Developmental Changes in College Engineering Students' Personal Epistemology Profiles

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Abstract

The current study empirically tested Greene, Azevedo, and Turney-Purta's (2008) combined theory of personal epistemology development among a sample of college engineering students ($N = 917$). Participants were invited to complete surveys assessing personal epistemology at the beginning and end of a semester. Using cluster analysis, students were categorized into six clusters. Four of these clusters mapped onto the epistemic positions predicted by the combined theory (*realist*, *dogmatist*, *skeptic*, *rationalist*), with two novel groups identified (*uncommitted*, *low-all-beliefs*). Shifts between clusters over the semester were examined. There was evidence for some of the theoretically predicted shifts in membership (i.e., skeptics to rationalists), but not others (i.e., realist to dogmatist or skeptic; dogmatists to rationalist). Finally, dogmatists earned lower course grades than students in other clusters. Implications for educational practice and proposed modifications to the combined theory of personal epistemology development are discussed.

Keywords: personal epistemology; development; undergraduate engineering education; person-centered

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Whether solving math problems, determining the reliability of Internet sources, or considering two sides of a debate, students constantly evaluate claims about knowledge. The way that individual students think about knowledge, which is referred to as their personal epistemology, has implications for learning strategies (Muis, 2004, 2007), motivation (Bråten & Strømsø, 2004; Buehl & Alexander, 2005; Chen, 2012), and achievement (Muis, 2004; Schommer, 1993; Trautwein & Lüdtke, 2007). Therefore, understanding the development of students' personal epistemologies through education is a critical task facing researchers and educators.

Several researchers have attempted to consolidate the vast literature on personal epistemology (e.g., Chinn, Buckland, & Samarapungavan, 2011; Hofer & Pintrich, 1997) or meld different viewpoints into a unified theory (e.g., Greene, Azevedo, & Torney-Purta, 2008; Muis, Bendixen, & Haerle, 2006). These approaches suggest that there is substantial heterogeneity in individuals' epistemologies (*multi-dimensional perspective*) and that beliefs change over time (*developmental-positions perspective*). In the current study, we tested Greene and colleagues' (2008) combined theory of personal epistemology development in a sample of college engineering students. Specifically, we used person-centered analyses to investigate what epistemic profiles emerged, how students shifted between profiles over time (a critical gap in the current literature), and how profiles predicted achievement.

1. Theoretical Background

Personal epistemology refers to beliefs about the nature and origins of knowledge (Hofer & Pintrich, 2002). Various terms are used in this field, including epistemic beliefs (e.g., specific beliefs about the nature of knowledge and knowing, Muis, 2007), personal epistemology (e.g., a system of epistemic beliefs, Green et al., 2008), and epistemic cognition (e.g., all mental processes associated with knowledge, Chinn et al., 2011). In keeping with these distinctions, we use personal epistemology to refer to sets of epistemic beliefs (e.g., dogmatism) and epistemic belief to refer to specific dimensions (e.g., simple/certain knowledge).

Two common perspectives on personal epistemology are the developmental-positions perspective and the multi-dimensional perspective. The developmental-positions perspective proposes that individuals systematically progress through different stages in their conceptualization of knowledge and knowing (see Hofer & Pintrich, 1997). At each stage, individuals take a particular stance towards knowledge (Chinn et al., 2011) such that they believe knowledge has a particular structure and manner of justification. Within the developmental-positions perspective, young children tend to be *realists*¹ (Chandler et al., 2002; Kuhn, Cheney, & Weinstock, 2000). Realists accept all information as true knowledge, regardless of the source (Burr & Hofer, 2002). As children gain more experience with knowledge claims, they gradually realize that not all information is true and progress to *dogmatism* or *skepticism*. Unlike realists, dogmatists rely entirely on authority figures as sources of knowledge. In contrast to realists or dogmatists, skeptics (or multiplists, Kuhn et al., 2000) reject the concept of true

¹While theoretical models use each term with slightly different connotations (Wildenger, Hofer, & Burr, 2010), the general developmental assumptions and trajectories bear many similarities. We focus on Chandler and colleagues (2002) description of development, as this view influenced the combined perspective (Greene et al., 2008).

knowledge and treat all opinions as equally valid. Dogmatism and skepticism represent dual pathways of personal epistemology development in this view (see Figure 1). The final stage of development is *rationalism* (or evaluativism, Kuhn et al., 2000).

Rationalists weigh and evaluate multiple sources of knowledge, taking a balanced view on how knowledge can be justified by both authority figures and personal experience in different contexts.

The precise timing of development remains contentious, ranging from occurring entirely during college (e.g., Perry, 1970) to progressing from early childhood to adulthood (Kuhn, Cheney, & Weinstock, 2000; Wildenger, Hofer, & Burr, 2010). Discrepant predictions might be due to the domain-specificity of personal epistemology (e.g., Buehl & Alexander, 2006; Muis et al., 2006). Students progress earlier in some domains (e.g., history) than other domains (e.g., mathematics; Greene et al., 2008). While the timing and nomenclature vary across researchers, the fundamental pattern of development is consistent.

In contrast to the developmental-positions perspective, the multi-dimensional perspective conceptualizes personal epistemology as a set of independent epistemic beliefs. Schommer (1990) provided early evidence of distinct belief dimensions using factor analysis. Among many belief dimensions, she consistently identified the belief in the *simplicity of knowledge* (i.e., knowledge is a collection of unambiguous facts) and *certainty of knowledge* (i.e., some true knowledge exists; Schommer, 1990, 1993; Schommer, Crouse, & Rhodes, 1992). Schommer (1990) also hypothesized that students had varying beliefs about *omniscient authority*: that knowledge is handed down by authority figures.

Building from prior research, Hofer (2000; Hofer & Pintrich, 1997) further differentiated multiple dimensions into beliefs about *knowledge* and *knowing*. Greene and colleagues (2008) noted three of Hofer's dimensions that relate to developmental positions: (1) *simple/certain knowledge* (belief that knowledge is composed of a collection of unchanging facts), (2) *justification by authority* (belief that knowledge is handed down by authority figures), and (3) *personal justification* (belief that individuals can each construct different views of knowledge). Beliefs about simple/certain knowledge were reframed as components of ontological cognition and beliefs about the source of knowledge as epistemic cognition. Many researchers note methodological issues with using surveys to measure epistemic beliefs, including low measurement reliability (DeBacker, Crowson, Beesley, Thoma, & Hestevold, 2008; Hofer & Sinatra, 2010) and the implication that each dimension has an adaptive, and non-adaptive extreme (e.g., low justification by authority is adaptive; Muis, 2004; Schommer, 1990).

Synthesizing across the developmental-positions and multi-dimensional perspectives, Greene and colleagues' (2008) proposed a combined theory describing different developmental positions (realists, dogmatists, skeptics, rationalists) based on simple/certain knowledge, justification by authority, and personal justification epistemic beliefs from the multi-dimensional perspective (see Figure 1). Specifically, they proposed *realists* strongly endorse simple/certain knowledge, justification by authority, and personal justification. The other three positions reject the notion of simple/certain knowledge, but are differentiated by varying beliefs about knowledge sources. *Dogmatists* strongly endorse justification by authority, but not personal justification. *Skeptics* strongly endorse personal justification but not justification by authority. *Rationalists* weigh and evaluate different sources of knowledge depending on the

circumstance, and therefore endorse moderate, balanced levels of personal justification and justification by authority.

The combined perspective offers several advantages. First, it combines two distinct theories for additional parsimony. Second, it acknowledges that epistemic beliefs coexist within an individual rather than assuming that they act independently (e.g., Hofer & Pintrich, 1997; Schommer et al., 1997). This corresponds with recent theoretical understandings of students' systems of beliefs (Schommer-Aikins, 2004; Chen & Barger, in press) and treats each person as an "organized whole" (Magnusson, 1998, p. 3). Third, this perspective acknowledges that it is sometimes appropriate to listen to experts. This differs slightly from the multi-dimensional perspective, which asserts that justification by authority beliefs are less mature. Finally, the combined perspective allows researchers to use survey measures to approximate individuals' developmental positions, which is traditionally done via time-consuming interviews.

When testing the combined perspective the main theoretical question is no longer, "What is the typical trajectory?" or "What dimensions matter?" Instead, researchers must ask (1) "What combination of dimensions exist in individuals?" (2) "Do these combinations resemble developmental positions?", and (3) "How do individuals move from one systematic combination of dimensions to another over time?" A person-centered approach (Bergman, Magnusson, & El Khouri, 2003; Laursen & Hoff, 2006) is well-positioned to answer the questions relevant to a combined perspective of personal epistemology. Person-centered analyses identify naturally-occurring combinations of variables and group similar individuals into categories (Hair, Anderson, Tatham, & Black, 1998). Such analyses provide insight into whether observed combinations of

epistemic beliefs (i.e., epistemic profiles) map on to theoretically-hypothesized combinations.

Several researchers have examined profiles of epistemic beliefs (Buehl & Alexander, 2005; Chen, 2012; Ferguson & Bråten, 2013; Greene et al., 2010). In one study, Buehl and Alexander (2005) created profiles of undergraduates' epistemic beliefs in mathematics and history using simplicity, certainty, and justification by authority dimensions. In both subjects, a group of students with relatively low simple and certain knowledge beliefs but high justification by authority beliefs was identified; this group might indicate either dogmatism (if accompanied by low personal justification) or rationalism (if accompanied by moderate personal justification). There were also groups low in simple/certain knowledge and justification, possibly indicating skepticism, and those moderately high on both domains, possibly indicating realism. Greene and colleagues (2010) conducted a person-centered analysis using all the dimensions in their combined model with middle-school to graduate students in mathematics and history. They identified six profiles, several of which mapped onto hypothesized personal epistemology positions (e.g., realists and skeptics in mathematics; skeptics and rationalists in history). The remaining profiles, however, did not fit with hypothesized positions. Older participants (e.g., college, graduate school) were more likely to endorse advanced positions, suggesting a general advancement in personal epistemology by educational experience. However, the cross-sectional design limits claims about how individuals move from one developmental position to the next.

2. Current Study

This study provides a critical extension to prior work on the combined perspective of personal epistemology by (1) investigating short-term changes in students' systems of

epistemic beliefs, or epistemic profiles, from the beginning to end of a fifteen-week semester and (2) relating epistemic profiles to achievement among college engineering students. Because personal epistemology has both domain-general and domain-specific components (Buehl & Alexander, 2006; Muis et al., 2006), it is important to consider domain when examining development. We selected undergraduate engineering for several reasons. First, engineering is considered a “hard,” structured domain (Biglan, 1973). It takes extensive experience before students fully appreciate the complexities of engineering’s problem-solving paradigms. Therefore, shifts away from realism should occur during college (Greene et al., 2008). Second, students are unlikely to have experience with engineering prior to college. Accordingly, students may not yet have a strongly committed attitude toward a particular system of beliefs, or strong epistemic stance (Chinn et al., 2011), towards engineering knowledge. Therefore, short-term shifts may be more likely in engineering than other subjects where college students have prior experience (e.g., mathematics). Finally, engineers are problem-solvers (Sevier, Youn Chung, Callahan, & Schrader, 2012), and should therefore benefit from possessing rationalist beliefs that treat knowledge as complex and coming from multiple sources. Thus, a better understanding of development should provide insights into how to structure engineering education to support rationalist beliefs.

The current study sought to answer three questions. First, what profiles exist? We expected realism, dogmatism, skepticism, and rationalism profiles, because Greene and colleagues (2008) argued that shifts shown in Figure 1 all occur during the college years in well-structured domains. We also anticipated potential profiles that did not fit with theory, in light of Greene and colleagues’ (2010) findings. For example, some students might endorse average levels of all beliefs, representing a lack of commitment (Chinn et

al., 2011) to a particular epistemic stance towards engineering. Our second research question asked how students develop and transition between profiles. Within-subjects, we expected developmental trajectories from realism to skepticism or dogmatism, and then to rationalism (Chandler et al., 2002; Figure 1). Cross-sectionally, we hypothesized that there would be a wide degree of variability at each class level, as students develop at different rates (Greene et al., 2010; Kitchener & King, 1981), but that advanced students would generally belong to more advanced epistemic profiles than introductory students. Our final research question examined the relation between profiles and achievement. We hypothesized that students in later stages of development (i.e., rationalism) would perform better, given prior research on the adaptiveness of low simple/certain knowledge (e.g., Muis, 2004; Trautwein & Lüdtke, 2007) and underlying assumptions from the developmental-positions perspective that advancement should produce success at higher levels of education.

3. Method

3.1 Participants

Participants were students from six introductory ($n = 671$) and advanced ($n = 246$) undergraduate engineering courses in thirteen classrooms in the southeastern United States (82% consent rate). The sample was majority male (65.1%) and racially mixed (50% Caucasian, 28% Asian, 6% Latino/a, 4% African American, 8% multiracial/other, 4% no response). The introductory course was a programming course required for all engineering students; students were almost exclusively first-year students (96.8%, $M_{age} = 18.2$ years). Advanced students were enrolled in upper-level courses on digital signaling, sustainable design, or concrete/composite structures. Students in advanced courses (M_{age}

= 20.0 years) included mostly sophomores (43.2%), juniors (24.5%), and seniors (31.4%).

3.2 Procedure

Participants completed surveys in class in weeks 2 (T1, $n = 832$) and 15 (T2, $n = 705$) of a 15-week course, with 620 students completing both surveys. Students completing both surveys did not significantly differ from single-survey participants in their epistemic beliefs, though they did receive higher final grades ($M = 89.07$, $SD = 6.84$) than single-survey participants ($M = 86.87$, $SD = 8.53$; $F(1, 856) = 15.456$, $p < .001$). Five surveys were removed before conducting analyses for non-compliance (i.e., all 3's). Students participated voluntarily, receiving no compensation.

The surveys were administered to intervention ($n = 376$) and no-treatment comparison ($n = 543$) students as part of a larger, 4-semester study evaluating a classroom intervention to increase students' interest in engineering through real-world problem solving projects (Authors, 2014). Intervention students applied classroom material to a central project addressing one of the "Grand Challenges" that will confront engineers in the near future. While the intervention was not specifically designed to change epistemic beliefs nor was it of primary interest to the current study, the intervention condition was taken into account in all preliminary analyses. The intervention did not affect students' epistemic beliefs (see below).

3.3 Measures

3.3.1 Epistemic beliefs. The survey contained engineering-specific items derived from two measures (Hofer, 2000; Greene et al., 2010). Each item was rated on a 5-point scale from 1 (strongly disagree) to 5 (strongly agree), thus providing a neutral midpoint. Using the participants from the first semester of the study ($n = 289$), we first conducted

exploratory factor analyses of T1 surveys. We excluded items that did not strongly load onto hypothesized factors or cross-loaded onto multiple factors, reducing the items 25 to 18 items. We tested the revised scale at T2 with the same sub-sample using confirmatory factor analysis ($\chi^2(132) = 325.11, p < .001, CFI = 0.88, RMSEA = 0.064$). The final factor solution captured simple/certain knowledge ($\alpha_{T1} = .76, \alpha_{T2} = .82$), justification by authority ($\alpha_{T1} = .78, \alpha_{T2} = .81$), and personal justification ($\alpha_{T1} = .70, \alpha_{T2} = .71$; see Appendix A for final items). Fit indices for the complete dataset suggested reasonable fit (T1: $\chi^2(132) = 606.71, p < .001, CFI = 0.87, RMSEA = 0.065$; T2: $\chi^2(132) = 545.63, p < .001, CFI = 0.89, RMSEA = 0.065$), comparable to past epistemic belief measures (DeBacker et al., 2008; Greene et al., 2010).

3.3.2 Demographic variables and course grades. At the end of the first survey, students reported their gender, race/ethnicity, and year in school. Instructors provided unadjusted overall course grades for consenting students ($M = 88.6, SD = 7.3$, 100-point scale). Course grades for classes were not curved and were based on exams, assignments, laboratory grades, and homework assignments.

4. Results

4.1 Cluster Analysis

To identify epistemic profiles, we employed an I-States as Objects Analysis procedure (ISOA; Bergman & El-Khoury, 1999). We first removed outliers using Grubb's test (Bergman et al., 2003), then conducted a hierarchical (Ward's) followed by a nonhierarchical clustering procedure (k means; Aldenderfer & Blashfield, 1984; see Hair, Anderson, Tatham, & Black, 1998). In ISOA analyses, participants' responses at each time point are treated as discrete units (i.e., i-state). I-states are clustered to identify a final, time-invariant profile solution; this procedure assumes that, while participants may

change in profile membership, the same profiles exist across time (Bergman & El-Khoury, 1999). In other words, the clusters that emerge are time invariant while the individuals subsumed within each cluster are not, allowing an examination of how individuals change over time. Therefore, issues of nestedness do not apply to the repeated-measurement of epistemic beliefs. ISOA is well-suited to study short-term changes in profile membership, and thus is appropriate for the current study as we would not expect different profile solutions across the semester (Bergman & El-Khoury, 1999; Nurmi & Aunola, 2005). Students who completed one survey were included in this analysis, as the cluster solution is time-invariant. Additional cluster analyses conducted separately at both waves revealed analogous cluster solutions, supporting our assumption of time-invariant clusters.

After considering the dendrogram, agglomeration schedule, theory, and explained variance in the clustering variables, a six-cluster solution was selected (Figure 2; see Bergman et al., 2003 for justification). The six-cluster solution explained 49.5%-79.1% of the variance in epistemic beliefs and included clusters that represented all four hypothesized positions; the five-cluster solution, by contrast, combined the theoretically distinct realist and rationalist clusters. We labeled clusters based on raw scores and z -scores (Figure 2).

4.2 Epistemic Profiles

Four clusters fit with theory. The first cluster represented a *realist* position ($n = 103$)². Realists had the highest levels of simple/certain knowledge, although raw scores indicate nearly neutral ratings of simple/certain knowledge. Realists possessed among the

²The cluster sizes reported here include clusters at both time points (i-states) and therefore are approximately doubled.

highest levels of justification by authority and personal justification. The second cluster reflected a *dogmatist* position ($n = 266$). Dogmatists had among the highest scores on justification by authority and the lowest score on personal justification. They also endorsed higher-than-average simple/certain knowledge, but raw scores indicate that simple/certain knowledge was below the scale midpoint. These responses still align with the assertion that dogmatists do not accept knowledge as simple/certain and may indicate a practiced form of dogmatism as opposed to the pure theoretical dogmatism. It may be difficult to fully reject simple/certain knowledge when simultaneously endorsing justification by authority. This was the only group that demonstrated the hallmark high justification by authority and low personal justification expected of dogmatism. The third cluster reflected a *skeptic* position ($n = 239$). Skeptics possessed among the lowest simple/certain knowledge and justification by authority, but among the highest personal justification. Students from the fourth cluster reported lower-than-average simple/certain knowledge, but higher personal justification and justification by authority. While these beliefs were above the scale midpoint, they are more similar to each other than among skeptics and dogmatists. Therefore, we labeled this cluster *rationalists* ($n = 323$).

The remaining two clusters were not hypothesized. Students in the fifth cluster reported approximately average scores on all epistemology scales. Moderate endorsement of the knowledge justification domains aligned with the rationalist profile, though the levels of simple/certain knowledge were higher than the rationalist cluster. Given that the students were near the average dimensional scores for the sample and the survey midpoint, we this cluster *uncommitted* ($n = 359$). Students in the final cluster weakly endorsement on all scales ($n = 247$); they did not agree that knowledge is simple and

certain, nor did they believe that knowledge originates from either authority or personal experience. We labeled this cluster *low-all-beliefs*.

We conducted several ancillary analyses using survey measures not included in the current study to investigate whether these final two clusters emerged due to non-compliant survey respondents. First, we examined whether students reported extreme scores (i.e., 1 or 5); 91.1% of uncommitted students responded in the extreme to at least one survey item, suggesting the majority of uncommitted students were not merely opposed to strongly agreeing or disagreeing with survey items. All students had multiple non-neutral responses (i.e., 2 or 4). In the low-all beliefs cluster, 89.9% of students selected a number on the high end of the scale (i.e., 4 or 5) multiple times and “5” at least once. Therefore, low-all-beliefs students did not exclusively disagree to survey items, but specifically disagreed with epistemic belief items. Second, we analyzed the reliability for survey scales not used in the cluster analysis. All scale reliabilities were high ($\alpha > .75$) for students in the uncommitted and low-all beliefs clusters, suggesting these students were not randomly filling out surveys. This suggests these clusters were unlikely due to non-compliance. Cluster membership at T2 was independent of the classroom intervention ($\chi^2(5) = 1.097, p = .954$). Since the intervention did not affect epistemic beliefs, it was not included in our analysis of cluster shifts.

4.3 Comparing Introductory and Advanced Students

Among students who completed both surveys, course level predicted cluster membership at T1 ($\chi^2(5) = 35.92, p < .001$). Introductory students were more likely to be realists (4.7%) or uncommitted (25.7%) and less likely to be dogmatists (13.9%) than advanced students (realists: 0.7%; uncommitted: 13.8%, dogmatists: 34.6%). Differences also emerged at T2 ($\chi^2(5) = 13.99, p = .016$). Introductory students were less likely to be

dogmatists (14.2%) than advanced students (22.3%). Because advanced students are self-selected and likely differ from introductory students in a number of other ways, the remaining developmental analyses focused on within-person cluster membership changes.

4.4 Shifts in Cluster Membership: Evidence for Development

We used configural frequency analysis (von Eye, Spiel, & Wood, 1996) to examine profile shifts during the semester for participants who completed both surveys ($n = 620$). This analysis identifies types (shifts more likely than chance) and anti-types (shifts less likely than chance) using adjusted standardized residuals (von Eye, Mun, & Bogat, 2008). We identified seven types (see Table 1, solid lines in Figure 3). Six types represented students remaining in the same cluster (38.7% of sample). As hypothesized, the final type was skeptics shifting to the rationalist cluster. We identified eight anti-types (dashed lines in Figure 3). Students were unlikely to shift from dogmatism to skepticism and vice versa. Surprisingly, dogmatists were significantly *less* likely to shift to rationalism. Together, these findings suggest that skeptics and dogmatists follow separate developmental pathways. Additional anti-types indicated that skeptics were unlikely to become uncommitted, rationalists were unlikely to regress to dogmatism or shift into the low-all beliefs cluster, and uncommitted students were unlikely to move to skeptic or low-all-beliefs clusters.

4.5 Profile Membership and Achievement

We conducted univariate ANOVAs to predict grades based on initial and final profile membership, controlling for gender, class level (introductory, advanced), and nature of class (control, intervention). All interaction terms were non-significant, and removed from the final models. Initial cluster membership was a significant predictor of

final course grade, $F(5, 766) = 3.276, p = .006$ (Table 2). Tukey's post-hoc tests revealed that students who began the semester as dogmatists received lower course grades than students who began the semester as uncommitted or rationalists. Final profile membership also predicted final grade ($F(5, 690) = 3.802, p = .002$); students who were dogmatists at T2 received lower course grades than skeptics and rationalists. Dogmatists generally performed more poorly than other students and rationalists generally performed better, providing limited support for our hypothesis that students in more advanced profiles would perform better.

5. Discussion

The current study provides novel empirical support for Greene and colleagues' (2008) combined perspective of personal epistemology by investigating students' transitions between belief systems. Our longitudinal design allowed for the identification of typical and atypical short-term developmental shifts, a critical addition to the combined perspective. Our findings also demonstrate that the developmental and multi-dimensional perspectives are complementary, not conflicting; students' personal epistemology can be conceptualized as holistic belief systems. Furthermore, epistemic profiles predicted student achievement.

Overall, our findings largely support the combined perspective. We identified profiles representing realists, dogmatists, skeptics, and rationalists, a key contribution as prior person-centered research has identified some, but not all, of the hypothesized positions (Greene et al., 2010). Our results also provide clear evidence for Chandler et al.'s (2002) position that skeptics and dogmatists follow separate developmental pathways. The number of rationalists increased during the semester as well, though the

simultaneous increase in the realist and uncommitted clusters might suggest a tendency for students to agree with both justification domains at the end of the semester.

Our data also suggest revisions to Greene et al.'s (2008) combined perspective. Notably, we identified an unexpected but sizable profile of uncommitted students. Our decision to use a five-point scale with a clear midpoint may have contributed to the cluster size. However, it is fairly common for person-centered analyses to find sizeable clusters near the average (e.g., Tuominen-Soini, Salmela-Aro, & Niemivirta, 2012). Many of the hypothesized clusters from Greene et al.'s (2008) model are categorized by extremes highs or lows; in reality, however, many students did not report polarized epistemic beliefs. Therefore, the developmental model should consider these fairly typical students. It is difficult to determine whether uncommitted students possess clear belief systems or were providing "default" responses. Uncommitted students may be neutral or undecided about the nature and source of knowledge. Schommer-Aikins (2002) acknowledged that "if learners cannot respond to specific questions...then participants may be in an undifferentiated point of development" (p. 111). Perhaps uncommitted students do not feel they have enough information about engineering knowledge and so respond neutrally instead of taking a strong epistemic stance. Introductory students were more likely to be uncommitted at the beginning of the semester, supporting this assertion. As students learned more about engineering, a sizeable proportion (53.3%) adopted a predicted position. Still, many other students shifted to the uncommitted cluster by the end of the semester. Interestingly, uncommitted students at the beginning of the semester did relatively well in the class, but uncommitted students at the end of the semester did not significantly differ from others. One possibility is that thinking about knowledge more tentatively early on allows for flexibility in adopting a position that fits with the

demands of the class, whereas this does not benefit students who remain uncommitted at the end of the course. We also identified a low-all-beliefs profile, representing students who disagreed with all of the scales. It is unclear what these students believe to be the source of knowledge. It is also unclear what type of developmental trajectory low-all-beliefs students may follow, as these students were not associated with any developmental shifts.

Regarding profile shifts, our findings suggest that the pathway from dogmatism to rationalism is rare. Dogmatism appears to be a developmental “dead-end;” it was the only group that was statistically unlikely to shift to rationalism. Only 6.2% of dogmatic students made the hypothesized shift to rationalism by the end of the semester, compared to 35.9% of skeptics. This is concerning considering dogmatists achieved lower grades. Dogmatists may have performed poorly because overly relying on authority figures for knowledge may interfere with the independent problem-solving required in engineering.

Educators can use this information in their teaching. The epistemic climate of the classroom, the amalgamation of students’ and teachers’ beliefs and the way teachers present knowledge in the classroom (Feucht, 2010; Muis & Duffy, 2013), likely impacts the developmental changes observed. Well-structured domains, like engineering, tend to socialize students to seek knowledge from authority figures (Trautwein & Lüdtke, 2007); thus, educators may need to exercise caution in the epistemic messages they send to students. If instructors consistently (and likely unintentionally) portray themselves as the sole source of knowledge, students may be less likely to move from dogmatism to more adaptive rationalism. The plurality of students in the uncommitted cluster should also be of interest to educators. Many students do not have a strong stance towards engineering

knowledge. Explicitly discussing engineering epistemology in class might help students commit to a more sophisticated position.

The proposed model received some support from two additional findings. First, introductory students at T1 were more likely to be at an earlier stage (realism) or an uncommitted stage and less likely to be at a slightly later stage (dogmatism) than advanced students. Some of these differences were no longer apparent by T2. However, it is difficult to draw overly strong conclusions from cross-sectional data; there are many possible contextual differences between introductory and advanced classes, and self-selection bias among engineering students (Felder, Felder, Mauney, Hamrin, & Dietz, 1995; Trautwein & Lüdtke, 2007). Second, analyses linking epistemic profiles to course grades provide some additional support regarding the relative development of the different profiles based on differences in achievement. Dogmatists were consistently among the worst performers and rationalists among the best.

5.1 Limitations and Future Directions

This study's limitations can be summarized into three categories: the relatively short time frame, alternative personal epistemology frameworks, and the two unexpected clusters. These limitations all suggest fruitful avenues for future research.

When considering development, time-scale is key. We focused on short-term changes during a semester to capture transitions between epistemic positions within a single classroom context. Many students remained in the same cluster, likely due to the relatively short time-period between assessments. Future research should extend our findings by including multiple assessments over longer time-periods. Given that development may be recursive (e.g., Chandler et al., 2002), following students over

longer time-periods might help to explain why less advanced positions increased by the end of the semester.

It is also important to consider our results in light of other personal epistemology perspectives. Recent theoretical propositions suggest broadening the scope of personal epistemology to include all epistemic cognitions, which might divide into many more specific dimensions (Chinn et al., 2011). Additional dimensions might clarify the unexpected clusters. For example, students in the low-all-beliefs cluster might be conservative believers who are cautious in adopting new truths, leading them to generally disagree with the simple/certain knowledge dimension and all possible sources of knowledge. Finally, our chosen labels of uncommitted and low-all beliefs should be treated tentatively. Future research should validate the person-centered results by conducting interviews (e.g., King & Kitchener, 1981; Perry, 1970) or think-aloud protocols (e.g., Hofer, 2004) with individuals from each cluster.

6. Conclusion

Studying personal epistemology development is complex and challenging. Our findings highlight the utility of the combined perspective, integrating multi-dimensional and developmental-positions perspectives. By treating personal epistemology dimensions as belief systems, we identified patterns of beliefs and provided evidence that some students advance through positions in a theoretically-predicted manner. Moreover, epistemic profiles predicted achievement. Findings also suggest several potential revisions to the combined perspective. For instance, our results suggest that dogmatist students were unlikely to progress to rationalism, at least during one semester, which seems particularly problematic because engineers need to solve novel, complex problems. A person-centered approach can help educators consider how students approach

knowledge and enable researchers to represent the complex nature of personal epistemology.

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Table 1

Results of Configural Frequency Analysis with T1 and T2 Cluster Membership

T1 to T2 cluster membership	Observed	Expected	χ^2	Type / Antitype
Realist to...				
realist	7	2.17	10.772**	T
dogmatist	0	3.83	3.832	
skeptic	4	3.64	0.036	
rationalist	4	5.61	0.463	
uncommitted	8	6.12	0.580	
low-all	1	2.63	1.006	
Dogmatist to...				
realist	5	10.21	2.656	
dogmatist	55	18.04	75.694***	T
skeptic	3	17.13	11.658***	A
rationalist	7	26.43	14.282***	A
uncommitted	34	28.80	0.940	
low-all	9	12.40	0.932	
Skeptic to...				
realist	3	8.31	3.393	
dogmatist	1	14.69	12.758***	A
skeptic	34	13.95	36.959***	T
rationalist	33	21.52	6.129*	T
uncommitted	11	23.45	6.606*	A
low-all	10	10.09	0.001	
Rationalist to...				
realist	15	11.02	1.438	
dogmatist	5	19.48	10.764**	A
skeptic	24	18.50	1.637	
rationalist	51	28.53	17.692***	T
uncommitted	23	31.09	2.105	
low-all	4	13.38	6.576*	A
Uncommitted to...				
realist	18	13.01	2.105	
dogmatist	23	22.99	0.000	
skeptic	9	21.83	7.542**	A
rationalist	31	33.68	0.213	
uncommitted	56	36.70	10.154**	T
low-all	7	15.79	4.896*	A
Low-all to...				
realist	8	11.29	0.959	
dogmatist	15	19.96	1.232	
skeptic	20	18.95	0.058	
rationalist	19	29.23	3.583	
uncommitted	26	31.85	1.076	
low-all	37	13.71	39.566***	T

Note. * $p < .05$, ** $p < .01$, *** $p < .001$.

Table 2

Final Grades Based on Cluster Membership

T1 Membership						
	Realist	Dogmatist	Skeptic	Rationalist	Uncommitted	Low-All
Final Grade	85.93 ^{ab}	87.02 ^a	89.15 ^{ab}	89.76 ^b	89.40 ^b	88.11 ^{ab}
SD	7.36	7.34	7.46	7.57	7.78	7.52
T2 Membership						
	Realist	Dogmatist	Skeptic	Rationalist	Uncommitted	Low-All
Final Grade	88.17 ^{ab}	86.87 ^a	89.61 ^b	90.24 ^b	89.16 ^{ab}	87.91 ^{ab}
SD	7.31	7.15	7.42	7.37	7.50	7.09

Note. Values with matching superscripts do not significantly differ from one another ($p < .05$).

Figure 1. Proposed developmental progression of personal epistemology with expected levels of dimensions (adapted from Chandler et al., 2002; Greene et al., 2008).

Figure 2. Six-cluster solution.

Figure 3. Shifts in profile membership. Large, dark arrows represent types, or shifts more likely than chance; light, dashed arrows represent antitypes, or shifts less likely than chance.

APPENDIX

Items	SCK	JA	PJ
All experts in engineering understand the field in the same way.	.51/.66		
Answers to questions in engineering change as experts gather more information. (reversed)	-.30/-.21		
Truth is unchanging in engineering.	.67/.72		
In engineering, most work has only one right answer.	.50/.53		
Principles in engineering are unchanging.	.62/.69		
All engineering professors would probably come up with the same answers to questions in engineering.	.55/.57		
Most of what is true in engineering is already known.	.47/.65		
In engineering, what is a fact today will be a fact tomorrow.	.63/.65		
Engineer's knowledge of the facts about engineering does not change.	.42/.56		
If you read something in an engineering textbook, you can be sure it's true.		.69/.70	
If my personal experience conflicts with ideas in an engineering textbook, the book is probably right.		.50/.53	
If an engineer says something is a fact, I believe it.		.52/.65	
Things written in engineering textbooks are true.		.62/.69	
I believe everything I learn in engineering classes.		.69/.64	
If an engineering professor says something is a fact, I believe it.		.68/.73	
In engineering, the truth means different things to different people.			.63/.65
In engineering, everyone's knowledge can be different because there is no one absolutely right answer.			.74/.70
In engineering, what's a fact depends upon a person's point of view.			.61/.68

Note. Final confirmatory factor analyses results for epistemic beliefs using the complete data set. Factor loadings at T1 and T2 are provided before and after the slash, respectively. SCK = simple/certain knowledge. JA = justification by authority. PJ = personal justification.