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Robert J. Thompson Jr.[a], Lorrie Schmid[b], Menna Mburi[c], Jason E. Dowd[d], Solaire A. Finkenstaedt-Quinn[e], Ginger V. Shultz[f], Anne Ruggles Gere[g], Leslie A. Schiff[h], Pamela Flash[i] and Julie A. Reynolds [j]

[a]Professor Emeritus, Department of Psychology and Neuroscience, Duke University, Durham, NC, USA; [b]Data and Analytics Lead, Social Science Research Institute, Duke University, Durham, NC, USA; [c]Researcher, Social Science Research Institute, Duke University, Durham, NC, USA; [d]Physics Course Manager of OnRamps, The University of Texas, Austin, TX, USA; [e]MWrite Project Manager, Department of Chemistry, University of Michigan, Ann Arbor, MI, USA; [f]Assistant Professor, Department of Chemistry, University of Michigan, Ann Arbor, MI, USA; [g]Professor and Director, Sweetland Center for Writing, University of Michigan, Ann Arbor, MI, USA; [h]Professor, Department of Microbiology and Immunology, University of Minnesota, Minneapolis, MN, USA; [i]Director, Center for Writing, University of Minnesota, Minneapolis, MN, USA; [j]Associate Professor of the Practice, Department of Biology, Duke University, Durham, NC, USA

ABSTRACT

Across undergraduate STEM learning contexts in several countries, students' intrapersonal attributes of epistemic beliefs, self-efficacy beliefs, intrinsic motivation, and sense of identity have been found to influence learning and to change in response to educational practices. However, research can mask individual and demographic differences in student's attributes that may moderate or mediate the relationship between educational practices and learning outcomes. We employed variable-centered and person-centered methods to examine individual and demographic differences in changes in students' intrapersonal attributes and patterns of interrelationship among attributes with a study sample of students ($N = 4{,}500$) in 14 STEM undergraduate courses (8 biology, 4 chemistry, and 2 statistics) at three research universities in the United States. Variable-centered analyses revealed overall increases in students' science self-efficacy beliefs and epistemic beliefs even though these outcomes were not intentionally targeted as learning objectives. However, person-centered analyses indicated that not all students experienced these gains. For example, self-identified Asian/Pacific Islander and Black students were more likely to be members of groups demonstrating a decrease in science self-efficacy, whereas Asian/Pacific Islander students and men were less likely to be members of the subgroup with consistently evaluativist epistemic beliefs and higher GPAs. Using latent profile analysis (LPA), we identified five distinct student profiles that reflected different patterns of interrelationship of epistemic beliefs, science and writing self-efficacy beliefs, and science identity. We discuss the implications of these findings for educational practices, particularly with regard to intentionally fostering diverse students' self-efficacy, sense of identity, and adaptive epistemic beliefs.

CONTACT Julie A. Reynolds ✉ Julie.a.reynolds@duke.edu 💬 Associate Professor of the Practice, Department of Biology, Box 90338, Duke University, Durham, NC, 27708, USA

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Efforts to improve learning outcomes for diverse groups of undergraduate students in science, technology, engineering, and mathematics (STEM) disciplines have focused on developing evidence-based educational practices (National Research Council 2012). In recognition of the considerable variability in student performance in response to educational practices, research is increasingly focused on identifying students' characteristics and educational and cultural contextual factors that mediate and moderate the relationship between educational practices and learning outcomes (National Academies of Sciences, Engineering, and Medicine 2017). Moreover, conceptual and methodological advances have shifted this research in four important ways. First, researchers are increasingly adopting a new conceptual framework, the ecological developmental systems perspectives, that focuses on the person-context transaction (Bae and Lai 2020). Second, the set of student characteristics examined has expanded beyond demographics and prior academic preparation to include an array of students' intrapersonal attributes, including beliefs about academic self-efficacy, sense of belonging (identity), and intrinsic motivation; all these attributes have been found to influence students' learning and to change in response to educational practices (National Academies of Sciences, Engineering, and Medicine 2017). Third, research methods increasingly combine person-centered research and variable-centered methods to identify different patterns of interrelationships among student's intrapersonal attributes (Bergman and Vargha 2013). And, finally, the design of educational practices and assessment of learning are increasingly discipline- and topic-specific (National Research Council 2012).

The current study combines person-centered and variable-centered approaches to address three questions about individual differences in students' intrapersonal attributes known to be related to student learning in STEM. First, do students' intrapersonal attributes change during participation in undergraduate STEM courses? Second, do these students exhibit different profile patterns of interrelationship among the attributes and do students' profiles change during participation in a STEM course? Third, do changes in students' intrapersonal attributes and profiles differ by demographic characteristics? The context is a larger project that is examining the effectiveness of writing-to-learn (WTL) educational practices in enhancing conceptual learning conducted with heterogeneous samples of students enrolled in biology, chemistry, and statistics courses across one private and two public research universities in the United States.

Conceptual framework

Ecological systems perspectives (Bronfenbrenner 1977; Bronfenbrenner and Morris 2006) are increasingly recognized as the necessary conceptual framework for investigating how student's personal attributes, in transactions with contextual factors, influence variability in learning in response to educational practices (Bae and Lai 2020). Systems perspectives focus on the person as the unit of analysis (rather than on the variable) and aim to identify the interrelationships among multiple systems, ranging from the biological and behavioral systems within the person, to the proximal (e.g. classroom) and distal (e.g. community resources/norms) environmental systems within which the person functions (Lerner & Schmid Callina, 2013; 2014). A holistic perspective on college students' development involves the intertwining of three dimensions: the epistemic cognition (How do I know?); the intrapersonal/identity (Who am I?); and the interpersonal (How do I related to others?) (Baxter Magolda 2009).

Implementation of systems perspectives and holistic analyses in research on student learning has been facilitated by the development of analytic methods (Hodis and Hancock 2016). Relevant examples include model-based clustering methods that aim to identify subgroups of students based on distinct statistical characteristics among variables of interest (Harring and Hodis 2016). The emphasis on holistic analysis of the interrelationship of systems across levels, however, is not meant to exclude investigation of the contributions at a single level, but the ultimate aim is to reintegrate the part into the whole (Lerner and Schmid Callina 2014).

Person-centered and variable-centered approaches

Consistent with an ecological systems perspective, person-centered approaches focus on the individual 'as an integrated psychological, biological, and social being' (Magnusson 2003, 3); 'describe differences among individuals in how variables are related to each other' (Laursen and Hoff 2006, 379); and aim to identify groups of individuals who share particular attributes, or patterns of relations across attributes, in a specific context (Harring and Hodis 2016; Hodis and Hancock 2016). In contrast, variable-centered approaches describe associations between variables. Variable-centered approaches 'are well suited for addressing questions that concern the relative contributions that predictor variables make to an outcome' whereas person-centered approaches 'are well suited for addressing questions that concern group differences in patterns of development' (Laursen and Hoff 2006, 377). The complementarity of person-centered and variable-centered approaches is well recognized (Bergman and El-Khouri 2003; Magnusson 2003) and combined approaches are increasingly being employed in the same study (Bae and Lai 2020).

Combined approaches offer the potential to identify different patterns of student's intrapersonal attributes that influence their response to specific educational practices, and the development of intrapersonal attributes can serve as educational outcomes in their own right. For example, whereas there have been investigations into how racial and ethnic identity and epistemology develop independently and impact academic achievement, Pizzolato and colleagues (2008) examined how ethnic identity and epistemological development function together to influence academic achievement among students from minoritized populations. More specifically, the study examined whether ethnic identity development is a possible explanation for why some students thrive in collegiate settings whereas others do not. The study employed a person-centered, qualitative analysis (i.e. structured interviews) of the relation between ethnic identity and epistemological development followed by a variable-centered, quantitative analysis of the relation between ethnic identity development, epistemic development, and academic achievement among high achieving college students from a diverse array of racial and ethnic populations.

Their person-centered interviews ($N = 67$) revealed that the college environment provided students with new opportunities to explore their ethnic identity ('described as one's affiliation and membership with a particular ethnic group that is based on one's conception of knowledge, attitudes, and feelings for that group') (Pizzolato et al. 2008, 302). Furthermore, 'ethnic identity and epistemological development were positively related; as participants grappled with revising their ethnic identities, they were compelled to reconsider their epistemologies, and the resulting epistemological development influenced ethnic identity development' (Pizzolato et al. 2008, 311).

Their variable-centered analysis ($N = 307$) of the relation between ethnic identity development, epistemological development, and academic achievement involved survey items drawn from two existing measures. Ethnic identity was assessed in terms of two subscales of the Multigroup Ethnic Identity Measure that reflect the degree and ways in which an individual has actively worked to construct an ethnic identity, and the comfort the individual experiences in relation to her or his ethnic identity. Epistemological development was assessed in terms of two subscales of 'The Self-Authorship Survey' that reflect the reasoning and action components of epistemological development. Hierarchical multiple regression analysis indicated that students' high school GPA and SAT score together explained 12.6% of the total variance in their college GPA. Beyond the contribution of these control variables, ethnic identity and epistemological development accounted for an additional 9.9% of the variance in college GPA. Although the amount of variance accounted for was relatively small, this study demonstrated that ethnic identity and epistemological development interact to produce greater development along both developmental trajectories and the value of combining person-centered and variable-centered research methods.

Student characteristics: intrapersonal attributes

Across undergraduate learning contexts, the intrapersonal attributes of epistemic and self-efficacy beliefs, intrinsic motivation, and sense of identity have been found to influence students' learning and to change in response to educational practices. Here, we briefly review the conceptualization of these intrapersonal attributes, the evidence of association with students' learning, and efforts to identify patterns of interrelationships among attributes.

Epistemic beliefs

An individual's personal epistemology, or beliefs about the nature of knowledge and the process of knowing (Hofer and Pintrich 1997), is a component of epistemic cognition that also includes aims and values (Chinn, Buckland, and Samarapungavan 2011; Chinn and Rinehart 2016) and specific reasoning processes. Personal epistemology has been characterized along four dimensions (Hofer and Pintrich 1997). Two dimensions concern the nature of knowledge: beliefs about the *certainty* of knowledge, ranging from knowledge as fixed and absolute to fluid, tentative, and evolving; and beliefs about the *simplicity* of knowledge, ranging from simple, discrete, and knowable facts to complex, interrelated, contingent, and contextual ideas. Two dimensions concern the process of knowing: beliefs about the *source* of knowledge, ranging from transmitted from authority to constructed by the knower in interaction with texts, experiences, and others; and beliefs regarding the *justification* for knowledge claims, ranging from uncritical acceptance of facts and opinions to evaluating competing claims based on reasoning and evidence.

The development of a person's epistemic views has been characterized in terms of assumptions about the nature of knowledge and the process of knowing. Epistemic development is viewed as a progression (Hofer and Bendixen 2012), starting from an *absolutist* view, in which knowledge is assumed to be certain and known by authorities. Next is a *relativist* view in which it is recognized that knowledge is constructed and uncertain, with multiple valid perspectives, and absence of an objective basis for adjudicating claims. Finally, the *evaluativist* view considers knowledge as continuously evolving and justified on the basis of reasoning and evidence. Those with *evaluativist* beliefs understand knowledge not as facts or opinions but rather as judgments that, in turn, 'require support in a framework of alternatives, evidence, and argument' (Kuhn 2005, 32). This developmental progression occurs as a function of the transactions of underlying neurocognitive development with the person's social context and is spiral-like rather than linear (Bendixen and Rule 2004; King and Kitchener 2004).

There are significant differences across academic disciplines in forms of knowledge, epistemic criteria for justification of knowledge claims, and processes of reasoning (Sandoval 2016). Correspondingly, a review found support for both generality and discipline-specificity in students' epistemic beliefs, with discipline-specific epistemic beliefs becoming more influential as students progress through higher levels of education and become enculturated into the epistemic beliefs that characterize their academic major (Muis, Bendixen, and Haerle 2006).

Epistemic beliefs have been found to influence multiple dimensions of academic motivation, learning, and achievement (Hofer and Bendixen 2012). For example, a meta-analysis of 132 studies involving 55,418 participants found that epistemic cognition was a significant predictor of academic achievement in general, and at discipline-specific and topic-specific levels, from elementary school through graduate school (Greene, Cartiff, and Duke 2018).

One way that epistemic beliefs affect learning is through the goals and standards that students set, which influences their recursive metacognitive monitoring of their cognitive strategies to fit different learning tasks (Bromme, Pieschl, and Stahl 2010). For example, college students with more sophisticated epistemic beliefs were found to be more likely than those with less sophisticated beliefs to use an array of effective learning strategies including self-regulated cognitive strategies (e.g. elaboration, rehearsal, organization, and metacognition) and behavioral strategies (e.g. effort regulation, time management, and help seeking) (Paulsen and Feldman 2005, 2007).

Person-centered approaches have identified subgroups of students based on different patterns of interrelationships among the four dimensions of epistemic beliefs (certainty, simplicity, source, and justification/development of knowledge). For example, in a study with tenth grade German students ($N = 4995$) in three science disciplines (biology, chemistry, and physics), latent profile analysis (LPA) identified subgroups of students with different profiles of epistemic beliefs about science (Kampa et al. 2016). Students with the *Sophisticated* profile had high science epistemic beliefs in all four epistemic belief dimensions, whereas those with the *Multiplistic* profile held sophisticated views only regarding source and certainty. Moreover, the profiles were differentially related to students' science achievement, self-concept, and motivation. Students with the *Sophisticated* profile had the highest science grades and relatively high self-concept and motivation, whereas those with the *Multiplistic* profile had the lowest science grades and self-concept and were the least motivated. The findings were consistent with those of Chen (2012) and Greene, Cartiff, and Duke (2018) in identifying the particular importance of the epistemic dimension of justification for knowledge claims and understanding of science knowledge as evolving based on new evidence.

Self-Efficacy

Self-efficacy refers to a person's belief that they can produce desired effects (Bandura 1997). Beliefs about efficacy are derived from experience; are both general and discipline specific; have consistently been shown to have both direct and indirect influences on academic performance (Honicke and Broadbent 2016); and can be improved (Bartimote-Aufflick et al. 2016). Research has focused on students' perceived ability to succeed in learning activities in general (academic self-efficacy), in science (science self-efficacy), in specific disciplines, and on the variability in self-efficacy perceptions across contexts. For example, Cervone, Mercurio, and Lilley (2020) reported that first-year engineering students demonstrated considerable intra-individual variability in their self-efficacy appraisals across 32 academic and personal challenges encountered in STEM education (e.g. mastering class material, asking for help, and balancing time commitments). Students' self-efficacy appraisals were linked to whether they viewed the educational challenges as relevant to their perceived personal strengths/weaknesses and environmental supports/barriers.

There is strong evidence that students' self-efficacy beliefs are positively related with academic performance and increase in response to educational practices. For example, a review of 64 articles found that self-efficacy of university students was strongly related to student achievement (reported in 92% of the studies) and to self-regulation, motivation, and strategy use, and they improved 'arguably as a result of completing a course or participating in a particular learning activity' (Bartimote-Aufflick et al. 2016, 1924). Relatedly, the meta-analysis by Honicke and Broadbent (2016) of 59 studies found that the relationship between self-efficacy and academic performance was mediated through variables such as effort regulation and deliberate goal setting prior to learning. More specifically, when academic self-efficacy influenced the adoption of mastery goals, academic success was more likely to result.

Motivation

The role of motivation in academic engagement and achievement has been extensively studied from both a drive perspective and a goal perspective (Covington 2000; Linnenbrink-Garcia and Patall 2016). The most basic distinction is between intrinsic motivation, doing something because it is inherently interesting or enjoyable, and extrinsic motivation, doing something because of its instrumental value, such as receiving praise or a reward (Ryan and Deci 2000). Moreover, intrinsic motivation has been viewed as a process whereby individuals come to value an activity by making it a more central part of their self-identity (Vallerand 1997). Considerable support has been provided for the association of intrinsic motivation with higher levels of student engagement and learning (Linnenbrink-Garcia and Patall 2016), and both initial levels and growth trajectories have been related to academic achievement and retention. For example, compared to their peers, students who began college with higher levels of identity-based motivation (e.g. 'because it is personally

important to me') had higher academic achievement and retention and those who demonstrated growth in intrinsic motivation (e.g. 'because I enjoy doing it') earned higher GPAs and were more than five times as likely to register for sophomore year (Corpus, Robinson, and Wormington 2020).

Person-centered approaches have been used to identify subgroups of students with different patterns of interrelationship among various dimensions of motivation (Fong et al. 2021). For example, Pastor et al. (2007) examined the advantages of LPA over variable-centered analyses in identifying subpopulations with different patterns of interrelationship among motivational goal dimensions among a large sample of college students (N = 1868).

Science identity

A person's *sense of identity,* represented on a continuum from low to high, refers to a person's having 'a firm sense of who one is, a purpose in life, a clear set of personal values, knowing what one wants out of life and where one is headed, and having personal goals for the future' (Lounsbury et al. 2005, 502). A person's sense of identity serves three important functions. It is a self-regulatory system; it motivates a striving for distinctiveness, belonging, and coherence between values, beliefs, and commitments; and it is an integrating structure for self-understanding and giving meaning and direction to our lives through our commitments, values, and goals (Adams and Marshall 1996). A person's sense of identity is multifaceted and includes social identities formed within a social group or context. For example, 'STEM identity is a socially based identity grounded in the extent to which individuals see themselves and are accepted as a member of a STEM discipline or field' (Kim, Sinatra, and Seyranian 2018, 591).

Support has been provided for a positive association between a well-developed sense of identity and academic performance and other intrapersonal attributes. For example, students' sense of identity was found to be positively related to GPA (Lounsbury et al. 2005), intrinsic motivation, and self-efficacy beliefs (Faye and Sharpe 2008). In addition to one's overall sense of identity, more specific dimensions of identity have also been found to relate to academic achievement. For example, as reported above, ethnic identity and epistemic development have been found to influence each other and account for a substantial portion of variance in the academic achievement of college students from minoritized populations (Pizzolato et al. 2008). More specific to the aims of this study, science identity was found to be a strong predictor of minoritized science students' persistence in pursuing a science career (Estrada et al. 2011) and strengthening professional identification has been included as one component of educational frameworks to foster persistence in STEM fields (Graham et al. 2014).

Identity development during college has also been examined. For example, Robinson et al. (2019) used person-centered analyses (specifically latent growth modeling) to examine individual differences in trajectories of science identity development during a single semester among students (*N* = 1,669) enrolled in an introductory chemistry course. Three profiles of students' science identity trajectories were identified: *High-and-Stable* (53.8% of the sample), *Moderate-and Slightly-Increasing* (40.5%), and *Moderate-and-Declining* (5.6%). Whereas stability in science identity was the norm, some students' identity appraisals shifted within a single semester and the findings indicated that both initial levels of science identity and stability over time were important for promoting students' achievement and persistence in STEM.

Profiles of intrapersonal attributes

Person-centered methods are beginning to be used to identify individual differences in patterns of intrapersonal attributes. For example, Dowd et al. (2019) used cluster analysis to identify individual differences in patterns of intrapersonal attributes among students in STEM writing courses. The study sample was drawn from students (*N* = 472) across four universities who participated in six courses in five disciplines (biology, chemistry, engineering, neuroscience, and economics) that were designed to scaffold the undergraduate honors thesis-writing process while the students

conducted independent research. Students completed a self-report survey before and after the course with items that addressed five attribute dimensions: mastery oriented or performance-oriented motivation for undertaking a thesis; writing self-efficacy and science self-efficacy; and epistemic beliefs about the certainty and simplicity of knowledge.

Analyses of pre-course/post-course surveys indicated no significant changes in epistemic beliefs but did find a significant increase in mastery motivation (with a small effect size) and increases in self-efficacy for both writing and science (with very large effect sizes). Cluster analysis, performed separately on the pre-course and post-course survey responses, identified three distinct profiles. The *nonefficacious evaluativist* cluster (32.3% of the pre-course sample) comprised students characterized as relatively evaluativist in their epistemic beliefs, mastery oriented, yet lacking self-efficacy in writing and science. The *efficacious absolutist cluster* (8.3%) comprised students characterized by strongly absolutist epistemic beliefs and a high sense of self-efficacy. The *nonefficacious uncommitted* cluster (12.9%) comprised students characterized by relatively low self-efficacy beliefs, a relatively neutral epistemic view, and relatively low mastery motivation. The evidence of changes in students' intrapersonal attributes known to be related to student learning and of different attribute profiles gives impetus to employing combined variable-centered and person-centered approaches to examine changes in student's intrapersonal attributes across an expanded range of educational contexts.

Study design and research questions

The context for the current study is a project conducted across three research universities in the United States that is examining the effectiveness of WTL educational practices in enhancing conceptual learning in STEM. The focus of the current study is not on students' learning in response to WTL; rather, the purpose is to employ combined variable-centered and person-centered approaches to examine individual and demographic differences in changes in students' intrapersonal attributes and patterns of interrelationship among attributes during participation in STEM courses in biology, chemistry, and statistics. More specifically, we address three research questions:

(1) Do students' science self-efficacy beliefs and epistemic beliefs change during participation in a STEM course?
(2) Do students in STEM courses: (a) exhibit profiles that reflect different patterns of interrelationship across a set of five intrapersonal attributes (epistemic beliefs, science self-efficacy and writing self-efficacy beliefs, science identity, and motivation); and (b) do students' profiles change during participation in a STEM course?
(3) Do changes in students' intrapersonal attributes and profiles differ by demographic characteristics?

Methods

Participants

Students enrolled in 14 STEM undergraduate courses (8 biology, 4 chemistry, and 2 statistics) at three R1: Doctoral Universities (Very high research activity; The Carnegie Classification of Institutions of Higher Education n.d.) were invited to participate in this study. Eleven of the courses were introductory-level, 1 was an advanced course, and 2 were capstone courses. With permission from course instructors, we emailed all their students ($n = 5,935$), introducing them to the study, and invited them to complete two online surveys, one during the first two weeks of the course (Time 1) and another during the last two weeks (Time 2). The survey (Appendix A in Supplemental Materials) is part of a larger research project and students were able to opt out of any part of the research that they wished. Each university's IRB approved this study independently.

Drawn from the 4,637 students who responded to the survey at Time 1 or Time 2 (78% overall response rate), the study sample of 4,500 comprised students who consented and had completed at least two questions correctly. Of the 4,500 students in the study, 3,497 students completed the survey at Time 1; 2,597 completed the survey at Time 2; and 2,483 completed the surveys at both Time 1 and 2. The number and percentage of respondents who identify with each demographic category, gender, race and ethnicity, native language, class year, and mean GPA are presented in Table S1 in the Supplemental Materials. All demographic characteristics for the samples at Time 1 were comparable with those at Time 2 with one exception; significantly more women completed the survey at Time 2 than at Time 1 ($z = 2.04$, $p = .04$).

Measures

The online survey included items to measure the five intrapersonal attributes and is included in Appendix A of the Supplemental Materials. Here we provide brief descriptions of each measure.

Epistemic beliefs

Characterization of students' epistemic beliefs was based on their response to the prompt: *People hold different views about what constitutes knowledge about our physical and social worlds. Three general views have been identified. Overall, please indicate which perspective best reflects your view.* Based on their responses, students' epistemic beliefs were characterized as one of three holistic epistemic views – absolutist, relativist, or evaluativist – that are differentiated in terms of beliefs about the four dimensions of knowledge: certainty, simplicity, source, and justification (Hofer and Pintrich 1997):

- Absolutist: Knowledge is discovered and consists of facts that have been determined to be true and about which we can be certain. Knowledge claims are verifiable as right or wrong on the basis of objective evidence and standards.
- Relativist: Knowledge is constructed and uncertain and consists of opinions and interpretations that are subjective. People are entitled to their own opinion, and thus there are no bases on which to judge the merits of knowledge claims.
- Evaluativist: Knowledge is constructed, imperfect, and provisional and consists of objectively verifiable facts and subjective opinions and interpretations. The merits of knowledge claims can be judged against alternative claims on the basis of the quality of the arguments and evidence.

Self-efficacy

Science self-efficacy was assessed using 11 items, with values ranging from 1 (not at all) to 10 (always), aligned with a previous measure of self-efficacy in science practice (Kardash 2000). The internal consistency of the 11 items was relatively high for both the pre-course ($\alpha = .95$) and post-course ($\alpha = .95$) samples. Because the overall project involved a focus on writing, we also included an assessment of students' W*riting* s*elf-efficacy* as an outcome measure for that project and included that measure in the identification of profiles of students' intrapersonal attributes in the current project. The measure of *Writing Self-efficacy* comprised 10 items, with values ranging from 1 (not at all) to 10 (always), drawn from the Writing Self-Regulatory Efficacy Scale (Zimmerman and Bandura 1994). Internal consistency was relatively high (pre-course: $\alpha = .93$, post-course: $\alpha = .95$).

Science identity

To assess students' *sense of science identity*, they were asked to rate their support from 1 (strongly disagree) to 4 (strongly agree) on five items used by Estrada et al. (2011), which was a modified version of the Scientific Identity Scale (Chemers et al. 2010): *I have a strong sense of belonging to*

the community of scientists; I derive great personal satisfaction from working on a team that is doing important research; I have come to think of myself as a scientist; I feel like I belong in the field of science; The daily work of a scientist is appealing to me. A student's sense of science identity was characterized by the average of their ratings on the five items and internal consistency was relatively high (pre-course: α = .85, post-course: α = .88).

Motivation for their major

Students were asked to indicate their intended major and distribute 10 points to reflect the relative importance of each of 4 types of motivation for choosing their major: performance, mastery, intrinsic, and extrinsic. Only the measure of intrinsic motivation is used in this study because we were particularly interested in the relationship of this dimension of motivation with other intrapersonal attributes. Scores ranged from 0 to 10, with higher numbers indicating stronger endorsement of intrinsic motivation.

Preliminary analyses

Variables were screened for normality and univariate outliers. We found no relations among observed variables and missing data. Missing data were handled using full information maximum likelihood estimation (FIML) in latent profile analysis (LPA) models. Students with missing data were included in all analyses except where otherwise specified.

   We also examined the interrelationship of the interval scale measures of students' intrapersonal attributes (science self-efficacy beliefs, writing self-efficacy beliefs, science identity, and intrinsic motivation for choice of major) with both the Time 1 and Time 2 samples. We first determined the correlations among the four measures (Table S2 in Supplemental Materials) and then conducted a Confirmatory Factor Analysis (CFA) to test the assumption of four distinct measures. As expected, there was a moderate correlation of students' ratings of their science self-efficacy and writing self-efficacy at both Time 1 ($r = .66$, $p < .0001$) and Time 2 ($r = .74$, $p < .0001$). However, the other correlations were low, ranging from ($r = .02$) for intrinsic motivation and science self-efficacy beliefs to ($r = .38$) for science self-efficacy beliefs and science identity scores. The CFA was conducted on the Time 1 data ($n = 3497$). The model failed the exact fit test ($X^2 = 8.81$, $p = .01$) at the > 0.05 level, but other indices [RMSEA = 0.043, CFI = 0.92, and SRMR = 0.019] indicated a moderately good fitting model (Appendix B in Supplemental Materials provides a fuller explanation of the CFA analysis). Together the correlation and CFA analyses provide support for considering these measures as reflecting four different intrapersonal attributes.

Latent profile analyses (LPA)

The use of ecological systems perspective in research on student learning has been facilitated by quantitative analytic methods that enable the investigation of individual variables and relationships between variables, level of organization involved in developmental change, and the role of time (Baltes, Reese, and Nesselroade 1977; Harring and Hodis 2016). In particular, latent profile analysis (LPA) is a probabilistic model-based method, which allows the identification of person-oriented subgroups based only on the patterns of individual responses, maximizing within-group homogeneity and between-group differences (Lawson and Masyn 2015). LPA also allows for replication, does not require standardization of variables for model construction, and includes model fit statistics to help empirically determine the optimal number of classes (Muthén and Muthén 2000).

   To address whether students in STEM courses exhibit profiles that reflect different patterns of interrelationship of intrapersonal attributes, we conducted LPAs of students' responses to the measures of epistemic beliefs, science self-efficacy beliefs, writing self-efficacy beliefs, science

identity, and motivation. LPAs were performed twice, with Time 1 and Time 2 data considered as separate samples. The data comprised dummy codes for each of the three epistemic views (absolutist, relativist, and evaluativist) and mean scores for science identity, science self-efficacy, writing self-efficacy, and intrinsic motivation.

When running the LPAs, no prior structure was specified regarding the profiles and/or the number of profiles. LPA models were conducted in an iterative way, running one to n profiles and evaluating each profile to the one before. As of now, there is no universally accepted method of comparing model fit and determining optimal number of profiles (Harring and Hodis 2016). Therefore, determining the optimal number of profiles was based on statistical indicators and substantive interpretation, i.e. model fit, convergence, size, and homogeneity of profiles (Lawson and Masyn 2015; Nylund, Asparouhov, and Muthen 2007). Description of the LPA model construction and fit statistics are included in Appendix C and Table S12 and Table S13 in Supplemental Materials.

Results

Changes in science self-efficacy and epistemic beliefs

To address whether students' intrapersonal attributes changed during participation in a STEM course, we formed a data set of the subgroup of students ($n = 2429$) who completed the survey at both Time 1 and Time 2. We first conducted a variable-centered analysis (paired t-test) of the change in students' science self-efficacy scores over the course of the semester. There was a significant increase in mean scores ($M_{T1} = 7.24$ ($SD = 1.47$); $M_{T2} = 7.86$ ($SD = 1.31$); $t = 21.71$, $p < .0001$, $d = .044$) with a medium effect size. Second, we went beyond the variable-centered analysis and conducted a person-centered analysis to examine individual differences in students' changes in science self-efficacy scores. Based on the mean change score statistics [MT1 – MT2 = 0.61(1.40)], we classified the distribution of change score in terms of 1-point units into 5 categories (negative change; no change; positive change < 1; positive change between 1 and 2; positive change > 2) and then counted the number of individuals with difference scores falling in each category. Table 1 presents the number and percentages of students who demonstrated a change in their science self-efficacy scores in terms of five categories. Whereas variable-centered analysis indicated a significant increase in students' science self-efficacy score, the person-centered analysis indicated that 64% of the students demonstrated an increase, 5% had no change, and 30% demonstrated a decrease in their score.

Logistic regression analyses identified several significant demographic differences among the students comprising the five science self-efficacy change groups (Tables S3–S7 in Supplemental Material). Students who demonstrated a negative change were more likely to have self-identified as Asian/Pacific Islander ($OR = 1.40$) or Black ($OR = 1.68$). Those who experienced no change were more likely to be Seniors ($OR = 3.08$). Members of the group who endorsed a small positive change (< 1 scale point) were less likely to have self-identified as Black ($OR = 0.61$) and were more likely to be Seniors ($OR = 1.55$). Students who endorsed a large positive change (> 2 scale points) were less likely to be men (compared to women) ($OR = 0.74$) and less likely to have self-identified as Asian/Pacific Islander students ($OR = 0.70$).

Table 1. Number and percentages of students who demonstrated a change in their science self-efficacy scores by the direction and magnitude of change.

	N	%	Location of logistic regression analyses
Negative change	756	29.89	Table S2
No change (= 0)	117	4.63	Table S3
Positive change < 1	768	30.37	Table S4
Positive change between 1 and 2	477	18.86	Table S5
Positive change > 2	311	12.30	Table S6

Changes in students' epistemic beliefs

To examine changes in students' epistemic beliefs over the semester, we determined the percentages of students who endorsed relativist, absolutist, and evaluativist beliefs at Time 1 and at Time 2, and those who endorsed the same epistemic beliefs at Time 1 and Time 2 (Table 2). We found three key results. First, most students endorsed evaluativist beliefs: 73% at Time 1 ($n = 1766$), 74% at Time 2 ($n = 1808$), and 57% ($n = 1397$) at both times. Second, most students (64%) endorsed the same epistemic belief at both times. Students who endorsed evaluativist beliefs had the greatest stability (79%) followed by those who endorsed absolutist beliefs (31%) and relativist beliefs (16%). A series of chi square analyses indicated that more students were stable in their endorsement of epistemic beliefs than expected ($p < .0001$). Third, 48% of the students who changed their endorsement moved to evaluativist.

A set of logistic regressions were conducted to examine whether the four groups of students formed on the basis of their epistemic beliefs (Consistently Evaluativist; Consistently Absolutist; Consistently Relativist; and Moved to Evaluativist) differed with regard to the demographic characteristics of race and ethnicity, gender, native English speaker, year in school, and GPA (Tables S8–S11 in Supplemental Material). Students who comprised the Consistently Absolutist group (Table S8) were more likely to be men (compared to women, $OR = 1.98$), more likely to self-identify as Hispanic ($OR = 1.86$), less likely to be Native English speakers ($OR = 0.52$), and less likely to be Juniors ($OR = 0.43$); additionally, students in this group were more likely to have lower GPAs ($OR = 0.64$). Members of the Consistently Relativist group (Table S9) were less likely to be Native English speakers ($OR = 0.42$). Members of the Consistently Evaluativist group (Table S10) were less likely to self-identify as Asian/Pacific Islander ($OR = 0.82$) and to be men (compared to women, $OR = 0.66$) and more likely to be Juniors ($OR = 1.73$) and Seniors ($OR = 2.18$); and students in this group were more likely to have higher GPAs ($OR = 2.11$). Those students who moved to an Evaluativist view (Table S11) were less likely to self-identify as Hispanic ($OR = 0.51$) and more likely to be Native English speakers ($OR = 1.71$).

Intrapersonal attributes profiles

For both the Time 1 and Time 2 samples, a four profile solution appeared to be most parsimonious with three profiles evident in both samples, one in the Time 1 sample, and another in the Time 2 sample, yielding a total of five discrete profiles. Profiles 1–3 occurred in both samples; Profile 4 only occurred in the Time 1 sample; and Profile 5 only occurred in the Time 2 sample. The intrapersonal attribute that most consistently distinguished the profiles in both samples was students' epistemic beliefs: students in Profile 1 endorsed relativist epistemic beliefs; students in Profile 2 endorsed absolutist epistemic beliefs; and students in Profile 3 and Profile 4 endorsed evaluativist epistemic beliefs. Additionally, students' writing self-efficacy, science self-efficacy, and science identity scores were associated with specific profile patterns. In the Time 1 sample, students in Profile 3 had the highest scores in these variables (ranging from 0.2 to 0.4 SD above the mean; Figure 1) and students in Profile 4 had the lowest (ranging from −0.6 to −1.2 SD below the mean). In the

Table 2 . Consistency and change in students' epistemic beliefs from Time 1 to Time 2.

Time 1	Absolutist	Time 2 Relativist	Evaluativist	Time 1 Total
Absolutist	146	38	288	472 (19%)
Relativist	42	31	123	196 (8%)
Evaluativist	246	123	1397	1766 (73%)
Time 2 Totals	434 (18%)	192 (8%)	1808 (74%)	2434

For all three beliefs, more students were consistent in their endorsement of epistemic beliefs over time than expected: absolutists ($\chi^2 = 68.60$, $p < .0001$); relativists ($\chi^2 = 18.44$, $p < .0001$); Evaluativist ($\chi^2 = 78.39$, $p < .0001$). Of these consistent students, those endorsing evaluativist beliefs has the greatest consistency (79%). Of the 35% of students who changed endorsements, the predominant direction was toward evaluativist beliefs (48%).
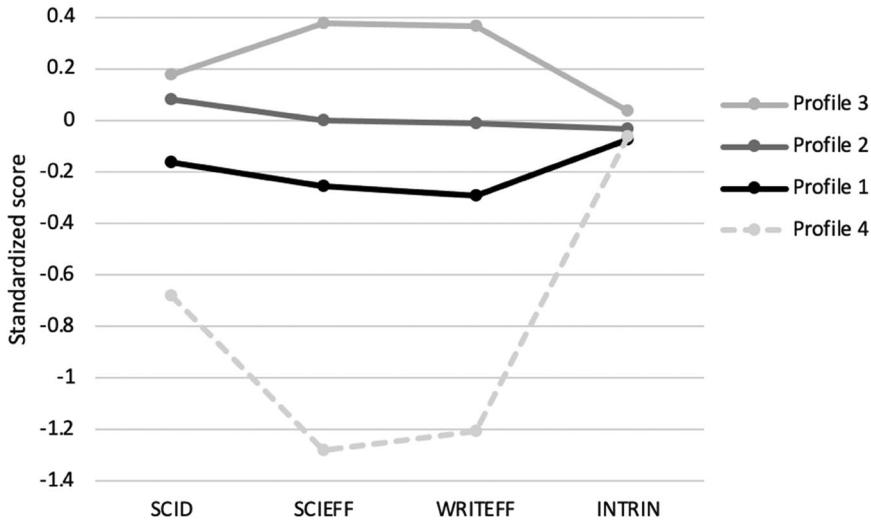
Figure 1 . For Time 1 (pre-course), this plot characterizes four profiles along dimensions of intrapersonal attributes: SCID = science identity, SCIEFF = self-efficacy in science, WRITEFF = self-efficacy in writing; INTRIN = intrinsic motivation. The profiles are plotted on a scale that is standardized with respect to the pre-course distributions in students' scores. Each series of points represents the average values of a particular profile.

Time 2 sample, students in Profiles 1, 2, and 3 did not significantly differ from each other (Figure 2). *Profile 5* students have the lowest scores on these items, ranging from −0.7 to −1.8 *SD* below the mean, and students in this profile endorsed all three epistemic beliefs.

Based on the findings with the Time 1 and Time 2 samples, we characterized profiles in terms of epistemic views*: Profile 1* as Relativist, *Profile 2* as Absolutist, *Profile 3* as Evaluativist-high efficacy, *Profile 4* as Evaluativist-low efficacy, and *Profile 5* as Low efficacy. The number and percentage of the students in the Time 1 and Time 2 samples classified in each profile are indicated in Table 3.
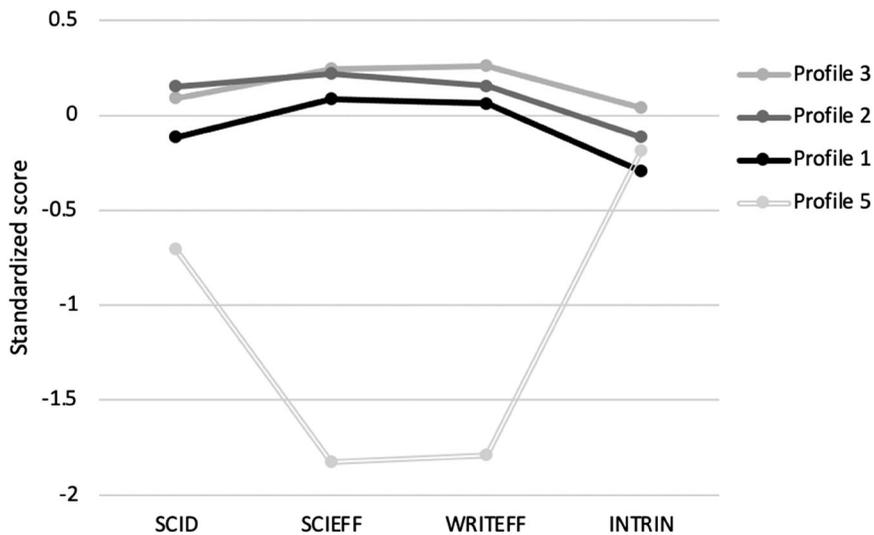

Figure 2 . For Time 2 (post-course), this plot characterizes four profiles along dimensions of intrapersonal attributes: SCID = science identity, SCIEFF = self-efficacy in science, WRITEFF = self-efficacy in writing; INTRIN = intrinsic motivation. The profiles are plotted on a scale that is standardized with respect to the pre-course distributions in students' scores. Each series of points represents the average values of a particular profile.

We also examined the demographic characteristics of the students comprising the five Intrapersonal Attributes Profiles (Table S14 in Supplemental Materials). Students in *Profile 2* (Absolutists) were more likely to be men than other profile profiles ($\chi^2 = 27.10$, $p < .0001$). There were no significant findings by race and ethnicity or by English as a second language. However, there were a few significant differences in Profile membership by year in school. In the Time 2 sample, First-year students were more likely to be part of *Profile* 3 (Evaluativist-high efficacy) and *Profile* 4 (Evaluativist-low efficacy) ($\chi^2 = 16.82$, $p = .008$) and Sophomores were more likely to be in *Profile 1* (Relativist) or Profile 5 (Low efficacy) ($\chi^2 = 14.61$, $p = .002$). Seniors were more likely to be part of *Profile* 3 (Evaluativist-high efficacy) in both the Time 1 and Time 2 samples (Time 1: $\chi^2 = 13.33$, $p = .004$; Time 2: $\chi^2 = 9.74$, $p = .02$).

Discussion

Changes in students' science self-efficacy beliefs and epistemic beliefs

This study employed a combination of variable-centered and person-centered approaches to examine changes in students epistemic and self-efficacy beliefs during participation in an undergraduate STEM course. Consistent with the findings of other studies (Dowd et al. 2019), we found mixed results depending on which approach we used. With the variable-centered approach, we found significant increases over the semester in mean scores for science self-efficacy with a medium effect size. However, person-centered analyses revealed that 30% of students had a decrease in their score and another 5% had no change.

Similarly, we found mixed results when we examined epistemic beliefs. Variable-centered analyses indicated no significant changes in the percentages of students who endorsed absolutist, relativist, and evaluativist epistemic beliefs at Time 1 versus Time 2. However, person-centered analyses revealed that, at the level of individual students, 35% of students endorsed different epistemic beliefs at Time 2 than they endorsed at Time 1, and 48% of the students who changed endorsements moved to evaluativist beliefs. Moreover, there were differences in stability depending on which epistemic belief students endorsed initially, with the highest level of stability demonstrated by those students who initially endorsed evaluativist epistemic beliefs. These changes in the stability of students' endorsement of epistemic beliefs are noteworthy for several reasons. Originally, the sophistication of epistemic beliefs was viewed in accordance with a developmental progression from the naïve *absolutist* view, through a *relativist* view, to the sophisticated *evaluativist* view (Hofer and Bendixen 2012). Given the consistent evidence in the research literature of the relationship of evaluativist thinking with enhanced student learning, a compelling case can be made for developing students as evaluativist thinkers as an educational objective. However, subsequent research has provided evidence that various belief dimensions of epistemic cognition are associated with numerous desirable educational outcomes (Sandoval, Greene, and Bråten 2016). For example, reliance on authority (i.e. an absolutist view) is not necessarily naïve or inherently inferior to other ways of knowing and is often necessary. Sophisticated epistemic cognition is coming to be viewed as characterized by *adaptive epistemic beliefs* that include multiple means of warranting knowledge claims depending on the context (Sandoval, Greene, and Bråten

Table 3 . Number and percentage of students classified in intrapersonal attributes profiles in time 1 and time 2 samples.

	Time 1		Time 2	
	N	%	N	%
Profile 1: Relativist	291	8	180	7
Profile 2: Absolutist	687	19	422	16
Profile 3: Evaluativist-High efficacy	2128	58	1803	67
Profile 4: Evaluativist-Low efficacy	555	15	NA	NA
Profile 5: Low efficacy	NA	NA	300	11
Total	3661		2705	

2016). One implication of a broader view about what constitutes sophisticated epistemic cognition is that educational practices should aim not only for students to develop their *capacities* for evaluative thinking but also their *adaptive epistemic beliefs,* so that they are able to employ their epistemic understandings in *nuanced* and *discerning* ways as the context requires.

Individual and demographic differences

Whereas the findings of this study indicate changes in students' epistemic and self-efficacy beliefs occurred during participation in a one semester STEM course, person-centered analyses identified considerable individual differences. Not all students exhibited these gains; some were unchanged and some declined. More specifically, self-identified Asian/Pacific Islander and Black students were more likely to be members of groups demonstrating a decrease in science self-efficacy. Similarly, self-identified Asian/Pacific Islander students and men were less likely to be members of the Consistently Evaluativist group, the group associated with higher GPA; and men and self-identified Hispanic students were more likely to be members of the Consistently Absolutist group, which was associated with lower GPA. Those students who moved to an Evaluativist view were less likely to self-identify as Hispanic ($OR = 0.51$) and more likely to be Native English speakers ($OR = 1.71$).

The findings of demographic differences have potential implications for educational practices but explaining the reasons for the differences is challenging. Our study was designed to examine changes in students' science self-efficacy and epistemic beliefs during participation in an undergraduate STEM course; identify profiles reflecting different patterns of interrelationship of students' intrapersonal attributes; and determine whether the changes, and membership in the different profiles, differed by students' demographic characteristics. However, we did not include measures of students' capabilities, other attributes and experiences, nor more fine-grained characteristics of their educational contexts, all of which is necessary to provide an empirical basis for explaining the demographic differences we found. Rather than speculate on reasons for the demographic differences, we point to research that has identified student characteristics that could be included in subsequent research to provide a fuller empirical basis for generating explanations for demographic differences should these emerge. More specifically, research on growth mindset (Dweck and Yeager 2019), sense of belonging (Walton and Cohen 2011), and sense of ethnic identity (Pizzolato et al. 2008) suggests that differences in these characteristics, along with inclusion of finer grained measures of educational contexts, could elucidate reasons for demographic differences in changes in personal attributes. Moreover, research on the contributions of these student characteristics to academic achievement has advanced to the experimental level of educational interventions that aim to foster the development of students' growth mindset, sense of belonging, and ethnic identity, which have been found to be differentially effective for 'at risk students' defined in terms of academic preparation, membership in racially or ethnically minoritized populations, and intrapersonal attributes. We consider this research in the section below on implications for educational practices and future research.

Here, we want to emphasize that the findings of the current study underscore two important points. First, research studies on the relationship of students' self-efficacy and epistemic beliefs with multiple educational outcomes needs to include an examination of demographic differences and the social/environmental factors that potentially give rise to these differences; without this type of examination, average changes may mask important variations within diverse student populations. Second, there is an on-going need not only to foster the development of students' self-efficacy and epistemic beliefs, but also to develop educational practices that are differently effective in fostering the development of these intrapersonal attributes among diverse students.

Profiles of students' intrapersonal attributes

Every student is unique but instructors typically cannot provide individualized instruction for every student; identifying patterns of intrapersonal attributes, i.e. profiles, potentially allows instructors to

create a discrete number of interventions to target at-risks groups in their classrooms. Using person-centered analysis (LPA) we identified five distinct profiles that reflected different patterns of inter-relationship of students' epistemic beliefs, science and writing self-efficacy beliefs, and science identity. Two profiles were characterized primarily with regard to epistemic beliefs: *Profile 1* (Relativist) and *Profile 2* (Absolutists). Two profiles we characterized by combinations of epistemic and efficacy beliefs: *Profile 3* (Evaluativist-High self-efficacy beliefs) and *Profile 4* (Evaluativist-Low self-efficacy beliefs). One profile was characterized primarily by efficacy beliefs: *Profile 5* (Low self-efficacy).

It is recognized that the intrapersonal attribute profiles identified in this study are unique to study sample characteristics, not only with regard to the demographic characteristics of the participants but also with regard to the educational context. In this case, our study included primarily first-year and second-year students enrolled in 14 STEM undergraduate courses (8 biology, 4 chemistry, and 2 statistics) at two public and one private R1: Doctoral Universities. Thus, generalizations to different samples and educational contexts will need to be empirically determined. However, the profiles identified in our study complement findings of previous studies, conducted in other science contexts, that have used different methods to examine the association of epistemic beliefs and self-efficacy beliefs. *Profile 3* (students with evaluativist epistemic beliefs and high science and writing self-efficacy beliefs) was similar to profile findings of other studies that have reported an association between evaluativist epistemic beliefs and high science self-efficacy beliefs (Chen 2012) and science self-concept (Kampa et al. 2016). *Profile 4* (students with evaluativist epistemic beliefs and low science and writing self-efficacy beliefs) is very similar to the Dowd et al. (2019) *nonefficacious evaluativist* cluster of students characterized as evaluativist in their epistemic beliefs, lacking in writing and science self-efficacy, and mastery oriented. *Profile 5,* (students with low self-efficacy beliefs) is very similar to the Dowd et al. (2019) *nonefficacious uncommitted* cluster of students characterized by relatively low self-efficacy beliefs, neutral epistemic beliefs, and low mastery motivation. The Dowd et al. (2019) study also identified the *efficacious absolutist cluster* of students characterized by strongly absolutist epistemic beliefs and a high sense of self-efficacy and provides evidence that high self-efficacy beliefs can be associated with absolutist epistemic beliefs, as well as with evaluativist beliefs. *Profile 2* was also characterized by student's with absolutist beliefs, but not markedly high in science identity or self-efficacy beliefs.

Across studies that have employed different person-center methods, evidence has been provided for different patterns of interrelationship between students' self-efficacy beliefs and epistemic beliefs: high self-efficacy with evaluativist, mixed, and absolutist epistemic beliefs; and low self-efficacy with evaluativist epistemic beliefs. The combination of self-efficacy beliefs and epistemic beliefs is of particular interest because of the evidence regarding the relationship of these attributes to learning. For example, more sophisticated epistemic beliefs have been associated with effective learning strategies, intrinsic goal orientation, and perceptions of self-efficacy (Paulsen and Feldman 2005, 2007). Similarly, students' self-efficacy was found to be strongly related to student achievement, self-regulation, motivation, and effective strategy use, and improved with participation in an undergraduate course (Bartimote-Aufflick et al. 2016). Furthermore, students with higher perceived competence at the beginning of the semester were much more likely to report high and stable science identities throughout the semester (Robinson et al. 2019). It will await subsequent experimental studies to determine whether these different profiles, characterized by a combination of epistemic beliefs and different levels of self-efficacy beliefs, are differentially associated with learning outcomes of diverse students in specific educational contexts.

Limitations

The limitations of this study are those common to large-scale survey studies that seek to examine multiple variables. Pilot testing prior to this study indicated that survey length was a limiting factor with regard to student response rate, which led us to an emphasis on parsimony in the

number of survey items allocated to the measurement of each intrapersonal attribute. In most cases, we used items employed in previous studies (e.g. science identity); in other cases, we constructed items in accordance with the standard forms employed in the field (e.g. self-efficacy). Our measures have satisfactory reliability and the findings are consistent with those of other studies in the literature. We chose to measure students' epistemic beliefs in terms of their endorsement of one of three wholistic epistemic views that are differentiated on the basis of the interrelationship of students' beliefs about the four underlying dimensions. We view this measure as both efficient and appropriate for our person-centered approach and our findings are consistent with other studies in the literature (e.g. Dowd et al. 2019; Kampa et al. 2016) that have measured epistemic beliefs in different ways. We acknowledge that additional studies are necessary to further establish the validity of the measure. The student survey and fuller descriptions of the items and sources have been included in Appendix A of the Supplemental Materials to facilitate examination and replication.

One criticism of person-centered approaches to identifying individual differences in student's patterns of interrelationship among intrapersonal attributes is that the profiles are, by design, unique to each sample, which raises concerns about the generalizability of the profiles (Linnenbrink-Garcia et al. 2018). The uniqueness extends beyond the demographic characteristics of the study sample to include the characteristics of the educational context with which the students are interacting. The educational context for this study was specific: STEM courses in R1: Doctoral Universities. A strength of the current study, however, is the inclusion of three universities, two public and one private, and 14 undergraduate courses across three STEM disciplines (8 biology, 4 chemistry, and 2 statistics). Both the generalizability and utility of students' intrapersonal attributes profiles will need to be determined through replication and ultimately experimental studies that examine the relationship of profiles to learning outcomes across diverse students in specific institutional and disciplinary contexts.

Conclusions and implications for educational practices and future research

This study provides evidence that students' self-efficacy and evaluativist epistemic beliefs – intrapersonal attributes known to be related to student learning – increase during participation in STEM courses. These changes were not intentionally targeted by the instructors of these courses and we recognize that there could have been other experiences, outside of taking a STEM course, that could have fostered the change. Nonetheless, these findings provide additional support for making students' epistemic beliefs (Kampa et al. 2016) and understanding of the epistemology of their discipline student learning objectives in their own right (Kalman 2009). Similarly, the robust evidence of the relationship of self-efficacy beliefs with academic performance coupled with the evidence of effectiveness of self-efficacy enhancement techniques (Richardson, Abraham, and Bond 2012) supports considering self-efficacy as a student learning objective in its own right. If the learning objectives of a course were to include enhancing students' epistemic and self-efficacy beliefs, what practices would likely be effective?

Efforts to enhance students' self-efficacy beliefs need to begin by promoting their belief that capabilities are malleable and not fixed. That is, it cannot be assumed that all students have a growth mindset (Dweck and Yeager 2019). However, a growth mindset can be intentionally fostered (Hacisalihoglu et al. 2020). In addition, recent evidence indicates that students' trust in their instructors as understanding ('My instructor gets me'), accepting ('My instructor accepts me for who I am'), and caring ('My instructor truly cares about my educational welfare') is even more strongly associated than growth mindset with students' engagement in self-regulatory learning strategies, intent to persist in science, and academic performance (Wang et al. 2021). This suggest that promoting students' trust in their instructors for 'getting them through a course' could be incorporated into the educational framework that already focuses on the importance of enhancing self-efficacy to promote students' persistence in STEM fields, particularly for students from populations that have been historically underrepresented (Graham et al. 2014). More specifically, programs that have been successful in fostering persistence commonly employ three interventions widely recognized

for enhancing students' motivation and confidence: Early research experiences, active learning in introductory courses, and membership in STEM learning communities (Graham et al. 2014). The current study findings that students who self-identified as Asian/Pacific Islander or Black were less likely to demonstrate gains in science self-efficacy during a STEM course suggests that intentionally fostering a growth mindset and students' trust in their instructors (Wang et al. 2021) could have a differentially positive impact with these students.

Another mindset that has been found to influence academic performance is whether students feel a sense of 'belonging' in their school or academic field (Walton and Cohen 2011). Concerns about belonging are associated with lower achievement and higher dropout rates (Rattan et al. 2015) and can be a particularly salient issue for members of minoritized, negatively stereotyped, and underrepresented groups in STEM (Fink, Frey, and Solomon 2020). Research has established that a positive sense of belonging (defined as perceptions of acceptance, fit, and inclusion in the campus milieu) is related to students' academic and social adjustment (Wilson et al. 2015). For example, Wilson and colleagues (2015) examined the hypotheses that students' sense of belonging at multiple levels (e.g. 'I feel that I am a part of this class [major, university/college]') would be positively related to their ratings of academic engagement. Their study included 1498 STEM undergraduates in five geographically and culturally distinct institutions in the United States (HBCU, Women's College, Private Faith-Based Teaching College, Regional Teaching College, Research University). Study findings provided evidence that both higher levels of self-efficacy and sense of belonging in the class were associated with greater academic effort and engagement in STEM coursework across the five schools. The authors identified the key findings:

> 'No matter what the institutional culture, no matter what the geographical location, no matter what the school size, this study has revealed evidence that a sense of belonging cultivated in a class is strongly related to the way the students feel, how hard they try, and how willing they are to participate in a class' (768).

Interventions to promote students' belonging mindsets have been found to narrow the achievement gaps of negatively stereotyped students. For example, Walton and Cohen (2011) developed a campus intervention to lessen psychological perceptions of threat by encouraging students not to attribute the perception to deficits unique to themselves or their ethnic group, but rather to attribute it to common and transient aspects of the college-adjustment process. As an often stereotyped and socially marginalized group, African-American students can experience relatively greater uncertainty about their belonging in school, and were expected to benefit from the intervention more than European-American students. Study findings indicated that the GPAs of African-American students who participated in the intervention rose from the fall of their freshman year through their senior year but the GPAs of African-American students in the control group showed no improvement. The GPAs of European-American students also rose over time with no difference by condition. Overall, the intervention set African-American students on an upward academic trajectory such that the GPA gap between them and their European-American classmates was reduced by 79% by senior year.

In addition to mindsets, the study by Pizzolato and colleagues (2008) provided evidence that students' sense of ethnic identity is another student characteristic that influences academic achievement for students from minoritized populations. Moreover, ethnic identity development is one possible explanation for why some students thrive in collegiate settings whereas others do not and can serve as a target for intervention efforts. Given the exposure of students from minoritized populations to negative stereotypes, the authors argue that: 'One way to combat negative messages is to help students of color construct ethnic identities that include achievement as not only a desirable characteristic of the ethnic group, but an achievable characteristic as well' (Pizzolato et al. 2008, 302).

Given that the design of educational practices and assessment of learning are increasingly discipline and topic specific (National Research Council 2012), intentional efforts to teach the epistemologies of each discipline are warranted (Kalman 2009). Disciplinary practices are learned through a combination of direct instruction, instructor modeling, and apprenticeship opportunities that enable students to engage the specific epistemologies underlying academic disciplines (Muis, Bendixen, and Haerle

2006, 2016). Epistemic beliefs not only reflect a person's way of thinking but also are a component of their sense of identity (Hofer 2004). Enculturation into the discourse of an academic discipline is a process of identity formation as students learn to view knowledge and its justification from the same perspective as the academic community with which they associate (Thompson 2014).

Alan Love's (2013) consideration of the lessons for teaching of biology from the interdisciplinary field of Evolutionary Developmental Biology (Evo-devo) provides a salient example of how shifting attention from the content to explicating the disciplinary practices with regard to epistemic cognition could foster student learning. Given that Evo-devo involves different disciplinary and sub-disciplinary paradigms, students cannot fully understand the content of this field without also understanding how researchers decide what to investigate and how. Pointing toward a non-reductionist epistemology in biology, Love (2013) explains why this field requires students to coordinate multiple epistemic resources. On the one hand, they need an absolutist view to build on the work of others but, on the other hand, they need an evaluativist view to synthesize the diverse approaches and methodologies to generate empirically adequate explanations. Furthermore, reasoning in biological science is not homogeneous and biologists prioritize one reasoning style over another depending on their explanatory goals. It is not only necessary to teach the disciplinary and sub-disciplinary reasoning strategies: 'We must teach that biological reasoning strategies can be incompatible and illuminating at the same time' (Love 2013, 269).

Aligned with the discipline-specific view of epistemic cognition, efforts to develop students' epistemic sophistication are increasingly adopting a resource enhancement focus (Elby, Macrander, and Hammer 2016). In addition to beliefs, epistemic cognition includes aims, values, and what students take to be reliable versus unreliable processes for achieving their epistemic aims (Chinn, Buckland, and Samarapungavan 2011). The implications are that students need to learn to navigate and coordinate multiple epistemologies entangled with their multiple communities (Elby, Macrander, and Hammer 2016) and respond adaptively to specific tasks through activating or deactivating fine-grained epistemic resource in response to situational demands (Sandoval, Greene, and Bråten 2016). Correspondingly, educational practices should be intentionally designed to develop students' *adaptive* epistemic beliefs so that they are able to employ their epistemic understandings in nuanced and discerning ways as the context requires.

Ecological systems perspectives (Bronfenbrenner 1977; Bronfenbrenner and Morris 2006) focus on how student's personal attributes, in transactions with contextual factors, influence variability in learning in response to educational practices. Our study constitutes a first step by employing both person-centered analysis and variable-centered analysis to delineate patterns of interrelationship among an array of within-person attributes involving beliefs, motivations, and identity, all of which are typically examined as independent dimensions. Consistent with the ecological systems perspective, our focus in this study on delineating different within-person patterns of personal attributes now needs to be followed by studies that analyze the transaction of person factors with characteristics of the environment (i.e. educational context). More specifically, research on evidence-based educational practices to enhance learning and persistence among diverse undergraduates needs to be informed by experimental studies of empirically based instructional methods designed to develop students' self-efficacy beliefs, sense of belonging (identity) and epistemic cognition as educational outcomes in their own right. In particular, combined person-centered and variable-centered methods are needed to identify practices that may be differentially effective for at-risk students.

Disclosure statement

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ORCID

Julie A. Reynolds http://orcid.org/0000-0002-0476-7933

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