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Empirical study

Epistemological beliefs in science—a person-centered approach to investigate high school students' profiles

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ABSTRACT

Epistemological beliefs (EB) are a prominent topic in educational research and considered important for the learning process. Science EB in particular are not only important for learning in science but also a unique learning goal itself. They are connected to science abilities and achievement as well as to students' personal features and background. Since EB are domain-specific we investigated the four relevant dimensions for the domain of science: justification, development, source, and certainty. We explored the number and characteristics of science EB profiles among 4995 tenth graders and, by means of latent profile analysis (LPA), related them to students' characteristics. We identified four groups that show level and shape differences. These groups also differed considerably regarding constructs related to students' learning, namely, self-concept, motivation, and science achievement as well as gender, social background, and school type. Implications for further research, in particular for cross-cultural studies, are discussed.

1. Introduction

In educational research, epistemological beliefs (EB) have been and still are a prominent subject of various studies (e.g., Bråten, Britt, Strømsø, & Rouet, 2011; Buehl & Alexander, 2001; Conley, Pintrich, Vekiri, & Harrison, 2004; Elder, 2002; Hofer, 2000; Hofer & Pintrich, 1997; Kitchener, 2002; Perry, 1999; Schommer, 1990, 1994). Defined as "individual representations about knowledge and knowing" (Mason & Bromme, 2010, p. 1), EB are viewed as an important factor with respect to the interpretation of information and knowledge and, therefore, with respect to the process of learning in general. For example, EB have been found to be associated with students' learning motivation (e.g., Mason, Boscolo, Tornatora, & Ronconi, 2013), learning strategies (e.g., Schommer, 1994; Urhahne & Hopf, 2004), learning outcomes, and achievement (e.g., Hofer, 2001; Trautwein & Lüdtke, 2007) as well as students' conceptual understanding (e.g., Songer & Linn, 1991).

The importance for the process of learning also holds true for EB about science and scientific knowledge (science EB); in particular, as views about science are also regarded an important learning goal of science itself (for an overview on the relation between views of science [nature of science] and science EB, see e.g., Neumann & Kremer, 2013). As a consequence, there have been vital research activities on science EB (Conley et al., 2004; Mason et al., 2013; Urhahne & Hopf, 2004). The vast majority of research on science EB employed a variable-centered approach, which may overshadow subgroups that may vary between different cultural settings or between different samples. Person-centered approaches assume subgroups within a population rather than a homogeneous population and could be a way to detect differences and similarities between different countries. In our study, we combine the investigation of the relation between science EB and constructs of students' learning with a person-centered approach. Evidence about different profiles of science EB and the characterization of these profiles are a first step towards improving effective differentiation in science learning. So far, science EB have rarely been investigated from a person-centered perspective. To our knowledge only one study took this perspective when investigating U.S. high school students' science EB profiles (Chen, 2012). In our German study, we therefore aim to provide further insights into students' science EB profiles applying the person-centered approach in order to characterize EB profiles in more detail and compare these findings to results from other countries.

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1.1. Epistemological beliefs in science

Research on EB dates back to the 1970s and stems from various traditions.[1] More recently, researchers investigated the multidimensional structure and the domain-specificity of EB (Bromme, 2005; Buehl & Alexander, 2005; Chen, 2012; Conley et al., 2004; Hofer, 2001; Hofer & Pintrich, 1997; Schommer, 1990). As for general EB (Hofer, 2000; Schommer, 1990), in the domain of science, researchers conceptualized science EB as made up of core dimensions (Conley et al., 2004). In our study we refer to a four-factor structure of science EB, which is in line with previous research on science EB and which has already been successfully applied to samples of various age cohorts (e.g., sixth, ninth and tenth graders, Chen, 2012; fifth graders, Conley et al., 2004). The four factors split into two factors in the area of nature of knowledge ([1] *certainty* and [2] *development of scientific knowledge*) and two factors in the area of nature of knowing ([3] *source* and [4] *justification of scientific knowing*).

Beliefs on the *certainty of knowledge* span from viewing scientific knowledge as either being right or wrong (naïve) to viewing scientific knowledge as a reflection from more than one perspective (sophisticated). Beliefs on the *development of knowledge* span from viewing scientific knowledge as a static and unchanging subject (naïve) to accepting that scientific ideas and theories change over time in light of new evidence (sophisticated). Beliefs on the *source of knowing* refer to viewing knowledge as residing in external authorities such as scientists or teachers (naïve) versus viewing knowledge as created within the student (sophisticated). Beliefs on the *justification of knowing* refer to discovering phenomena through scientific investigations, e.g., experiment or observation (naïve) versus understanding that knowledge comes from reasoning, thinking, and multiple experimentations as well as observations (sophisticated; Conley et al., 2004).

This dimensional approach enables researchers to investigate whether views on science EB dimensions are separate and may develop independently. For example, a person could view the knowing of science as absolutely right or wrong (naïve view regarding source) and at the same time believe that scientific knowing is justified by empirical evidence gained from experiments (sophisticated view regarding justification). Dealing with a multidimensional EB model makes it possible to analyze different aspects of EB in more detail and to explore the relationship of the differentiated EB construct with other important personal features, such as motivation, self-concept or learning strategies (Conley et al., 2004; Trautwein & Lüdtke, 2007).

Although first evidence on differences in science EB dimensions for specific groups (e.g., ethnic background and gender) has already been obtained by various studies (for a review see Chen, 2012; Dai & Cromley, 2014), this research was largely based on variable-centered investigations. The first large-scale exploration of science EB employing a person-centered approach and leading to a systematic characterization of groups has recently been provided by Chen (2012). In his study, 1225 sixth, ninth and tenth graders from one U.S. state completed a science EB instrument (four subscales) by Conley et al. (2004) and an adapted scale on implicit theories of science ability by Dweck (1999). Implicit theories of ability refer to the students' opinion on whether effort or one's own ability is seen as a cause of performance outcome. The students also reported on their science grade, self-efficacy, science achievement, goal orientation, gender, and race/ethnicity. Chen, (2012) investigated profiles regarding science EB *and* implicit theories by means of latent profile analysis (LPA) and identified four differing profiles: *thriving, fixed/sophisticated, growth/passive*, and *uncommitted*. He found the majority (62.8%) of the surveyed middle and high school students to show a thriving or fixed/sophisticated profile. Both profiles did not differ with regard to science EB but did so with regard to implicit theories. Students in these two profiles held science EB that can be seen as more sophisticated beliefs on all four science EB dimensions. They rejected the idea that knowledge in science resides in science teachers or professional scientists only, believed that scientific knowledge is constantly evolving and that there is not just one answer to a scientific question. These students only differed regarding implicit theories. Students in the thriving profile showed a more incremental view which means that they put more emphasis on effort; students in the fixed/sophisticated profile showed a more fixed view which means that they put more emphasis on ability. Students in the growth/passive profile (31.2%) held the least sophisticated views with respect to the source and certainty aspect of science EB, and therefore, reflected a rather passive view of science knowledge. They did not believe that they themselves are able to construct knowledge and they believed that knowledge is rather fixed. Students in the uncommitted profile (6.0%) did not hold a particular position about science EB, and thus, the values of all four dimensions grouped around the scale mean. Both groups showed average scale means regarding fixed implicit theories and the students in the growth/passive group had higher values on incremental implicit theories than students in the uncommitted profile.

Overall, many studies on science EB have been performed, yet person-centered research on science EB profiles is far less established. Also, most of the variable-centered studies have been carried out in the U.S., where the majority of instruments on EB and science EB had been developed (Khine, 2008), and there is only little research in other cultural contexts or even on comparing different cultures. The present study therefore aims to address both issues, by applying a person-centered approach to identify science EB profiles of German students, which then may be compared to Chen's findings. By implementation of a person-centered approach, our study also provides the opportunity to identify similar and different groups when interpreting results across differing countries and samples.

1.2. Relation of EB to other student learning constructs

Literature provides a substantive amount of research on how EB relate to other aspects of students' learning (e.g., Hofer, 2001; Köller, Baumert, & Neubrand, 2000; Mason & Bromme, 2010; Nussbaum, Sinatra, & Poliquin, 2008; Songer & Linn, 1991; Tsai, Jessie Ho, Liang, & Lin, 2011; Urhahne & Hopf, 2004). Researchers have provided various models, for example on how EB relate to motivation, learning strategies, and learning outcomes (e.g., Hofer, 2001; Kizilgunes, Tekkaya, & Sungur, 2009; Köller et al., 2000). All of these studies either employed the instrument developed by Conley et al. (2004) or an adapted version (with the exception of the early work of Köller et al., 2000). Also, the existing models conceptualize science EB either as dependent variables (Chen, 2012; Conley et al., 2004), as independent variables (Kizilgunes et al., 2009; Köller et al., 2000; Mason et al., 2013; Tsai et al., 2011) or in path models as both at the same time (Trautwein & Lüdtke, 2007). These different conceptualizations indicated that the effect mechanisms are not clarified yet. For example, Kizilgunes et al. (2009) and Tsai et al. (2011) modeled self-efficacy as being a dependent variable with EB as the independent variable whereas Chen (2012) modeled these constructs within a LPA framework with these constructs as independent variables and students'

[1] We are aware that several labels as well as closely related constructs such as epistemic beliefs, personal epistemology or epistemic cognition do exist. We understand epistemological beliefs as individuals' theory of the epistemic (Kitchener, 2002).

classes as depended variables. Due to these inconsistent results regarding directions of the relations we are not able to elaborate a corresponding model depicting influential patterns of these epistemological patterns. Together with the fact that LPA, as employed in the present study, does not assume predictive relations (for details see Section 3.4 "Analyses"), we therefore mainly focus on correlations from former studies in the following literature review.

Regarding personal features, more sophisticated science EB were found to go along with higher science achievement goals (an aspect of learning motivation) and self-concept for fifth, eighth and eleventh graders in an Italian study (e.g., Mason et al., 2013). The Italian study revealed positive correlations with rather intrinsic dimensions of goal orientations (mastery and performance approach), negative correlations with rather extrinsic goal orientations (performance avoidance), and positive correlations with self-concept for the dimensions development and justification. The same result regarding self-concept was found for German sixth through tenth graders (Urhahne, Kremer, & Mayer, 2008). By contrast, motivation patterns differed with regard to the four factors justification, source, development, and certainty for German ninth graders. On the one hand, Urhahne and Hopf (2004) found positive correlations between the dimensions justification and development and motivation in science as well as the self-concept in physics and biology. The relation was stronger for students' self-concept in biology than for physics. On the other hand, source and certainty beliefs did not correlate with both constructs. Slightly different results were found in Chen's (2012) analyses with the overall sample for self-efficacy. Self-efficacy correlated with the dimensions justification and development, did not correlate with source, and correlated negatively with certainty beliefs.

Further studies identified relations between EB and achievement (Köller et al., 2000; Mason et al., 2013). In particular, the four science EB dimensions were found to positively correlate with students' grades for various school age cohorts in Germany and in the U.S. (e.g., Chen, 2012; Urhahne et al., 2008).

Few previous studies also investigated relations between science EB and students' demographics. For example, primary school students having a lower socio-economic status (SES) were found to have lower scores in each of the four belief scales than those having an average SES (Conley et al., 2004). Likewise, students' ethnic background and gender also seem to be related to students' EB profiles. Females tended to be more present in a fixed/sophisticated group than boys (Chen, 2012), but Conley et al. (2004) revealed that females and males showed the same changes regarding science EB over time.

In some countries, another demographic variable—the school type—is of particular relevance. In Germany, academic track secondary schools (*Gymnasium*) and general track secondary schools (e.g., *Real-, Mittel-, Sekundarschule*) have different curricula, different subject timetables, different teacher training, and students with differing SES. Since most studies are performed in academic track secondary schools, little is known about similarities and differences of students' science EB across the different school tracks.

Concluding, there have been various studies on the relationship between science EB and other constructs related to students' learning. Mostly, these studies convey similar results. However, there are some relations, which seem less generalizable. Such inhomogeneous results may stem from the fact that the various studies took place in different countries and cultural determination of science EB has only started to be investigated (Khine, 2008). Also, not all studies are based on a representative or even large-scale sample (e.g., Conley et al., 2004; Kizilgunes et al., 2009), and some of the described studies are based on positively selected samples as they investigated students from the highest academic school track (e.g., Köller et al., 2000; Urhahne & Hopf, 2004) or included students at early college (e.g., Trautwein & Lüdtke, 2007). The present study may add to this research, as we based our analyses on a large-scale sample in Germany. Germany is a country with a particular school system, which may cause different results compared to former studies from other countries.

1.3. The person-centered approach: individual and group differences in science EB

From the above overview, it seems there is no doubt that (science) EB are connected with personal features and learning-related constructs. However, research investigating this relation did not produce an overall homogeneous picture for all variables. For instance, the relation between overall science EB and achievement as well as between different science EB dimensions and school achievement (A-level grade) was found to vary in size (Trautwein & Lüdtke, 2007). These varying results from different study samples may be due to the existence of groups with specific characteristics. Consequently, analyses on individual or group patterns on these dimensions may reveal different findings (Hayenga & Corpus, 2010).

Only little research has been conducted so far from a person-centered perspective (Chen, 2012; Dai & Cromley, 2014). These few studies included science EB and one other construct (epistemic preferences or implicit theories) to establish subgroups. However, research on psychological phenomena also requires a shift from variable-centered approaches to person-centered approaches since the latter enable the derivation of instructional implications to the needs of unique groups of students (Hayenga & Corpus, 2010). Within the person-centered approach individuals with similar patterns on personal features are grouped together into particular combinations of variables rather than focusing on each variable itself (Hayenga & Corpus, 2010; Lubke & Muthén, 2005; Muthén & Muthén, 2000), in our case into types of science EB. The focus of this approach lies in relations among individuals within heterogeneous groups and each participant can be uniquely assigned to a single group based on one or more grouping variables (Lubke & Muthén, 2005; Muthén & Muthén, 2000). Examples of person-centered methods comprise, for instance, cluster analysis, latent class analysis (LCA) or LPA, which is a special case of LCA for continuous indicators.

LPA and LCA are similar to cluster analysis. They produce maximally different groups by assigning individuals who are similar regarding specific indicators in one group and by assigning individuals who are less similar into different groups. Accordingly, LPA detects homogeneous, mutually exclusive latent groups within a heterogeneous population in an exploratory way based on similar response patterns on a set of observed variables. Number and forms of groups are unknown beforehand (Magidson & Vermunt, 2002). Person-centered approaches have the advantage of analyzing these distinct groups regarding their indicators and significant covariates. LPA has several advantages over the more traditional cluster analyses that make this method highly appropriate for our intentions: First, densities are used to assign individuals to groups so that every individual is assigned to one group (Vermunt & Magidson, 2004). Second, derived groups can be characterized by the inclusion of covariates or auxiliary variables. And third, tests of statistical significance regarding the group means of covariates help in finding relevant group differences.

2. Research questions

Summing up the advantages of our theoretical and methodological approach, on the basis of a large-scale assessment (LSA) sample we investigate science EB from a person-centered perspective in order to substantiate and extend first results, which have already been generated through this methodological approach (Chen, 2012). In particular, we add to this previous work by also including personal features: motivation and self-concept as well as two measures of science achievement, grades and competence-based achievement measures. We also extend the research to a European country, thereby showing chances of the methodological approach for different cultural settings.

To extend previous research on science EB, we aim to give more in-depth results uniquely for science EB by (a) applying the person-centered approach, (b) enlarging Chen's (2012) results on relation to constructs relevant for learning by also including motivation and self-concept, and (c) corroborating first science EB profile analyses that have been generated by investigating a U.S. sample, by performing equivalent investigations based on a German sample. Additionally, we (d) incorporate a standardized achievement measure and grades in the same study, and (e) differentiate the personal features and achievement measures for biology, chemistry, and physics. We therefore analyzed data from a national LSA on high school students' science learning outcomes and science EB using LPA in order to provide more evidence for science EB profiles. Specifically, we investigated the following research questions:

(1a) Are there science EB profiles to be identified in a large-scale population?
(1b) To what extent can these profiles be characterized regarding science EB dimensions?
(2a) How far do students of varying science EB profiles differ regarding their personal features, motivation to learn in science disciplines, and their self-concept in the science disciplines?
(2b) To what extent do students of varying science EB profiles perform differently in science with respect to science grades and achievement?
(2c) How can the science EB profiles be demographically described by gender, students' SES, and school type?

In accordance with Chen (2012), we expect to extract groups that differ in shape and level; that is we expect qualitative (shape) differences between groups (i.e., groups which show different patterns of characteristics on the four EB scales, such as high justification and development, but low source and certainty beliefs in one group, in contrast to low justification, source and certainty and high development beliefs in another) and quantitative (level) differences between groups (i.e., high measures on all scales in one group in contrast to low measures on all scales in another group). Related to this, we expect that more than half of the sample will show level differences only. We also expect that rather sophisticated groups will also have high values in the achievement measures, the personal features, and the background variables. We also expect to find these profiles in the academic track secondary schools more often. The remaining groups will show lower scores on these aspects relevant to student learning and will be more present in non-academic track schools. With regard to gender, females might be more present in groups incorporating a rather naïve or fixed perspective (Chen, 2012).

3. Method

3.1. Participants

Our analyses are based on a German large-scale study that was conducted in order to establish educational standard assessment in science and was carried out by the Institute for Educational Quality Improvement at the Humboldt-Universität zu Berlin (IQB) in autumn 2009. The students first completed booklets containing items measuring science achievement and then a randomly assigned questionnaire. Of the 6084 students who participated, 4995 students (51.7% female) received a questionnaire that contained items on science EB. These students were enrolled in 299 tenth-grade classes within 158 schools in 8 (out of 16) federal states. Two classes per school were randomly drawn (17 schools only offered one tenth-grade class). On average, 17 students per class ($SD = 4.60$) answered the test items and the questions on science EB. The students were either enrolled in academic track secondary schools (*Gymnasium*, 48.8%), general track secondary schools (*Real-, Mittel-, Sekundarschule*, etc.) or mixed track secondary schools (*Gesamtschule*, the latter two secondary school types, 51.2%). Academic track secondary schools usually lead to A-level graduation and general track secondary schools to an equivalent to high school graduation. Students enrolled in mixed track secondary schools can opt for both graduation levels. On average, students were 15.48 years old ($SD = 0.73$). The average SES according to the Highest International Socio-Economic Index of Occupational Status (HISEI, see Section 3.3.3 "Demographic variables"; Ganzeboom, De Graaf & Treiman, 1992) was 51.62 ($SD = 16.15$), which relates to occupations like civil engineering technicians or medical practice assistants. While Turkish was the most mentioned foreign language spoken at home (2.9%), 90.4% of the students spoke German at home.

3.2. Test instruments and procedure

The students completed science achievement test items of which 501 addressed science content knowledge and 496 addressed scientific inquiry. The test was a paper-and-pencil test that consisted of two parts. During the first two hours the students completed a booklet containing science items having 15 minutes breaks in the middle of and right after the test. Then, the students proceeded with a questionnaire. To keep the individual workload within acceptable limits an incomplete block design was applied to the science standard test (Frey, Hartig, & Rupp, 2009). Each student only received a subsample of about 50 items. The questionnaire randomly contained self-concept and motivation questions on two out of three science disciplines (e.g., motivation in biology and physics, but not chemistry).

3.3. Measures

Among the described student characteristics, we focus on the ones that we perceive as internal student characteristics. The personal features motivation and self-concept are characteristics that define the students themselves and that are built through various feedback processes not reduced to the school environment. On the contrary, learning strategies are specific action patterns that are highly influenced by the school environment. The background variables SES and gender are also student characteristics. Regarding achievement measures, former studies have either included science achievement tests (Conley et al., 2004; Kizilgunes et al., 2009; Köller et al., 2000) or science grades (Chen, 2012; Mason et al., 2013; Trautwein & Lüdtke, 2007) into their studies. In order to be able to determine possible differences between the two achievement measures we included both measures into our study, one being rather objective and the other one being influenced by the students' achievement and teachers' attributions.

3.3.1. Science EB

To determine students' science EB, we employed a 29 item questionnaire based on the four science EB dimensions by Conley et al. (2004). The instrument was already administered to German sixth to tenth graders in academic track secondary and mixed track secondary schools (Urhahne et al., 2008). Urhahne et al. (2008) described the development of the German instrument and provided first evidence supporting its validity in a German context. To this end, the authors performed an exploratory factor analysis in which the scales were established. In addition, students' EB measures were found to increase with increasing grade level and to be correlated with self-concept and grades in the sciences, both of which, according to the authors, support the instruments' validity. Items consisted of a statement and students were asked to rate their agreement with the statement on a 4-point Likert scale (1 = *strongly agree* to 4 = *strongly disagree*). In accordance with the core factors of science EB, the statements targeted four dimensions: justification, development, source, and certainty. Each item was worded so that the focus on *science* and *scientific* knowledge was clear. Justification items (8 items, McDonalds ω = .81) referred to science as based on empirical evidence and to how scientific knowing is justified (e.g., *It is good to try experiments more than once to make sure of your findings*). One item was discarded from the scale due to a very low item-total correlation ($r_{\text{itemtotal}} = .12$). Development items (8 items, McDonalds ω = .85) addressed change in science and the evolving nature of scientific knowledge (e.g., *Sometimes scientists change their minds about what is true in science*). Source items (5 items, McDonalds ω = .77) focused on how scientific knowledge is constructed, in particular, on who builds new scientific knowing (e.g., *Only scientists can observe natural phenomena*). Certainty (7 items, McDonalds ω = .82) addressed the tentativeness of scientific knowledge including views about whether there is only one correct scientific knowledge (e.g., *Scientific knowledge is always true*). Note that the source and certainty items were stated from a naïve point of view and the justification and development items from a sophisticated point of view. For better understanding we recoded the items so that higher values indicated more sophisticated science EB. The missing rate for the items of the four scales ranged between 0.5 and 2.5%.

3.3.2. Science achievement

The test booklets contained one, two or all three of the science disciplines. Items in either multiple-choice, short constructed-response, or extended constructed-response format were developed for two achievement areas: content knowledge as well as scientific inquiry in biology, chemistry, and physics. They comprised different basic concepts across the three science disciplines. The broad use of basic concepts and the coverage of these two areas within the three science discipline areas assured a linkage of our achievement measures to the relevant school curricula (example items for concept knowledge and scientific inquiry each are depicted in Appendix A, see Figs. A1 and A2). In order to ensure that the tests are in line with school curricular requirements, the test development process included item development by teams of science education researchers and experienced teachers from all over Germany as well as a continuous feedback and revisions by external science education experts. Therefore, the applied test is rather considered a curricular test (like e.g., the Trends in International Mathematics and Science Study [TIMSS] test) than a literacy test (like e.g., Programme for International Student Assessment [PISA] test). For the analyses we used plausible values (PV) for six achievement areas: one for content knowledge and scientific inquiry within each of the three disciplines. The reliabilities of these scales ranged between McDonalds ω = .97 and .98. The students' grades in biology, chemistry, and physics in their last semester was retrieved from the participation list that was turned in by the school principals.

3.3.3. Demographic variables

Students' gender was retrieved from the participation list. The students' SES was operationalized with the HISEI, which is an index that combines characteristics of occupations to build a continuous scale: the education needed for the occupation, the social status of the occupation, and its outcome. The scale ranges from 16 (e.g., cleaning personnel) to 90 (e.g., judge; Ganzeboom et al., 1992). The HISEI reflects the highest occupation in the family of a student, so the basis is either the ISEI of the mother or the ISEI of the father.

3.3.4. Motivation and self-concept

We used measures on self-concept and on future-oriented science motivation from the PISA 2006 study. Since Urhahne and Hopf's (2004) results suggest differences between the three science disciplines, we used instruments which were adapted to the three scientific disciplines of biology, chemistry, and physics. The level of agreement was measured on a 4-point Likert scale (1 = *strongly agree* to 4 = *strongly disagree*). Both have been successfully implemented in former large-scale studies and have gone through extensive field trial studies in order to ensure reliability, validity, and cross-cultural comparability (OECD, 2009).

Students' future-oriented science motivation contributes to their extrinsic motivation to learn science, and thus, to the perception of the relevance for either their future studies or job prospects (Pekrun, 2005). This construct has been found to predict science performance, mastery and performance goal orientation, and is an important factor for course selection or career choice (Chen, 2012; Kizilgunes et al., 2009; Mason et al., 2013; Wigfield, Eccles, & Rodriguez, 1998). It was important to us to investigate motivational aspects, which are relevant on a long-term basis for students in order to investigate how the structure of science EB is affected by a rather sustainable learning motivation. The questionnaire contained five questions for each discipline (McDonalds $\omega_{\text{bio}} = .92$, McDonalds $\omega_{\text{che}} = .93$, McDonalds $\omega_{\text{phy}} = .93$), and students had to disagree or agree on items like *What I learn in biology/chemistry/physics is important for me because I need this for what I want to study later on*.

Self-concept in science was measured by six items for each discipline (McDonalds $\omega_{\text{bio}} = .91$, McDonalds $\omega_{\text{che}} = .94$, McDonalds $\omega_{\text{phy}} = .94$), asking students to what extent they believe in their own science achievement and abilities (e.g., *Learning advanced biology/chemistry/physics topics would be easy for me*). In our approach we are interested in how self-concept is related to a more naïve or elaborated view on science EB and in particular, how self-concept differs between different groups of science EB.

3.4. Analyses

All analyses were carried out in Mplus7 (Muthén & Muthén, 1998). We used the full information maximum likelihood method (FIML) to account for missing values (see Table B1 for the missing rates in Appendix B). In a first step, we performed LPA on the basis of the four means of science EB. In a second step, we introduced the continuous covariates to the model and calculated frequencies for the nominal covariates. In the first step, we carried out the LPA for the science EB using scale-means for each of the four science EB dimensions. We ran LPAs with increasing numbers of groups (one through six) and based the analyses on 2000 random sets of starting values. After 50 iterations the 200 best sets of starting values were selected for the final optimization. By applying LPA, we used the same method as Chen (2012) with the same four science EB dimensions but only introduced one measure in order to establish groups solely based on the science EB system.

The literature suggests choosing models based on multiple indices derived from the different models and based on theoretical interpretability (Nylund, Asparouhov, & Muthén, 2007; Tynkkynen, Tolvanen, & Salmela-Aro, 2012). As suggested by Vermunt and Magidson (2005) we used the Bayesian information criterion (BIC), the Akaike Information Criterion (AIC), and the consistent Akaike Information Criterion (cAIC) as well as the entropy to evaluate the class[2]-solutions' fit. Regarding the information criteria BIC, AIC, and cAIC, lower values indicate a better fit of the model to the data (Kline, 2011). The entropy index ranges between 0 and 1 with values closer to 1 indicating a more certain classification of single individuals. The employed cutoff for the entropy index was .70 (Nagin, 2005). Additionally, we used the bootstrapped likelihood ratio test (BLRT), Vuong–Lo–Mendell–Rubin likelihood ratio test (VL-LRT), and the Lo–Mendell–Rubin adjusted LRT test (LMR) as suggested by Muthén and Asparouhov (2012). These tests can be interpreted like a *p*-value and indicate that the model with *k* latent classes fits the data better than the model with *k*-1 latent classes (Muthén & Asparouhov, 2012). To validate the final class-solution we reran the LPAs on two random split-half datasets.

In the second step we introduced the covariates as auxiliaries (e) to further describe each group (PVs of science achievement, means of grades, motivation, self-concept, and SES). Note that the PVs of science achievement stem from one-dimensional analyses for each achievement area within each science discipline. Only students who were assigned a booklet including items on the area (e.g., concept knowledge in biology) received a respective PV.

In LPA, covariates can be introduced in two ways. They can either be introduced as regression coefficients (auxiliaries (r)) that determine classification of students into groups, or they can be introduced as auxiliaries (e). In the latter case, the group means of the auxiliary variables are tested against equality with a Wald χ^2 test in order to test the statistical significance of the mean differences. In both cases, the covariates are seen as independent variables, though in case of mean comparisons these independent variables do not serve as predictors. Our chosen option calculates the means of the covariates for each group and tests the mean differences between the groups against equality. Auxiliaries (r) assumes a causal ordering from the covariates to the latent groups (Marsh, Lüdtke, Trautwein, & Morin, 2009). As described in Section 1.2 "Relation of EB to other student learning constructs", this assumption cannot be met by most of our covariates. With our LPA approach we follow up on Chen's study (2012) and also conceptualize science EB as the dependent variable. However, from our point of view, the concept of dependent and independent variables is more diluted than in a regression analysis or in a structural equation model (SEM) framework. Also, we were not interested in how the covariates would *alter* the group probabilities but in how members from different science EB groups also differ regarding the covariates. Since the integration of PVs is not available for LPA analyses we performed the analyses on the achievement measures with all five PVs separately and report the results for the first PV. Different results for the remaining PVs are indicated. For the categorical variables school type and gender we inspected contingency tables including the group membership as a variable.

4. Results

4.1. Descriptives

Our research concerns science EB and the role of the personal features motivation and self-concept, the science achievement measured by grades and standardized achievement tests as well as the demographics gender, school type, and SES. Before we investigate the science EB profiles, we display the correlations between the science EB dimensions (see Table 1).

[2] Throughout the manuscript, we display results for both: classes (of students at a school) included in our sample and groups derived from LPA. In order to not confuse the terms, we therefore use the terms *classes* for referring to the classes in schools, and *groups* for the subgroups derived from LPA. In order to stay consistent with LPA literature, we use the term class when describing the LPA method.

Table 1
Zero-order correlations between the science EB dimensions justification, development, source, and certainty as well as means and standard deviations (in the diagonal).

	Justification	Development	Source	Certainty
Justification	3.21 (.44)			
Development	.73	3.20 (.48)		
Source	.06	.16	2.89 (.63)	
Certainty	.06	.21	.64	2.88 (.58)

Note. Categories from 1 = *naïve* to 4 = *sophisticated* perspective.
All correlations are significant at the level $p > .05$.

Students' answers indicated that on average they hold sophisticated beliefs on justification of knowing in science and that they assumed scientific knowledge to change over time. To a lower degree, they also believed that knowing in science can come from a variety of sources, not just external authorities, and that there is more than one answer in science when addressing a specific problem. Remember that the scales certainty and source were originally stated from a naïve perspective and the scales development and justification are originally stated from a sophisticated perspective. The two scales that were stated from a sophisticated perspective as well as the two scales that were stated from a naïve perspective correlated quite high with one another. The scales with opposing perspectives correlated moderately. Our correlation patterns resemble those reported in previous studies (e.g., Chen, 2012; Conley et al., 2004).

4.2. Description of science EB profiles

In order to examine profiles of science EB we first ran LPA analyses from one through six groups and compared the fit statistics, indices, and likelihood ratio tests of the solutions (see Table 2).

Given the large sample size, it is not surprising that the sample size dependent BIC, AIC, and cAIC continue to decrease up to the six classes' model and the likelihood ratio tests consistently show significant results through model 6. Models 3, 5 and 6 show a low entropy. Therefore, we chose the 4-classes model. It is the model which has a high entropy value and significant likelihood ratio tests. Reliability of latent profiles is an important issue, which is why we randomly split our sample into two halves and performed the same analyses ($n_{\text{dataset1}} = 2498$, $n_{\text{dataset2}} = 2517$; see Appendix C, Table C1). The split half approach led to the same pattern, which provides evidence for the validity of our decision.

Groups 1 and 4 (see Fig. 1) contain the highest number of students (group 1: 41.8%, group 4: 41.9%), group 2 contains 11.9% and group 3 only 4.4% of the students. First, the groups can be distinguished by their science EB values. Group 1 is characterized by a slightly sophisticated perspective on science EB in all four EB dimensions that is above but close to the average of the whole sample. We named this group *slightly sophisticated*. Group 4 is characterized by a sophisticated perspective on science EB, with high science EB values in all four science EB. We named this group *sophisticated*. Both groups showed level differences in all four dimensions but no pattern differences.

Group 2 showed the first pattern differences. Students in this group hold more sophisticated views in the dimensions justification and development and rather naïve views concerning the dimensions source and certainty. These students appreciate the importance of evidence and experimentation for the science endeavor and recognize the evolving construction of science knowledge over time. At the same time, they tend to believe that knowledge comes from external authorities, that it is not subject to change, and that scientific questions have only one answer. Emphasizing the sophisticated features of this group we named it *evidence-based/dynamic*

Table 2
Comparison of fit statistics, indices, and likelihood ratio tests with decreasing number of groups.

No. of groups	Log likelihood	No. of free parameter	AIC	BIC	cAIC	LMR	BLRT	VL-LRT	Entropy	Smallest group frequency
1	−15,433.91	8	30,883.82	30,935.95	30,943.95					
2	−14,159.40	13	28,344.79	28,429.50	28,442.50	.00	.00	.00	.67	43.5%
3	−12,985.53	18	26,007.05	26,124.34	26,142.34	.00	.00	.00	.78	6.5%
4	−12,133.69	23	24,313.38	24,463.25	24,486.25	.00	.00	.00	.82	4.4%
5	−11,889.32	28	23,834.64	24,017.10	24,045.10	.00	.00	.00	.74	3.8%
6	−11,707.12	33	23,480.24	23,695.28	23,728.28	.54	.00	.53	.76	2.6%

Notes. The corresponding results of the two split-half datasets are shown in Appendix C. BIC = Bayesian information criterion; AIC = Akaike's Information Criterion; cAIC = consistent Akaike's Information Criterion; LMR = Lo–Mendell–Rubin adjusted likelihood ratio test; BLRT = parametric bootstrapped likelihood ratio test; VL-LRT = Vuong–Lo–Mendell–Rubin likelihood ratio test.

since students in this group appreciate evidence and the evolving character of science.

Group 3 showed the opposing pattern to group 2. Students in this group hold quite sophisticated views in the dimensions source and certainty as well as below average views in the dimensions justification and development. These students especially recognize that science does not need to come from external authorities and that it can be questioned and challenged by different people. But they do not necessarily appreciate the importance of evidence and the changing and evolving character of science over time. We named this group *multiplistic* since students in this group appreciate that knowledge can come from multiple people and multiple sources.

Fig. 1 depicts the means and distributions for each science EB dimension and for overall science EB within the four groups. The distributions indicate that students in all groups show higher variability in the dimensions source and certainty than in justification and development. The multiplistic science EB group (group 3) shows the smallest distribution for the averaged science EB mean.

Additionally, we analyzed whether teachers face homogeneous or heterogeneous classes regarding the distribution of science EB. In the 135 academic track secondary schools, either two (29), three (80) or four (26) science EB profiles can be found within one class. In the classes with three science EB profiles, the students belong either to all but the evidence-based/dynamic group (11) or to all but the multiplistic group (69). The majority of classes that showed two science EB profiles incorporate the slightly sophisticated and the sophisticated group (28). Only in one of these classes we found the slightly sophisticated and multiplistic group.

In contrast, in the 164 general track secondary schools we also identified classes with two (21), three (76) and four (67) science EB profiles. Within the classes with three profiles, we found classes in which all but the evidence-based/dynamic group (4) and classes in which all but the multiplistic group (61) were present, but we also found classes in which all but the sophisticated group was present (11). It emerged a similar picture regarding the classes incorporating two profiles. Here, we found 16 classes with a slightly sophisticated and a sophisticated profile, 2 classes with a slightly sophisticated and multiplistic profile but also 3 classes with a slightly sophisticated and evidence-based/dynamic profile. To sum up these frequencies, the classes in academic track secondary schools are much more homogeneous than the classes in the general track secondary schools.

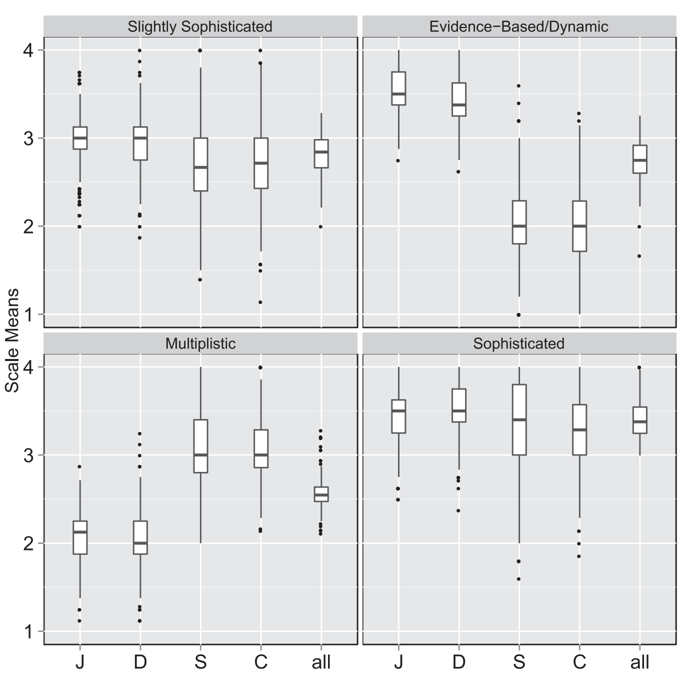

Fig. 1. Boxplots for science EB groups. J = justification, D = development, S = source, C = certainty.

4.3. *Science EB profiles and personal features, science achievement as well as demographics*

In a next step, we want to further distinguish the science EB groups by variables that have been brought in connection with science EB in previous studies. Mean differences are depicted in Table 3 and differences for categorical covariates in Table 4. We report results on the covariates alongside the four groups in order to be able to arrive at a deeper understanding of them and focus on the most distinct differences between the groups.

4.3.1. *Group 1: slightly sophisticated*

With the exception of self-concept in chemistry, students with a slightly sophisticated view in science EB could be distinguished from all other groups regarding motivation and self-concept (lowest $d_{motp14} = 0.06$, highest $d_{skb13} = 0.48$). They showed the second lowest values in both personal features. Regarding science achievement, the students in this group could either be distinguished from all groups or from the multiplistic and the sophisticated group (lowest $d_{chesi12} = 0.11$, highest $d_{phyck13} = 0.33$). Regarding grades, the slightly sophisticated students showed the second highest values, which can be distinguished from the multiplistic and the sophisticated group (lowest $d_{chegr14} = 0.28$, highest $d_{biogr13} = 0.38$). Female students were overrepresented in this group and compared to the other groups the social background was average. Furthermore, slightly sophisticated students were rather underrepresented in the academic track secondary schools.

Table 3
Group means of the covariates motivation, self-concept and, achievement.

	Slightly sophisticated (1)	Evidence-based/ dynamic (2)	Multiplistic (3)	Sophisticated (4)
Motivation				
Biology*	$2.35^{2,3,4}$	$2.66^{1,3,4}$	$1.92^{1,2,4}$	$2.49^{1,2,3}$
Chemistry*	$2.17^{2,3}$	$2.53^{1,3,4}$	$1.90^{1,2,4}$	$2.21^{2,3}$
Physics*	$2.33^{2,3,4}$	$2.61^{1,3,4}$	$1.99^{1,2,4}$	$2.40^{1,2,3}$
Self-concept				
Biology*	$2.71^{2,3,4}$	$2.99^{1,3}$	$2.30^{1,2,4}$	$3.01^{1,3}$
Chemistry*	$2.44^{2,3,4}$	$2.71^{1,3,4}$	$2.04^{1,2,4}$	$2.61^{1,2,3}$
Physics*	$2.45^{2,3,4}$	$2.71^{1,3}$	$2.07^{1,2,4}$	$2.61^{1,3}$
Achievement				
Biology_{si}*	$-.09^{3,4}$ (487)	$-.17^{3,4}$ (477)	$-.46^{1,2,4}$ (443)	$.24^{1,2,3}$ (526)
Biology_{ck}*	$-.19^{3,4}$ (484)	$-.25^{3,4}$ (479)	$-.81^{1,2,4}$ (427)	$.29^{1,2,3}$ (529)
Chemistry_{si}*	$-.13^{2,3,4}$ (485)	$-.36^{1,4}$ (464)	$-.57^{1,4}$ (444)	$.36^{1,2,3}$ (531)
Chemistry_{ck}*	$-.14^{2,3,4}$ (483)	$-.36^{1,4}$ (461)	$-.54^{1,4}$ (444)	$.39^{1,2,3}$ (534)
Physics_{si}*	$-.13^{2,3,4}$ (483)	$-.30^{1,4}$ (463)	$-.52^{1,4}$ (439)	$.34^{1,2,3}$ (536)
Physics_{ck}*	$-.08^{3,4}$ (486)	$-.25^{3,4}$ (469)	$-.68^{1,2,4}$ (427)	$.37^{1,2,3}$ (531)
Grades				
Biology*	$2.93^{3,4}$	$2.92^{3,4}$	$3.32^{1,2,4}$	$2.57^{1,2,3}$
Chemistry*	$3.04^{3,4}$	$2.96^{3,4}$	$3.34^{1,2,4}$	$2.74^{1,2,3}$
Physics*	$3.06^{3,4}$	$3.04^{3,4}$	$3.37^{1,2,4}$	$2.76^{1,2,3}$
Background				
SES*	$49.60^{3,4}$	$49.50^{3,4}$	$46.29^{1,2,4}$	$54.59^{1,2,3}$

Notes. Subscript si = scientific inquiry, subscript ck = concept knowledge, SES = socio-economic status. For the standardized achievement measures, the means of the first plausible value are displayed as well as the corresponding value on the PISA metric (in parentheses). For each group value, the superscripts indicate the group(s) that statistically differ from that group.
* = $p < .05$ for the overall test.

Table 4
Percentage of females and of students visiting academic track secondary schools across the four groups.

Covariate	Slightly sophisticated (1)	Evidence-based/ dynamic (2)	Multiplistic (3)	Sophisticated (4)
Female*	51.63	43.68	38.53	55.48
Atss*	38.95	33.05	27.52	65.28

Note. Atss = academic track secondary school.
* = $p < .05$ for the covariate.

4.3.2. Group 2: evidence-based/dynamic

This group had high values in the dimensions justification and development. Students in this group also held the highest motivation in all three science disciplines (lowest $d_{motb24} = 0.15$, $d_{motb23} = 0.66$) as well as the highest self-concept in chemistry ($d_{skc23} = 0.72$). Regarding the two other self-concept related comparisons, students from this group could not be distinguished from the sophisticated group. The mediocre science achievement values of the evidence-based/dynamic group could be distinguished from two groups[3], always from the sophisticated group and alternating from the remaining two (lowest $d_{physi12} = 0.10$, highest $d_{physi24} = 0.39$). The science grades were midrange as well. Female students were underrepresented in this group and the social background was average again. This group was also slightly underrepresented in the academic track secondary school.

4.3.3. Group 3: multiplistic

Students holding a multiplistic perspective believed that evidence in science can derive from multiple sources and multiple (groups of) persons. They were least motivated regarding all three science disciplines (lowest $d_{motc13} = 0.27$, highest $d_{motb23} = 0.66$) and had the lowest self-concept (lowest $d_{skp13} = 0.37$, highest $d_{skb34} = 0.80$) compared to all other groups. The science achievement of the multiplistic group again showed the lowest values which were consistently significantly lower compared to the sophisticated and slightly sophisticated but not always compared to the evidence-based/dynamic group (lowest $d_{biosi23} = 0.20$, highest $d_{biock34} = 0.62$). Regarding grades, students holding multiplistic views again had the least favoring values (lowest $d_{chegr13} = 0.20$, highest $d_{biogr34} = 0.75$). The multiplistic group had the lowest social background ($d_{socback34} = 0.49$). In this group, we found the highest underrepresentation of female students as well as the highest underrepresentation of enrolment in academic track secondary schools.

4.3.4. Group 4: sophisticated

With the exception of motivation in chemistry as well as self-concept in biology and physics, students with a sophisticated view showed the second highest values which can be distinguished from all other groups (lowest $d_{motp14} = 0.06$, highest $d_{skb34} = 0.80$). Also, the sophisticated group showed either statistically significant higher motivation compared to the slightly sophisticated group or to the multiplistic group regarding biology and physics self-concept (lowest, $d_{skp14} = 0.16$, highest $d_{skb34} = 0.80$) but not compared to the evidence-based/dynamic group. Compared to the three other groups, students in this group had the highest science achievement and the highest grades (lowest $d_{chegr23} = 0.21$, highest $d_{biock34} = 0.62$) across all six achievement areas. The biggest gap for science achievement and grades was 109 achievement points and about half a grade (0.41) between group 3 and group 4. The sophisticated group showed the highest social background ($d_{socback} = 0.49$) and female students were overrepresented in this group. Within the sophisticated group the majority of students were enrolled in the academic track secondary school.

The gender differences across all groups became statistically significant but the low Cramer's V (.09) suggests only minor differences. The school type differences were more pronounced. The differences showed a higher Cramer's V of .29.

5. Discussion

The aim of our study was the investigation and characterization of science EB profiles. Our analyses emphasize the importance of person-centered analyses as an enrichment of typical variable-centered approaches concerning in-depth understanding of the relations between science EB and students' personal features, achievement, and other background characteristics. As a result of applying the person-centered approach we identified four science EB types that differ in level and shape: slightly sophisticated, evidence-based/dynamic, multiplistic, and sophisticated (research questions 1a and 1b). These groups do not only differ with regard to the four science EB dimensions justification, development, source, and certainty but also with regard to personal features, the students' science achievement, and their background (research questions 2a, 2b and 2c). The differences were similar in all three science disciplines of biology, chemistry, and physics.

5.1. Science EB profiles and its implications

Two of the four science EB profiles—the sophisticated and the slightly sophisticated profile—showed level differences. The 83.8% students in these two profiles had quite similar views across the four science EB dimensions and did not show any differentiation between science EB dimensions. Our results resemble and oppose Chen's work (2012) at the same time. Just like Chen (2012), who found two even more similar groups (fixed/sophisticated and

[3] In two comparisons across all PVs, the evidence-based/dynamic group can only be distinguished from the sophisticated class and in one comparison to all other groups.

thriving, 62.8%) showing high values in all four science EB dimensions of the middle and high school students, we have found similar tendencies (sophisticated group with high values on all four science EB dimensions, slightly sophisticated group with above average values in all four dimensions). In contrast, regarding shape differences, the evidence-based/dynamic and the multiplistic group show a pattern that has not been found by Chen (2012).

Our study supports former results which showed that science EB dimensions are multidimensional (Conley et al., 2004; Kizilgunes et al., 2009; Tsai et al., 2011; Urhahne & Hopf, 2004) and that students can develop different science EB nuances represented by different profiles (Chen, 2012). The small differences between our study and Chen's study (2012) could be caused by various reasons. First, the studies were carried out in two different western countries and cultural differences between countries regarding science EB are still not investigated in depth (Khine, 2008). Second and besides the cultural differences, the U.S. study took place in a more unified educational system compared to Germany. Due to the fact that the school type has a considerable effect on students' science EB, the type of school should also be taken into account when present. Third, the differences could also be produced by learning experiences throughout high school. While Chen (2012) tested sixth, ninth and tenth graders, we investigated tenth graders only. Assuming that younger students tend to have less sophisticated EB profiles (Chen, 2012), this may change once they receive science instruction. Fourth, Chen's study was not investigated on the basis of a representative student sample. Future cross-country *and* longitudinal studies including learning opportunities should shed further light onto cultural differences and the development of the four science EB dimensions throughout the school career on the basis of national or state representative samples, for instance on the basis of LSA studies.

As discussed above, we assume the differentiated profiles to be developmentally later stages. Once the evolvement of the two differentiated profiles is revealed, teachers could be informed to target the weaker dimensions throughout the science curriculum in secondary school. In order to address science EB profile development in teaching, diagnostic and formative feedback instruments as well as learning material targeting this evolvement would need to be developed. Another strand of future research would be to identify teaching approaches that positively impact students' science EB. Both research strands would enable to transfer our results into classroom practice and enable integration into knowledge transfer in science.

By producing similar and opposing results compared to the first LPA study (Chen, 2012), we have given valuable hints on possible cross-cultural differences in science EB profiles. With a variable-centered approach, the mere inspection of mean differences across the four dimensions of science EB would have veiled the similar patterns regarding the sophisticated and the slightly sophisticated group as well as the opposing patterns regarding evidence-based/dynamic and the multiplistic group. By incorporating LPA, similarities and differences in cross-cultural sample comparisons are more likely to be detected. Therefore, we see this approach as promising in determining international comparative differences, e.g., for science EB.

5.2. Differences between science EB profiles regarding constructs related to student learning and implications

By incorporating personal features, background, and science achievement into the four-class solution we detected expected as well as unexpected patterns. Before going into detail we need to point out that all covariates, namely, motivation, self-concept, gender, social background, grades, science achievement, and school type, differed significantly between groups. These differing patterns show that we succeeded in depicting relevant covariates (research questions 2a, 2b, 2c).

In addition to holding the lowest science EB values, the multiplistic group showed the least favorable values in all constructs which in the majority of comparisons was significantly different from all other groups. This is the smallest group and one could argue that it is negligible. However, this small subgroup is a high risk group and interventions to support them need to be developed. So a closer investigation of this group seems inevitable.

Another more surprising result was that the sophisticated group did not outperform the other groups regarding all constructs related to student learning. Students from this group did not show the highest motivation and self-concept, instead it was the evidence-based/dynamic group. In the latter group this did not translate into high science achievement measures or grades. This result is of particular interest for two main reasons. First, when applying variable-centered analyses, these peculiar differences would have been concealed. Linking overall motivation and self-concept in science to the four dimensions of science EB for the whole sample would simply have shown an average to high correlation just as in earlier studies (Mason et al., 2013). Second, we showed that students do not need to have sophisticated views of science EB on all four dimensions in order to show high motivation and self-concept. Believing that scientific knowledge develops and that it needs to be justified seems to already go hand in hand with high motivation and self-concept in science. Thus, our results showed how the person-centered approach can provide explanations for differential correlation patterns in variable-centered analyses. We also extended the discipline-specific results found by Urhahne and Hopf (2004) to chemistry. While self-concept in physics and chemistry showed almost the same means in all four dimensions of science EB, the means for self-concept in biology stand out. So whenever science is taught discipline-specific, relating science EB to overall science constructs that are relevant to teaching does not seem to be adequate. Future studies should also investigate whether differential patterns for the three disciplines can be found even though science is taught integratively in school. This validity question should be addressed in future studies.

With regard to gender, more females are in the sophisticated and slightly sophisticated groups and more males are in the multiplistic and evidence-based/dynamic group. Accordingly, our results are not in line with Chen (2012) which again may result from the differing samples or cultural differences. The more astonishing result is the distribution across school types. Even though all science EB profiles occur in both school types, we revealed tremendous differences. Almost ¾ of the students in the sophisticated group are enrolled in an academic track secondary school, and about ¾ of the students in the multiplistic profile are enrolled in a general track secondary school. The other two groups are more present in general track secondary school classrooms. On the one hand, these two school types seem to offer different learning experiences regarding science EB and the constructs related to student learning. On the other hand, since the profiles are differently present in the two school types, students in different school types might need different science instruction to foster their science EB. These school type related differences and how to reduce them through interventions in the general track secondary schools should be targeted in further studies.

6. Limitations

Besides the aforementioned insights and contributions our study certainly shows some limitations. First, although we already included various constructs related to student learning that have already been discussed in relation to science EB (Tsai et al., 2011;

Urhahne & Hopf, 2004), we were not able to include all of the discussed constructs, e.g., learning strategies. In LPA, the relation between covariates and group defining variables is not of directional nature. To overcome this limitation, future LPA research on science EB should apply mixture models. Mixture models bear the possibility to integrate, for instance, SEMs which enable to model directional relations and LPA which allow exploring groups with different relational patterns. Up until now, an integration of both approaches for a big sample like ours is not possible. Second, the employed instrument by Conley et al. (2004) consisted of four subscales with two subscales formulated positively and two subscales formulated negatively. The reported correlations of these four dimensions—just like in any other utilization of the instrument—showed particularly high relations between the positively formulated scales (justification and development) on the one hand and the negatively formulated scales (source and certainty) on the other hand. Based on the literature on the structure of EB (Hofer & Pintrich, 1997), we would have expected another pattern of correlations (i.e., high relations between source and justification as well as between development and certainty, respectively). We therefore cannot rule out that the found pattern of relationship is a methodological artifact due to the wording of the scales rather than a finding due to students' personal features. This possible artifact needs to be investigated with multitrait-multimethod models in future studies. Finally, with the exception of the achievement measures we relied on self-report measures. This is still common practice but bears the problem of confounding variables, such as social desirability, SES, motivation or self-concept. For self-concept specifically, the social determination is well researched. One important mechanism is the big-fish-little-pond effect (Marsh & Hau, 2003) which describes the dependency of self-concept on a reference group, in our case the school or the classroom. Nevertheless, we chose the self-report measure since it allows us to rely on well-established measures and relate our findings to previous studies. In the future, comparisons between self-report measures and other modes of assessment should be evaluated in order to determine the dependencies of these measures on the described confounding variables and mechanisms.

7. Conclusions and outlook

In conclusion, the main focus of the present study was on investigating students' science EB profiles. In particular, the present study was characterized by:

(a) applying a person-centered approach,
(b) enlarging results from previous research on the relation to constructs relevant for learning, namely, motivation and self-concept,
(c) substantiating first science EB profile analyses in the U.S. in a European country,
(d) differentiating the personal features and achievement measures for biology, chemistry, and physics, and
(e) incorporating a standardized achievement measure *and* grades in the same study.

Our study provides some valuable insights into science EB profiles. (1) Our results are, to a large extent, in line with the findings by Chen (2012) who had conducted a similar study, yet in another country and not for science EB only. We identified four science EB profiles with two of them being comparable to two of the ones found by Chen. However, we also identified two other profiles which showed patterns across the four dimensions of science EB that did not arise in previous research. Comparing the results in such detail was only possible by applying the person-centered approach. (2) The majority of students were found to show the same pattern and to have quite similar science EB on all dimensions. However, even small differences in science EB were in parts accompanied by huge differences in constructs relevant to student learning, which holds true for all three science disciplines. This indicates that unifying these three does not seem to be appropriate when investigating science EB. Future person-centered approaches need to incorporate these important constructs to enlighten these relations. (3) By including the school type into our analyses, we found classes in academic track schools to be less heterogeneous with respect to science EB profiles than classes in general track secondary schools. This insight may help to view previous research from another perspective. For instance, Urhahne and Hopf (2004) examined academic track secondary schools, which means that—generalizing from our results—they very likely mostly investigated the sophisticated group. Based on these considerations, the findings may also be interpreted differently.

Overall, our study may also lead future research. Now that we showed that different science EB profiles exist, the development of these profiles should be observed applying longitudinal studies in different school types and countries. For these investigations, the person-centered approach is particularly suitable since it enables (a) to detect whether students switch profiles throughout the development of science EB or accumulate staying in the same profile, (b) to reveal similar and different patterns across countries, and (c) deepen the knowledge on developmental patterns across countries.

Once the science EB profiles are consolidated, the next step will be investigating implications and interventions on a more fine-grained level. Analyses on this fine-grained level will enlighten the relationship between and the importance of science EB, including personal features such as motivation and self-concept in science. Once these interrelations are discovered, school stake holders will better know how to prepare their students for participation in a society that is more and more influenced by science.

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Appendix A

For hundreds of years, the South American indigenous peoples have used the poison "Curare" in arrows for hunting. Derived from plant extracts, this poison can completely paralyze and kill animals within moments.

This is possible because curare prevents signal transmission between nerve and muscle cells. Then the muscles, which the animal needs to move the body, become paralyzed. The respiratory musculature also becomes affected. However, the poison has no effect on the heart muscle and the Curare effect decreases with time.

In the 18th century, a scientist administered a deadly dose of curare to mammals. Despite the dose, he was able to keep them alive.

Which life-saving procedure did he perform in order to prevent the death of the animals?

Fig. A1. Example item for concept knowledge (Curare).

Max wants to observe the growth conditions of plants. For the experiment, he uses the "busy lizzie", a low maintenance and resistant houseplant.
He conducts the following experiment:

Factors	Plant 1	Plant 2
Temperature	25 °C	25 °C
Placement	At a sunny window	In a dark closet
Watering	Once a week	Once a week
Fertilization	Twice a week	Twice a week

What hypothesis (an educated guess), is Max's experiment based on?

Fig. A2. Example item for scientific inquiry (Busy Lizzie).

Appendix B

Table B1
Missing rates of employed variables in percentages

	Missing rate	Of these not administered or not taught
Grade biology	17.81	17.65
Grade chemistry	10.30	10.13
Grade physics	19.72	19.60
Biology ck/si	-	60.68/59.25
Physics ck/si	-	63.69/66.30
Chemistry ck/si	-	65.56/69.74
HISEI	8.22	
Self-concept biology	39.66	39.44
Self-concept chemistry	20.80	20.31
Self-concept physics	40.67	40.25
Motivation biology	39.68	39.44
Motivation chemistry	20.86	20.31
Motivation physics	43.26	42.94

Notes. Due to the rotation design of the scales within the questionnaires, the missing rates for self-concept and motivation are about 40%. High missing rates resulted from students' course selection. si = scientific inquiry. ck = concept knowledge. - = since we only had access to PVs, the missing rates for individual items were not available.

Appendix C

Table C1
Comparison of LPA with decreasing number of classes of split-half datasets (n_{half1} = 2,498, n_{half1} = 2,517)

No. of groups	Dataset	Log likelihood	No. of free parameter	BIC	AIC	cAIC	LMR	BLRT	VL-LRT	Entropy	Smallest relative class frequency
1	half1	–7,702.48	8	15,420.96	15,467.54	15,475.54					
	half2	–7,724.74	8	15,465.47	15,512.06	15,520.06					
2	half1	–7,115.22	13	14,256.44	14,332.13	14,345.13	.00	.00	.00	.66	40.8%
	half2	–7,028.95	13	14,083.90	14,159.60	14,172.60	.00	.00	.00	.68	46.5%
3	half1	–6,514.58	18	13,065.16	13,169.96	13,187.96	.00	.00	.00	.79	5.8%
	half2	–6,454.45	18	12,944.90	12,049.72	13,067.72	.00	.00	.00	.79	6.9%
4	half1	–6,060.37	23	12,166.74	12,300.65	12,323.65	.00	.00	.00	.82	4.2%
	half2	–6,049.44	23	12,144.88	12,278.83	12,301.83	.00	.00	.00	.82	4.1%
5	half1	–5,932.40	28	11,920.80	12,083.83	12,111.83	.00	.00	.00	.75	4.0%
	half2	–5,927.36	28	11,910.73	12,073.79	12,101.79	.03	.00	.03	.75	3.6%
6	half1	–5,839.22	33	11,744.43	11,936.57	11,969.57	.03	.00	.03	.74	4.1%
	half2	–5,823.73	33	11,713.46	11,905.64	11,938.64	.03	.00	.03	.78	2.6%

Note. BIC = Bayesian information criterion; AIC = Akaike Information Criterion; cAIC = consistent Akaike Information Criterion; LMR = Lo–Mendell–Rubin adjusted LRT test; BLRT = parametric bootstrapped likelihood ratio test; VL-LRT = Vuong–Lo–Mendell–Rubin likelihood ratio test.

Appendix D

Year	Authors	*N*	Country	School type	EB measure	Covariates	Dependent variables	Major results on science EB
2000	Köller et al.	/	Germany	Secondary level II	Six dimensions: certainty, complexity, development, justification, societal, and private relevance	Course choice	Science EB	Higher course choice = more empiristic idea of science and more claim on truth and insights
2004	Conley et al.	187	USA	Elementary school: fifth grade	Four dimensions (Elder, 2002)	Gender, SES, ethnicity, achievement	Science EB: source, development, certainty, justification	Covariance analyses main effect of SES, not gender and ethnicity achievement significant covariate for all dimensions
2004	Urhahne & Hopf	167	Germany	Academic track secondary school ninth grade	Four dimensions (Conley et al., 2004)	Achievement motivation, self-concept (interest, learning strategies)	Science EB	Positive correlations between justification/development and motivation, self-concept in biology, and self-concept in physics
2005	Buehl & Alexander	482	USA	University: undergraduate students	DSBQ: isolation of knowledge DFEBQ: certainty, source	Motivation, task performance	Math EB: certainty, isolation, authority	Positive correlation between motivation and science EB
2007	Trautwein & Lüdtke	T1: 2854, T2: 1886	Germany	Upper secondary school	Two dimensions: fallibility of scientific theories; certainty (Hofer, 2000; Schommer, 1990)	Cognitive abilities, gender, students' family background, college major, A-level grade	Certainty beliefs	Positive correlation between certainty and SES, cultural capital, cognitive abilities, and school grades
2008	Urhahne, Kremer, & Mayer	272	Germany	Academic and general track secondary school, secondary level I	Seven dimensions: source, certainty, development, justification, simplicity, purpose, creativity			Positive correlation between source/ development/justification and self-concept in biology, self-concept in physics, and science grade positive correlation between certainty and self-concept in physics as well as science grades
2009	Kizilgunes, Tekkaya, & Sungur	1041	Turkey	Elementary school: sixth grade	Four dimensions (Conley et al., 2004)	Motivation, learning approach, achievement	Learning approach, achievement, performance goal, learning goal, self-efficacy	Dimensions development/source positively predict self-efficacy/ performance goal orientation and learning goal orientation; justification negatively predicts self-efficacy/ performance goal orientation; certainty negatively predicts performance goal orientation and learning goal orientation; and justification positively predicts learning goal orientation
2011	Tsai, Ho, Liang, & Lin	377	Taiwan	High school	Four dimensions (Conley et al., 2004)	Self-efficacy, conceptions of learning science	Conceptions of learning science, self-efficacy	Higher values in certainty = lower values in self-efficacy; all other EB not significant
2012	Chen	1225	USA	Middle and high school	Four dimensions (Conley et al., 2004)	Gender, race/ ethnicity, grade, self-efficacy, mastery goal, performance approach goal	Fixed theory of ability, incremental theory of ability, and the four dimensions of epistemic beliefs	Correlational results: Positive correlations between self-efficacy and development/justification, negative correlations between self-efficacy and certainty, positive correlations between mastery goal and development/justification/source; positive correlation between grade and development as well as justification; no relation between grade and source; negative correlation between grade and certainty Profile results: Uncommitted profile (average in all dimensions): low self-efficacy, low in grades thriving and fixed-sophisticated (high in all dimensions): high self-efficacy, high grades
2013	Mason et al.	696	Italy	Elementary through secondary level II	Two dimensions: development and justification (Conley et al., 2004)	Development, justification	Various independent and dependent variables in path model: e.g., science achievement goals, science self-concept, science knowledge, science achievement	Positive correlation between development/justification and mastery goal orientation, self-concept as well as self-efficacy; positive correlation between justification and performance-approach goal orientation
2014	Dai & Cromley	488	USA	University	Four dimensions: simple and certain knowledge, attainable truth, alternative knowledge claims, source: authority, adapted from Hofer's DEBQ (2002)	Race, gender, parents' highest educational attainment, year in college, age, high school GPA, domain knowledge in chemistry	EB of chemistry and epistemic preferences	Different ethnic distribution across profiles, no sex differences

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