped into 5 dimensions each) can be seen in the Appendix.

Philosophical classification.

Items selected for the five epistemic belief dimensions were next classified as axiomatic, ontologic, deontologic or procedural. Items that were ambiguous (e.g., "A course in study skills would probably be valuable") were not classified and were omitted from the survey. Additionally, as the possible religious or moral concept was perceived as potentially ambiguous for some participants, no deontological items were included. At most, two classifications were used within each dimension. An example of an item classified as axiomatic is, "What is true in mathematics today will be true in mathematics tomorrow," as this concept of "truth" provides an axiomatic definition for knowledge in the discipline of mathematics. An example of an item classified as ontologic is, "The more mathematics you know, the more there is to learn," as this suggests the process of learning (knowledge creation). Finally, a procedural item that suggests how knowledge is used as opposed to created or defined is, "When someone who knows more math than I do tells me what to do, I usually do it." Of the final list of 25 items, 3 were classified as axiomatic, 16 as ontologic and 6 as procedural. The complete list of classifications can be seen in the Appendix.

Results

From the pre- and post-surveys from both academic terms, there were 1420 subjects who provided information on the 25 personal epistemology items (with a missing response rate of 0.4%). As is discussed below, 6 of these items were not used in the composite scales, and the remaining information refers to the subset of 19 items used. Data was retained for participants that answered all 19 items, leaving a final sample size of $n = 1345$.

The data collection process imposed two important constraints that were subsequently addressed in the statistical analyses. Data was collected from some individuals at more than one time (pre- and post-survey in two terms). This means that multiple responses were obtained from the same individual. Additionally, it is possible that time of collection influenced student responses. To address the first concern, a data set of randomly chosen single appearances was tested. Comparable results were obtained to those from the analysis of the complete data set. This suggests that the five-factor MTMM solution is invariant across test-retesting situations, thus supporting test-retest reliability of the survey instrument. As such, results for the complete data set are presented. The possible effect of time of data collection was also examined by comparing models across time groupings (pre-post testing and the two academic terms). The final model demonstrated relative invariance across time (term: CFI = 0.937 & RMSEA = .024; pre-post: CFI = 0.938 & RMSEA = .024).

Prior to assessing the MTMM CFA, the survey items were examined to determine if some items should be omitted from the analysis. This was done by examining a random split-half of the data set. Items were removed from the model, and correlations between latent variables were introduced into the model. The resultant model was then confirmed on the remaining half of the data set. Results strongly indicated agreement between the two analyses, and the remaining analyses were conducted on the entire data set. It is necessary to note that this EFA differs from previous processes as it was not used to determine the number of factors (this was always assumed to be five, as the theory suggests), and this was not used to determine which items loaded onto which factors (this was assumed prior to the model). The purpose of the EFA was solely to remove items. The intention was to obtain dimensions that might have higher internal reliabilities when examined separately (a desired psychometric property allowing cross-sample analysis and comparisons).

The method used to assess possible adjustments to the model followed these criteria. Ideally, at most one—but no more than two—items per dimension would be dropped. An item would be dropped if exceptionally weak loadings were observed on both latent variables associated with that item. Additionally, the Lagrange Multiplier (LM) test was used to determine if the model fit would increase if a constraint were to be freely estimated. (The main purpose for this was to locate correlations between latent variables, but an item could be dropped if the model suggested strong loading on a latent variable other than that suggested by theory.) Correlations between the latent variables (traits and quasi-methods) were not forbidden by the multidimensional epistemic belief model. Thus, inclusion of these parameters in the model seemed acceptable.

In the end, 19 items were retained. Each dimension retained 4 items except the structure dimension; this dimension retained three items (factor loadings and communalities presented in Table 1). Additionally, the final model had no error correlations and included the following latent variable correlations: authority-ontologic, certainty-ontologic, structure-axiomatic, and structure-ontologic. The overall fit of the model was strong: $\chi^2(116) = 342.35$, $p < .001$; NFI = 0.909; CFI = 0.937; GFI = 0.974; AGFI = 0.958; SRMR = .031; RMSEA = .038, 90% C.I. (.033, .043). As a concern regarding lack of normality was indicated in some of the item responses, a robust maximum likelihood analysis was run. Results were comparable (and stronger), suggesting the lack of normality was not an issue for concern.

The reliability coefficient was $\rho = .725$ for this model. This value would indicate a moderate—but psychometrically acceptable—internal consistency. While it was hoped that removing items might increase the internal reliability of the subscales, the Cronbach's α values for the subscales were all $\alpha = .595$ or lower. See Table 2 for summary statistics for each epistemic belief dimension.

Next, it was necessary to confirm that the MTMM structure is the appropriate model for this data. As is customary, 3 pairs of models were examined in comparison to the MTMM model. The first pair examines the model where one set of traits is missing, and the remaining set of traits is free to correlate (no traits with correlated methods and correlated traits with no methods; models 2a and 2b, respectively). These models would be comparable to one-factor of influence, as opposed to two-factors of influence. The second pair examines the models where one set of traits is perfectly correlated, and the remaining set of traits is free to correlate (perfectly correlated traits with freely correlated methods and freely correlated traits with perfectly correlated methods; models 3a and 3b, respectively). These models assume the influence of a method effect, but as a single global influence, as opposed to a differentiated form of influence. The final pair examines the model where one set of traits is freely correlated, and the remaining set of traits is strictly uncorrelated (freely correlated traits with uncorrelated methods and uncorrelated traits with freely correlated methods; models 4a and 4b, respectively). It is customary to only analyse one of each pair in an MTMM analysis. However, since the second dimension is not truly conceptualized as a "method," it is more appropriate to treat both dimensions as quasi-traits, and thus it is prudent to run all pairs of analyses. Results are summarized in Table 3.

Discussion

The principal hypothesis for this research project was that the MTMM CFA analysis of a multidimensional personal epistemology survey incorporating a quasi-method effect associated with item classification would support the existence of five distinct epistemic belief dimensions. The NFI and CFI are both above 0.90 but below 0.95, thus suggesting adequate—if not excellent—fit between the model and the data. Alternatively, the GFI and AGFI are both above 0.95 suggesting superior fit between the model and the data. Further evidence for superior fit is an SRMR less than .05 along with the bound on the 90% confidence interval for the RMSEA that was below .05. As the goodness-of-fit measures were strong to excellent, this hypothesis appears to be confirmed. Furthermore, while this research project did not attempt to address the content validity of the survey, it is noted that these items have consistently been associated with comparable epistemic belief dimensions in other analyses (DeBacker et al., 2008; Schraw et al., 2002; Schommer, 1998; Wood & Kardash, 2002; Hofer, 2000; Hofer & Pintrich, 2002).

The five epistemic belief dimensions were found to be distinct traits. However, it was also observed that there was a correlation between these beliefs. As the dimensions all relate to a person's belief in knowledge or learning, this correlation would not be unexpected. The correlations were not strong, ranging from $r = .20$ to .43, but they were significant. The strongest correlations appeared between the dimensions of innate ability and quick learning and between innate ability and authority. As these dimensions were more related to instruction and learning as opposed to knowledge and knowing, this is a reasonable finding.

Another subtle element of the findings provides support for the quasi-method effect. The factor loadings for the epistemic belief dimensions, with reverse coding as appropriate, all have positive signs. This would be expected as the epistemic belief would be expected to influence each manifest item in a unidirectional manner. However, it is noted that the quasi-method effect was positive in all items except those items that were reverse coded. This suggests an influence related to the actual item (the method) as opposed to the content of the item (the relation to the latent trait being measured).

The second hypothesis was that the goodness-of-fit measures would be consistently higher than those observed to date using CFA on items aligned with multiple dimensions. While it is not possible to statistically test such a claim, it is noted that to date, this is the only analysis conducted that has produced fit statistics in the strong to excellent range for all standard measures. Thus, this provides support for the existence of the five epistemic belief dimensions, and it provides compelling evidence for the need to consider other influential elements of the survey items in future studies.

While space limitations prohibit a more detailed analysis of the alternate models that should be considered when testing a MTMM CFA model, it is important to note that one model was excluded: the correlated uniqueness model. This model assumes that multiple dimensions exist, but the method effect is modelled by correlations among the error terms, as opposed to a new set of latent variables. An attempt was made to test this model, but convergence issues prevented doing so. The strongest support for the existence of the quasi-method effect was the comparison of the MTMM CFA model to the single-factor models (the first pair of alternate models). The models proposing one-factor of influence demonstrated much poorer fit indices and the MTMM model was statistically significantly superior. It was noted that the only alternate model that suggested adequate fit was a multidimensional model with a perfectly correlated quasi-method effect (model 3b: one general method effect as opposed to distinct method effects). However, a chi-square test supports the claim that the MTMM model is the better fit ($\Delta\chi^2(4) = 28.0$, $p < 0.001$). In total, these analyses provide strong evidence in support of the hypothesis that the MTMM CFA model is the superior model regarding fit to the observed data.

As noted, the reliability coefficient ($\rho = .725$) would indicate a moderate—but psychometrically acceptable—internal consistency. Yet, this consistency depends on the MTMM analysis, and this internal consistency may not be present with simple aggregate measures for each subscale or dimension of the epistemic beliefs (e.g., creating a scale by averaging the item responses in each dimension). While it was hoped that removing items might increase the internal reliability of the subscales, the Cronbach's α values for the subscales were exceptionally low (all below $\alpha = .595$).

Future Research

One unforeseen artefact of the choice of items was the collusion effect of the axiomatic classification with the certainty belief dimension. The classifications for procedural and ontologic cross at least two epistemic belief dimensions. However, as the axiomatic classification appears only in the certainty belief dimension, there is some concern that the weak factor loadings on this epistemic belief dimension may be confounded. As this is not a standard factor analysis, the introduction of the MTMM model can account for slightly smaller factor loadings than traditionally accepted. However, this should be explored with future research that includes items classified as axiomatic across more than one epistemic belief dimension.

Regarding additional items, it is recommended that future research be conducted with larger sets of items in the hope that improved internal reliabilities can be obtained for aggregate subscales for each epistemic belief dimension. Aggregate subscales are more desirable than the latent factor scores because this will permit comparison of epistemic beliefs across samples. Additionally, with the introduction of more items, it would be possible to consider introducing items classified as deontologic.

In conclusion, it has been hypothesized that five distinct epistemic belief dimensions influence people's responses to personal epistemology surveys. Yet, this had yet to be strongly confirmed with CFA. This research demonstrated a very strong fit between a model proposing five dimensions of epistemic belief and observed data. With the use of the MTMM CFA model, it is possible to examine the relationship of all five distinct dimensions of epistemic beliefs with other academic variables, including motivation (Ricco, Pierce & Medinilla, 2010), academic performance (Lodewyk, 2007), and self-efficacy (Bandura, 1997). The current findings indicate that concerns with sample-specific analyses will need to be examined in future research. Refinements to the survey used here and alternate analysis of other surveys currently being used in the literature should strengthen the psychometric reliability of the instruments and provide rich avenues of exploration of areas of research in educational psychology.

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Appendix

Epistemic belief survey items grouped by dimension and classification.

	A	O	P
Certainty			
If two students are arguing about a math problem, at least one of them must be wrong.	✓		
What is true in mathematics today will be true in mathematics tomorrow.	✓		
The best thing about math courses is that most problems have only one right answer.	✓		
If mathematicians try hard enough, they can find the answer to almost every problem.		✓	
The most important aspect of mathematical work is precision and careful work.		✓	
Structure			
I try my best to combine information from math class with knowledge I have about other topics.		✓	
The more mathematics you know, the more there is to learn.		✓	
Being a good math student generally involves memorizing procedures and formulas.			✓
It's a waste of time to work on math problems that have no possibility of coming out with a clear-cut answer.			✓
Mathematical information should be presented in a straightforward fashion; students should not have to read between the lines.			✓
Authority			
Sometimes you just have to accept answers from a math instructor even though you don't understand them.		✓	
How much math a student learns mostly depends on the quality of the teacher.		✓	
When someone who knows more math than I do tells me what to do, I usually do it.			✓
The most important part of being a good math student is original thinking.			✓
When you first encounter a difficult concept in a math textbook, it's best to work it out on your own.			✓
Innate Ability			
Really smart students don't have to work hard to do well in math classes.		✓	
How well you do in math class depends on how smart you are.		✓	
People's mathematical abilities are fixed at birth.		✓	
Genius is 10% ability and 90% hard work.		✓	
Working hard on a difficult problem for an extended period of time only pays off for really smart students.		✓	
Quick-Learning			
Successful math students understand things quickly.		✓	
Working on a math problem with no quick solution is a waste of time.		✓	
Working on a difficult math problem for an extended period only pays off for really smart students.		✓	
If a person can't solve a math problem in a short amount of time, they should keep on trying.		✓	
If a person spends too much time trying to understand a problem, they will most likely just end up being confused.		✓	

A: axiomatic; O: ontologic; P: procedural

Table 1. Epistemic belief subscales (with MTMM) and factor loadings

C	I	A	S	Q	O	P	Ax	Subscales & items	R^2
								Certainty	
.438					.360			The most important aspect of mathematical work is precision and careful work.	.17
.193							.441	What is true in mathematics today will be true in mathematics tomorrow.	.23
.340					.491			If mathematicians try hard enough, they can find the answer to almost every problem.	.20
.086							.454	The best thing about math courses is that most problems have only one right answer.	.21
								Innate Ability	
	.561				.339			Really smart students don't have to work hard to do well in math classes.	.43
	.421				.454			People's mathematical abilities are fixed at birth.	.38
	.553				–.233			Genius is 10% ability and 90% hard work.*	.36
	.359				.438			How well you do in math class depends on how smart you are.	.32
								Authority	
		.363			.432			Sometimes you just have to accept answers from a math instructor even though you don't understand them.	.18
		.352				–.130		When you first encounter a difficult concept in a math textbook, it's best to work it out on your own.*	.14
		.469				–.299		The most important part of being a good math student is original thinking.*	.31
		.362				.478		When someone who knows more math than I do tells me what to do, I usually do it.	.36
								Structure	
			.579			.315		It's a waste of time to work on math problems that have no possibility of coming out with a clear-cut answer.	.43
			.381		–.221			I try my best to combine information from math class with knowledge I have about other topics.*	.16
			.521		–.299			The more mathematics you know, the more there is to learn.*	.30
								Quick-Learning	
				.421	.462			Working on a difficult math problem for an extended period only pays off for really smart students.	.39
				.664	.399			Working on a math problem with no quick solution is a waste of time.	.60
				.388	.225			If a person spends too much time trying to understand a problem, they will most likely just end up being confused.	.20
				.414	–.080			If a person can't solve a math problem in a short amount of time, they should keep on trying.*	.18

C: Certainty; I: Innate Ability; A: Authority; S: Structure; Q: Quick-Learning; Ax: axiomatic; O: ontologic; P: procedural. Reverse coded items indicated with a (*). The single factor loading not significant at the α = .05 level indicated in bold. n = 1345.

Table 2. Epistemic belief subscales: Summary statistics, reliabilities and correlations

M (*SD*)	α		Certain	Innate	Authority	Structure	Quick
7.4 (2.1)	0.463	**Certain**		0.196	0.209	0.220	0.177
2.6 (1.4)	0.576	**Innate**			0.432	0.217	0.398
5.0 (1.5)	0.595	**Authority**				0.244	0.243
2.5 (1.4)	0.242	**Structure**					0.242
2.4 (1.3)	0.400	**Quick**					

Correlations predicted by the MTMM CFA model. *n* = 1345.

Table 3. Summary of goodness-of-fit for related MTMM models for epistemic beliefs

Model	χ^2	d.f.	SRMR	CFI	RMSEA	90% C.I.
1 freely correlated beliefs freely correlated classifications	342.35	116	0.031	0.937	0.038	(0.033,0.043)
2a no beliefs freely correlated classifications	1472.0	149	0.081	0.633	0.081	(0.077,0.085)
2b freely correlated beliefs no classifications	1099.7	142	0.074	0.734	0.071	(0.067,0.075)
3a perfectly correlated beliefs freely correlated classifications	594.59	126	0.039	0.870	0.053	(0.048,0.057)
3b freely correlated beliefs perfectly correlated classifications	370.31	120	0.032	0.931	0.039	(0.035,0.044)
4a freely correlated beliefs uncorrelated classifications	615.03	122	0.058	0.863	0.055	(0.051,0.059)
4b uncorrelated beliefs freely correlated classifications	838.62	127	0.069	0.803	0.065	(0.060,0.069)

Model 3b respecified with a latent factor correlation set to zero (structure and axiomatic). Model 4a respecified with an equality constraint imposed between a certainty item (E5) and a quick-learning item (E22), between an innate ability item (E9) and the same quick learning item (E22), and with a latent factor correlation set to zero (authority and ontologic). Model 4b respecified with an equality constraint imposed between an authority item (E15) and a quick learning item (E22).