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Besides knowledge: a cross-sectional study on the relations between epistemic beliefs, achievement goals, self-beliefs, and achievement in science

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Abstract This study examines the contribution of learner cognitive and motivational characteristics to achievement in science at three grade levels. Specifically, the relations between domain-specific epistemic beliefs about the development and justification of scientific knowledge, achievement goals, knowledge, self-concept, self-efficacy, and achievement in science were simultaneously examined. Students in fifth ($n = 213$), eighth ($n = 202$), and eleventh ($n = 281$) grades completed questionnaires measuring the various constructs, and a domain knowledge test. Their grades in science were also collected. Results from structural equation modeling reveal that the hypothesized model fitted the observed data at the three grade levels, although not all expected paths were statistically significant. Students' epistemic beliefs about the development of scientific knowledge had a direct effect on domain knowledge, whereas beliefs about the justification of scientific knowledge had a direct and an indirect effect via achievement goals on knowledge acquisition. Mastery, performance-approach, and performance-avoidance goals had a direct effect on self-efficacy. Knowledge had a direct and an indirect effect via self-concept on achievement. Educational implications are discussed.

Keywords Epistemic beliefs · Achievement goals · Self-concept · Self-efficacy · Domain knowledge · Achievement in science

Introduction

In various countries there is great concern about students' underachievement in science as revealed by recent international assessments such as PISA 2009 (Programme for International Student Assessment, OECD 2010), or TIMSS 2007 (Trends in International Mathematics and Science Study, Olson et al. 2008). Deficits in science achievement have negative consequences which go far beyond academic performance as students need to be

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equipped with the necessary tools to become citizens able to understand the scientific issues that confront them. What individual factors contribute to achievement in science? This study was based on the assumption that multiple learner characteristics, besides domain knowledge, may interact and lead to achievement in science (Britner and Pajares 2001; Chen and Pajares 2010; Pajares et al. 2000). We moved theoretically from the issue that when dealing with new scientific knowledge to be learned, students do not only activate their prior knowledge about a topic, but also their beliefs about knowledge itself, which may influence the goals they set for learning and learning itself (Muis 2007). We were interested in testing a comprehensive model that integrates simultaneous interactions of epistemic beliefs with various motivational factors, besides knowledge, to explain differences in achievement in the core academic domain of science in primary, lower, and upper secondary school. We sought to extend current research by relating lines that have mainly been investigated separately or have been integrated to a limited extent, that is, research on domain-specific epistemic beliefs, achievement goals, and self-beliefs in relation to knowledge acquisition and overall achievement.

Epistemic beliefs

Beliefs about knowledge and knowing, namely epistemic beliefs, are individuals' representations about the nature, organization, and source of knowledge, its truth value and the justification criteria of assertions (Hofer and Pintrich 1997, 2002). Research on epistemic beliefs started flourishing after Schommer's (1990) seminal article. A review of the literature on epistemic beliefs is outside the scope of this paper and we focus only on the issues that are most pertinent to the current study.

There is widespread theoretical agreement among educational psychologists on the construct of epistemic beliefs as multidimensional, that is, organized around four dimensions (Buehl 2008). Two dimensions are about the nature of knowledge (*what knowledge is*). The first regards beliefs about the *simplicity* vs. the *complexity of knowledge*: the degree to which knowledge is represented as compartmentalized or interrelated, ranging from knowledge as comprising discrete and simple facts to knowledge as a complex set of interrelated concepts. The second dimension regards beliefs about the *certainty* vs. the *uncertainty of knowledge*: the degree to which knowledge is conceived as stable or evolving, ranging from absolute to hypothetical and changing knowledge. Two belief dimensions are about the nature of knowing. The first regards the *source of knowledge*: the relationship between knower and known, ranging from the belief that knowledge resides outside the self and is transmitted, to the belief that it is constructed by the self. The second dimension regards the *justification of knowledge*: what makes a sufficient knowledge claim, ranging from the belief in direct observation or authority to the belief in the use of rules of inquiry and evaluation of expertise as criteria for knowledge justification (Hofer 2000, 2004).

According to some scholars (e.g. Schommer 1990), epistemic dimensions may be independent, therefore individuals may hold more availing beliefs in one dimension and less availing in another. According to other scholars (e.g. Hofer 2000), beliefs about knowledge and knowing do not comprise a set of independent ideas, but rather a coherent integration of theories, whose core is articulated around the four dimensions. In spite of divergences in conceptualizing the construct and methodological questions (see also Greene et al. 2008; Hammer and Elby 2002), it can be said that scholars substantially agree on the direction of the developmental trend in the four belief dimensions.

Research has also documented that epistemic beliefs are multilayered, that is, they are not only domain-general but also domain-specific (Limón 2006; Muis et al. 2006). This means that they differ according to subject-matter, as empirical research has indicated (Buehl and Alexander 2002; Hofer 2000; Mason et al. 2008; Schommer and Walker 1995; Trautwein and Lüdtke 2007). Although the topic-specific level has also been examined more recently (Bråten and Strømsø 2010), the domain-general and domain-specific have been the levels of epistemic representation most investigated.

Regarding the science domain, which is of interest to our study, the belief dimensions about the nature of scientific knowledge and knowing are conceptualized as follows:

- *simplicity* of scientific knowledge: the degree to which science is believed to be made up of questions have only one right answer (a less availing belief) or questions that can have more than one correct answer (a more availing belief);
- *certainty* of scientific knowledge: the degree to which science is believed to be a static (a less availing belief) or continuously evolving (a more availing belief) body of knowledge;
- *source* of scientific knowledge: the degree to which it is believed to reside in omniscient experts (a less availing belief) or to be personally constructed (a more availing belief);
- *justification* of scientific knowledge: the degree to which science experiments are believed to be used to perform activities (a less availing belief) or to test hypotheses and produce explanations (a more availing belief).

In the literature, the direct relation of epistemic beliefs to knowledge acquisition in science has been shown by studies on conceptual change (Mason et al. 2008; Qian and Alvermann 1995; Sinatra et al. 2003; Stathopoulou and Vosniadou 2007; Tsai 2008), learning from searching and evaluating web-pages (Mason et al. 2011; Mason et al. 2010a, b; Tu et al. 2008), and comprehension of multiple texts (Bråten and Strømsø 2010; Strømsø and Bråten 2009). Epistemic beliefs have also been proved to be directly related to overall achievement in a domain, as reflected in a final course grade, and overall academic performance measured by grade point average (Hofer 2000; Schommer-Aikins et al. 2005).

From the methodological perspective, the instruments most widely used to measure domain-general and domain-specific epistemic beliefs are self-report questionnaires. All the above-mentioned studies on the relationship between epistemic beliefs and learning or achievement, which are based on the multidimensional conceptual framework of the construct, have measured representations about knowledge and knowing by means of self-reported questionnaires with items to be rated on Likert-type scales. The first questionnaire, used by Schommer (1990) to measure domain-general epistemic beliefs served as the basis for the construction of slightly different (e.g. Schraw et al. 2002) or substantially modified inventories (e.g. Hofer 2000) to assess both domain-general and domain-specific epistemic beliefs. Self-report questionnaires have mostly been used with university students. However, a self-report questionnaire has been developed for much younger students, fifth graders, to measure their domain-specific epistemic beliefs about science (Elder 2002). In the study reported below, a version of this questionnaire adapted by Conley et al. (2004) was used.

According to the developmental perspective, epistemic beliefs become more availing or constructivist as an effect of cognitive development and education (King and Kitchener 1994; Kuhn et al. 2000). This implies that, in the domain of science, older students are more likely to believe that scientific knowledge is complex, tentative, and evolving, does not reside in omniscient authorities and can be validated in the light of corroborative evidence.

Achievement goals

Achievement goals explain the why and how of student involvement in a task or learning activity (Ames and Archer 1988). The classic distinction in achievement goal theory is between mastery-goal orientation and performance-goal orientation. Mastery-oriented students are focused on learning and understanding, and developing new skills, while performance-oriented students are focused on getting a good grade, reward, or performing better than others, (Dweck and Leggett 1988; Pintrich and Schunk 2002).

In the 1990s, the mastery-performance distinction was debated and reframed according to two important dimensions. The first regarded approach-avoidance motivation. In Dweck and Leggett's (1988) conceptualization, performance goals include both approach (attaining good evaluation, outperforming peers) and avoidance (not demonstrating incompetence) orientation. Elliot and Church (1997) proposed a trichotomous achievement goal framework, including mastery approach and two distinct performance goals: approach and avoidance. The second dimension regarded the standard used to evaluate competence: intrapersonal or normative. Therefore, by combining the two dimensions of approach/avoidance and intrapersonal/normative standard, a 2×2 achievement goal framework was proposed which incorporates the "missing" goal, mastery avoidance (Elliot 1999; Elliot and McGregor 2001). Mastery avoidance orientation is focused on avoiding task-referential or self-referential incompetence, for example avoiding the loss of skill.

However, the debate on achievement goals, in particular performance goals, did not end with the 2×2 framework. Several studies in the last decade have shown a stronger relationship between school achievement and performance approach rather than mastery approach goals, leading some scholars to propose a multiple goal perspective, considering the positive effects of performance as well as mastery goals. In this regard, Midgley et al. (2001) have posited that performance-approach maybe a resource for some students when combined with mastery goals. Hence, an optimal achievement goal profile may be represented by mastery goals coupled with performance-approach goals (Elliot 2005). Multiple goals can indeed influence students' academic motivation and performance through converging, conflicting, or compensatory interactions (Barron and Harackiewicz 2001; Dowson and McInerney 2003).

From a different perspective, Brophy (2005) proposed distinguishing *outcome* from *performance* goals, the former emphasizing attainment, the latter peer comparison and competition, and suggested that goal theorists "move on from performance goals". Recently, Senko et al. (2011) reviewed several criticisms of the multiple goal perspective and concluded that most of the criticism lacked empirical support, and that normative performance goals should be investigated in greater depth.

Research has widely documented that mastery approach goals are typically related to positive outcomes as indicated by the use of deeper processing strategies, task engagement, retention of information, conceptual change, persistence in front of difficulties, self-regulation, and high achievement (DeBacker and Crowson 2006; Elliot and McGregor 1999; Linnenbrink and Pintrich 2003; Pintrich 2000; Schunk 1996; Urdan 1997). Research has also indicated that performance-approach goals are more typically related to negative outcomes such as low self-efficacy, avoiding help-seeking, lack of persistence, use of surface processing strategies, and test anxiety (Anderman and Maehr 1994; Middleton and Midgley 1997; Urdan 1997). However, as mentioned above, the issue that performance-approach goals are always maladaptive has been questioned (Harackiewicz et al. 2002; Harackiewicz and Elliott 1993). More recently, positive outcomes have been associated with performance-approach goals, such as task engagement, self-regulatory strategies, conceptual change, high aspirations, and high achievement (Elliot and Church 1997; Elliot and Harackiewicz 1996; Pintrich 2000; Qian and Pan 2002).

In contrast, performance-avoidance goals have been found to be related only to negative outcomes, that is, low task engagement, unwillingness to seek help, and lower achievement (Elliot and Church 1997; Elliot and Harackiewicz 1996; Middleton and Midgley 1997). Finally, mastery-avoidance goals, which have been investigated less than mastery approach, performance approach, and performance-avoidance approach, have been found to be related to fear of failure, test anxiety, external regulation, and lower achievement (Elliot and McGregor 2001).

With regard to mastery-avoidance goals, we should point out that they were not examined in the present study, as they are much less prevalent in the school context. Students' adoption of achievement goals reflects their perceptions of the classroom and family context pressures, such as the emphasis on approach motivation (mastery and performance) and performance avoidance (Ames 1990; Linnenbrink and Pintrich 2001). In other words, students are typically focused on doing well in understanding and learning (mastery-approach goal), attaining a good grade or outperforming others (performance-approach goal), or avoiding a demonstration of low competence compared with others. They are not usually focused on losing competence since they do not view their achievement in terms of a comparison with themselves, but rather, in relation to peer achievement and teacher evaluation. Striving to avoid not doing as well as in the past is more typical, for example, in the sports context (Ciani and Sheldon 2010; Conroy et al. 2006).

From a developmental perspective, research has documented a decrease in students' approach orientation across grade levels, especially from elementary to middle school. These changes in achievement goals are related to changes in the contexts in which learning activities take place (Anderman et al. 2002; Meece et al. 2006). However, there are still few studies that have investigated achievement goals in students at different grade levels, mostly focused on mastery and performance-approach goals. From a developmental perspective it is also legitimate to expect that performance-avoidance goals are more likely to increase across grade levels. Students become more focused on not demonstrating lack of ability compared with others as school requirements become increasingly more demanding and challenging.

Self-beliefs

The two self-beliefs most investigated in academic motivation research were also examined in this study, that is, self-concept and self-efficacy.

Self-concept. This construct can be defined as a person's self-perceptions about her or his competence, which are influenced by the evaluation of significant others, attributions for one's own behavior, and reinforcements. Self-concept is therefore formed through personal experiences and interpretations of one's environment (Marsh 1990a, b; Shavelson et al. 1976). Seven characteristics of this construct have been identified by researchers, that is, self-concept is organized, multifaceted, hierarchical, stable, developmental, evaluative, and differentiable. Two of these characteristics, hierarchical and multifaceted, have been more widely addressed (Schunk and Pajares 2005). Self-concept is hierarchical as the perceptions that a person has about the self involve the totality of one's self-knowledge as well as the perceptions that one has in relation to specific areas or domains, in our case the academic domain of science (science self-concept). Self-concept is also multifaceted as it includes cognitive-evaluative and affective components (Bong and Clark 1999).

Domain-specific self-concept has been found to be highly related to achievement (Marsh et al. 2005; Marsh and Köller 2004; Trautwein et al. 2006).

Self-efficacy. This construct regards a person's beliefs about his or her capabilities to learn or perform at a designated level (Bandura 1986). This type of belief has been widely investigated in relation to multiple domains, from mathematics (e.g. Pajares and Miller 1994) to reading (e.g. Schunk 2003), from science (Pajares et al. 2000) to writing (e.g. Pajares et al. 1994). Self-efficacy beliefs, which are considered important to emotional regulation, are nurtured by four sources: personal accomplishment, vicarious or observational experience, social persuasion, and physiological reaction (Bandura 1997). Typically, success increases self-efficacy, whereas failure reduces it. Students also form beliefs about their own future performance by comparing their performance with those of others, and by observing similar peers. If peers perform a task well, other students may believe that they are also capable of accomplishing it. Their self-efficacy is also fostered by parents, teachers, other adults, and peers who are positive and encouraging in their appraisals. Furthermore, physiological indicators, such as sweating and heart rate, act as signals that one lacks competence, but the experience of decreased anxiety may increase self-efficacy (Schunk 2003).

There is abundant evidence that self-efficacy is directly related to academic achievement at various educational levels. All studies that have investigated this relationship have documented that higher self-efficacy about success in a given domain acts as an incentive for performing well, while lower self-efficacy acts as a barrier (e.g. Pajares 1996; Schunk 1995). The positive effects of higher self-efficacy are related to increased effort and persistence in difficult tasks, and resilience in the face of obstacles and adverse situations (Schunk and Pajares 2005).

Bong and Skaalvik (2003) have posited that although some concepts overlap, self-efficacy and self-concept differ in important aspects. Self-efficacy concerns future-oriented cognitive judgments of competence that are goal-referenced, relatively malleable, and more context-specific. In contrast, self-concept regards past-oriented, essentially affective self-perceptions that are normative, hierarchically structured, and relatively stable. Nevertheless, neither self-concept nor self-efficacy can be adequately measured at a domain-general level, but rather within a domain or realm of activities. The self-beliefs assessed should correspond to the achievement indicator with which they are compared (Schunk and Pajares 2005). Empirically, self-concept and self-efficacy have been found to be related. A positive self-concept in a domain may lead students to approach new tasks with self-efficacy. However, the relationship between self-efficacy and self-concept is not automatic. A student can approach, for example, a science task with confidence but without a positive self-concept, partly because self-efficacy in science is only one contributor of overall self-concept in the domain (Schunk and Pajares 2005).

In the study reported below we included both self-concept and self-efficacy to analyze the relationships of this constructs not only to each other, but also to the cognitive and motivational factors underlying overall achievement at different grade levels. Although the differences and similarities between the two constructs have been quite clearly described (Bong and Skaalvik 2003), to our knowledge, no studies have investigated their relationships in specific domains, in particular to domain knowledge, epistemic beliefs, and achievement goals on the one hand, and to achievement on the other. While, for instance, the role of self-constructs in learning mathematics and writing has been proved to be affected by developmental changes (Pajares and Cheong 2003; Pajares and Miller 1994), the relations of self-concept and self-efficacy beliefs with epistemic beliefs, domain knowledge, and achievement goals are underexplored in any domain.

Epistemic beliefs and achievement goals

A theoretical account of the relations between the two constructs can be found in Muis's (2007) model of epistemic beliefs and self-regulated learning. In this model, which derives from Hofer and Pintrich's (1997) hypothesis, epistemic beliefs are part of the various cognitive, affective, and motivational internal conditions of a task, which influence the standards applied by students when defining learning goals. This, in turn, influences the cognitive and metacognitive learning strategies selected to deal with a task, and the extent to which processing is activated during task execution. The products are then compared to set standards through monitoring. All these aspects of the learning process affect its outcome. For example, if students have an unavailing belief that scientific knowledge is certain, they are less likely to consider information that is conflicting with their current conceptions and engage with an inconsistency in their cognitive structures. In other words, they are less likely to set up the goal to understand by deep processing of different conceptions and solutions to a question, which can lead to conceptual change. In contrast, if students have a more availing or constructivist belief that scientific knowledge is continuously evolving and can change in the light of new evidence, they are more likely to consider anomalous information with respect to their current conceptions and establish a goal to understand new ideas, which may imply knowledge restructuring (Muis 2007).

Some empirical studies have provided evidence of the relations between epistemic beliefs and achievement goals. Bråten and Strømsø (2004) documented that college students' domain-general epistemic beliefs were associated with achievement goals. For example, students who believed in stable and given knowledge were less likely to adopt mastery goals. Bråten and Olaussen (2005) indicated that college students' more availing epistemic beliefs were related to a higher motivational profile, which included mastery-goal orientation, personal interest, task value, and self-efficacy across different academic contexts. College students' domain-specific epistemic beliefs about history and mathematics and their relations with academic motivation were investigated by Buehl and Alexander (2005). For both domains, more availing belief profiles were associated with higher levels of motivation as revealed by achievement values and competence beliefs, as well as with task performance. DeBacker and Crowson (2006) also found that college students' less availing domain-general epistemic beliefs were negatively associated with mastery goals and positively associated with cognitive engagement. In addition, less availing epistemic beliefs were positively associated with performance-avoidance goals, need for closure, and shallow learning strategies. Furthermore, Muis and Franco (2009) documented that college students' domain-specific epistemic beliefs were related to their achievement goals which, in turn, were related to learning strategies and achievement. Achievement goals were mediators of the relations between epistemic beliefs and learning strategies, and learning strategies mediated the relations between achievement goals and achievement in an educational psychology course.

The relation between epistemic beliefs and achievement goals also emerged in a study with younger sixth grade students. Their representations about the development and source of scientific knowledge were positively related to both mastery and performance-approach goals, whereas representations about the justification of knowledge were positively related to mastery goals only, and negatively to performance-approach goal. Students' representations about the certainty of knowledge were negatively associated to both mastery and performance-approach goals (Kizilgunes et al. 2009). Further evidence of the relations between epistemic beliefs and academic motivation has been provided very recently in two studies that also involved grade level students. Chen and Pajares (2010) documented that sixth graders' domain-specific epistemic beliefs about science mediated the influence of implicit theories of ability on achievement goals, self-efficacy, and achievement in the domain. Murphy et al. (2010) examined the influence of epistemic beliefs and goal orientations on the academic achievement of eighth and ninth graders enrolled in high-poverty, high-minority schools. Beliefs about knowledge and learning had a positive direct effect on both mastery goal and the overall achievement of eighth graders, but not on their performance and performance-avoidance goals. At ninth grade, positive direct paths from students' beliefs about hard work and effort to mastery and performance goals emerged, but beliefs about learning no longer predicted their academic achievement. In contrast, performance-avoidance goal predicted it negatively. It is interesting to note that epistemic beliefs may be positively related to performance-approach goals, especially when they are focused on demonstrating ability. In contrast, they are always negatively associated with maladaptive performance-avoidance goals.

Achievement goals and self-beliefs

Research has mainly investigated the relations between achievement goals and self-efficacy documenting that it emerges in students at different educational levels. Adopting a mastery goal, as well as a relative performance goal focused on demonstrating ability, was positively associated with self-efficacy in junior high school students, among other factors, (Wolters et al. 1996). Self-efficacy also emerged as a moderator in the relationship between performance-avoidance goals and self-regulated strategies in post-secondary students (Bråten et al. 2004). Task goals were related to science self-efficacy in highly gifted elementary students (Neber and Schommer-Aikins 2002). Moreover, self-efficacy mediated the positive relationship between mastery goals and achievement in maths in elementary school students (Muis and Foy 2010).

Regarding self-concept, it has been documented that a decrease in mastery goals in two subjects, Greek language and physical education, was accompanied, among other factors, by a decrease in self-concept in junior high school students (Papaioannou and Siskos 2008). The role of perceived competence as a moderator of achievement goal effects has been documented in sport performance (Cury et al. 1997). Individuals invested less effort especially when they were ego-oriented and had low perceived competence.

Research questions and hypotheses

We sought to extend our understanding of learner cognitive and motivational characteristics that contribute to achievement in science. Specifically, we examined the simultaneous associations between domain epistemic beliefs, achievement goals, knowledge, self-concept, and self-efficacy. These factors were included in a conceptual model to be tested to give a more complete account of individual differences in achievement in the core school subject of science. Current research has been extended in three ways. First, we took into consideration the cognitive factor of domain knowledge, which can be measured objectively, and self-beliefs as further motivational variables underlying achievement. Second, we involved students younger than those involved in almost all previous studies. Third, we examined the simultaneous relations between the examined individual characteristics at three grade levels in primary, lower, and upper secondary school.

The following research questions guided the present study: (1) For the science domain, what are the relations between domain-specific epistemic beliefs, achievement goals, knowledge, self-concept, self-efficacy, and achievement in fifth grade? (2) Does the conceptual model also account for domain achievement in higher grades, specifically in eighth grade (lower secondary school) and eleventh grade (upper secondary school)?

Regarding research question 1, based on previous empirical work and theoretical arguments that suggested the ordering of the variables, we hypothesized a model that included the direct and indirect effects of the examined variables on achievement. According to this model, epistemic beliefs about science would be positively related to mastery and performance-approach goals, and negatively related to performance-avoidance goals. Mastery goal and performance goal would also be positively related to knowledge in science, while performance-avoidance goals would be negatively related. However, based on the literature, a direct effect of epistemic beliefs on domain knowledge was also expected. In addition, mastery and performance-approach goals would be positively associated with both self-beliefs, while performance-avoidance goals would be negatively related to both. Furthermore, we hypothesized that domain knowledge would have both a direct effect on achievement and an indirect effect via self-concept and self-efficacy. The hypothesized model is reported in Fig. 1.

A clarification is necessary about our hypothesis that epistemic beliefs would be positively related to both mastery and performance-approach. Although research has documented a negative relation between some epistemic belief dimensions and performance-approach goal (DeBacker and Crowson 2006; Muis and Franco 2009), none of these studies has focused on beliefs about scientific knowledge and knowing, and more specifically, on the dimensions that have been examined in this study, that is, development and justification of knowledge. It should be noted that in the studies in which epistemic beliefs about science were measured using the same scales (Conley et al. 2004) as used in the present study (see below), beliefs about the justification of knowledge were not negatively related to performance-approach goals (Chen and Pajares 2010) and beliefs about the developmental nature of knowledge were positively related to performance-approach goals (Kizilgunes et al. 2009). Therefore, on the basis of theoretical and empirical considerations, we expected that epistemic beliefs about the nature and justification of scientific knowledge could also be positively related to a goal of demonstrating competence. Specifically, a student who believes that scientific knowledge continuously evolves and experimental evidence must support scientific knowledge claims (more availing belief), may also be more oriented, not only to understanding scientific knowledge, but also to

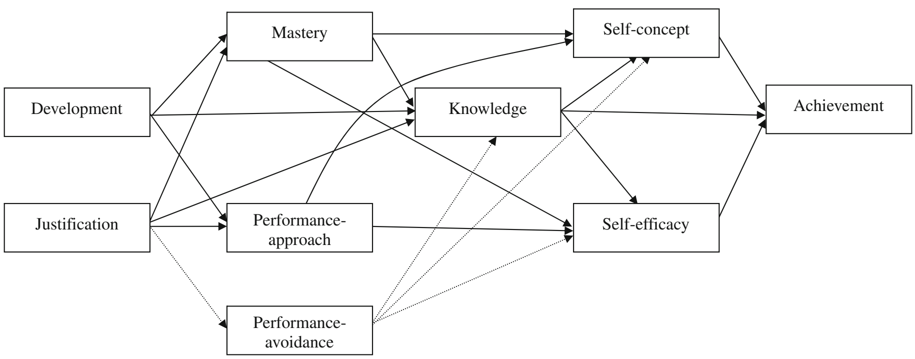

Fig. 1 Hypothesized path model representing relations among variables in the study. *Solid lines* indicate a positive relation and *dashed lines* indicate a negative relation

performing well in science activities, including performance in the lab, and to demonstrating her/his competence in doing science.

Regarding research question 2, we hypothesized that the same conceptual model would give an account of the relations between the various individual characteristics contributing to achievement in science, also in lower and upper secondary school. However, we also expected that not all the same hypothesized paths would emerge at the three grade levels with similar magnitude, since the constructs examined would be more differentiated and solidly represented in the individual belief system in eighth and eleventh grades, compared with fifth grade. Teaching practices, especially assessment, may influence the relations between the motivational and cognitive factors of science achievement. The negative effects of assessment usually tend to increase in lower secondary school, with consequences not only on students' self-efficacy but also on self-concept and goal orientations. In upper secondary school, where students have more availing epistemic beliefs and domain knowledge acquisition is more demanding, students' performance may become more independent from performance goals but more dependent on mastery goals, and the multiple relations between learning goals and domain knowledge, on the one hand, and learning goals and self-beliefs, on the other, may vary to some extent.

Method

Participants and instructional context

The sample consisted of 696 Italian students. Three grade levels were assessed, including 213 students from fifth grade (F = 100, mean age 10.66, SD = 0.33), 202 students from eighth grade (F = 93, mean age 13.95, SD = 0.52), and 281 eleventh grade students (F = 139; mean age 15.92, SD = 0.61). All were Caucasian and shared a middle class social background. Participants were recruited from various primary and secondary schools in a region of north-eastern Italy. The schools were largely comparable in terms of the instructional context in which the science lessons take place. They were not only based on direct instruction about the topics to be covered according to the science curriculum for the grade levels examined, but they also allowed some room for inquiry-based learning as an essential way for students to construct scientific knowledge. Although inquiry was less frequent than direct instruction in the science classes, it was generally valued in all the schools. It can be assumed, therefore, that all the participants involved received a similar style and quality of science instruction.

Participants took part on a voluntary basis with parents' consent. They were tested in the classroom setting by the third author.

Measures

Science epistemic beliefs. Science epistemic beliefs were assessed using an abbreviated version of Conley et al.'s (2004) 26-item questionnaire for measuring epistemic beliefs about science starting from elementary science students. The instrument comprises four scales that focus on the core dimensions of the construct, described above. Our reduced version comprised two scales regarding the development (certainty/uncertainty) of knowledge (six items, e.g. "Some ideas in science today are different from what scientists used to think" and "The ideas in science books sometimes change") and justification of knowledge (nine items, e.g. "Good answers are based on evidence from many different experiments" and "A good way to know if something is true is to do an experiment"). We focused on two scales only, one about the nature of knowledge and the other the nature of knowing, for two main reasons. First, practical reasons due to time restrictions in the classroom sessions led us to consider a shorter version of the instrument. Second, the scales had already been used in previous studies with Italian students (Authors 2008; Authors 2010a, b). Items from these scales, as well as all other self-reported scales used in the study, were rated on a 4-point Likert-type scale (1 = strongly disagree; 4 = strongly agree). Higher scores reflected more availing beliefs. Reliability coefficients (Cronbach's alphas) for this measure, as well as for the other measures used in this study, are reported in Table 1 for fifth grade, in Table 2 for eighth grade, and in Table 3 for eleventh grade. All measures showed acceptable-to-good reliability.

Science achievement goals. Science achievement goals were assessed using three scales largely derived from the patterns of adaptive learning survey (PALS) (Midgley et al. 2000). The scales were adapted to reflect goal orientations towards achievement in science. Seven items were included in each scale to assess the three goal orientations focused in the instrument provided by Midgley et al.(2000), that is, mastery (e.g. "I put as much effort as I can into learning difficult science concepts" and "It's important to me that I thoroughly understand my science class work"), performance-approach (e.g. "One of my purposes is to demonstrate that I am good in science" and "When the science teacher asks a difficult question, I would like to be the only one who gives the right answer"), and performance-avoidance (e.g. "It is important to me that I don't look stupid in my science class" and "The reason I do my science class work is so my teacher does not think I know less than the others").

Science self-concept. Science self-concept was measured using a six-item scale taken from the self description Questionnaire (Marsh 1990a, b). Items were adapted for science (e.g. "I have always done well in science" and "Science is easy for me").

Science self-efficacy. Science self-efficacy was measured using a six-item scale, taking into account Bandura's (1997), guidelines (e.g. "I am confident that I will get high grades in science" and "I am confident I will do well in the science tests").

Science knowledge. In fifth grade, knowledge in the science domain was measured using a test devised by the national testing agency (INVALSI). It comprises 25 multiple-choice questions. Each correct answer was scored 1. In eighth grade, science knowledge was measured using a test made up of 25 multiple-choice questions taken from TIMSS. Each correct answer was scored 1. In eleventh grade, science knowledge was measured using a test comprising 18 open-ended, multiple-choice, and true–false questions taken from the released items of PISA 2006. Open-ended answers were coded strictly, according to the guidelines provided, using the range 0−2 (1 point for a partially correct answer and 2 points for a fully complete answer; maximum score = 36).

It should be pointed out that since there were no science tests available from the national testing agency for eighth and eleventh grades, we used questions from TIMSS and PISA, respectively, which were the only ones available and suitable for measuring scientific knowledge in these grades. Examples of items from the domain knowledge tests used in the three grade levels are reported in the Appendix.

Science achievement. Science achievement was measured using students' midterm (end of term in which they completed the instruments) grade in science. The overall grade, assigned by the science teachers, was based on several tests performed during the term. In the Italian school system grades range from 1 to 10 (highest grade = 10).

Table 1 Means, standard deviations, reliability coefficients, and zero-order correlations for the measures in fifth grade ($n = 213$)

Variable	M	SD	α	1	2	3	4	5	6	7	8	9
1. Achievement	7.92	1.21		–								
2. Development	3.19	0.45	0.70	0.09	–							
3. Justification	3.41	0.37	0.75	0.19	0.42**	–						
4. Mastery	3.09	0.50	0.70	0.26**	0.18**	0.35**	–					
5. Performance-approach	2.95	0.61	0.76	0.08	0.02	0.23**	0.22**	–				
6. Performance-avoidance	2.52	0.59	0.74	−0.42**	0.05	−0.13	−0.32**	−0.11	–			
7. Knowledge	18.68	3.97	0.75	0.50**	0.25**	0.21**	0.19**	0.04	−0.22**	–		
8. Self-concept	2.73	0.63	0.83	0.51**	0.09	0.17*	0.35**	0.15*	−0.72**	0.30**	–	
9. Self-efficacy	3.09	0.56	0.82	0.44**	0.08	0.27**	0.45**	0.38**	−0.57**	0.20**	0.68**	–

* $p < 0.05$

** $p < 0.01$

Table 2 Means, standard deviations, reliability coefficients, and zero-order correlations for the measures in eighth grade ($n = 202$)

Variable	M	SD	α	1	2	3	4	5	6	7	8	9
1. Achievement	6.57	1.18		–								
2. Development	3.13	0.45	0.71	0.30**	–							
3. Justification	3.22	0.44	0.79	0.30**	0.48**	–						
4. Mastery	2.65	0.55	0.76	0.21**	0.17*	0.30**	–					
5. Performance-approach	2.67	0.57	0.77	0.24**	0.13	0.22**	0.40**	–				
6. Performance-avoidance	2.61	0.50	0.70	−0.27**	−0.12	−0.09	−0.22**	−0.04	–			
7. Knowledge	13.18	3.98	0.70	0.39**	0.35**	0.26**	0.27**	0.15*	−0.20**	–		
8. Self-concept	2.67	0.57	0.84	0.52**	0.26**	0.25**	0.34**	0.36**	−0.60**	0.41**	–	
9. Self-efficacy	2.76	0.52	0.77	0.54**	0.32**	0.30**	0.42**	0.53**	−0.40**	0.28**	0.64**	–

* $p < 0.05$

** $p < 0.01$

Table 3 Means, standard deviations, reliability coefficients, and zero-order correlations for the measures in eleventh grade ($n = 281$)

Variable	M	SD	α	1	2	3	4	5	6	7	8	9
1. Achievement	6.44	1.05		–								
2. Development	3.28	0.45	0.81	0.15*	–							
3. Justification	3.30	0.37	0.80	0.09	0.57**	–						
4. Mastery	2.80	0.54	0.80	0.17**	0.26**	0.43**	–					
5. Performance-approach	2.53	0.58	0.82	0.14*	0.03	0.19**	0.45**	–				
6. Performance-avoidance	3.43	0.70	0.71	−0.13*	0.06	−0.07	−0.07	−0.08	–			
7. Knowledge	18.60	6.78	0.72	0.27**	0.34**	0.38**	0.40**	0.12*	−0.05	–		
8. Self-concept	2.69	0.49	0.78	0.37**	0.20**	0.20**	0.46**	0.22**	−0.48**	0.30**	–	
9. Self-efficacy	2.74	0.49	0.80	0.30**	0.11	0.16**	0.47**	0.50**	−0.26**	0.18**	0.60**	–

* $p < 0.05$

** $p < 0.01$

Procedure

Participants were involved in two sessions near the start of a school term. In the first, lasting from 30′ to 40′, they were collectively administered the questionnaires to measure epistemic beliefs about science and achievement goals. Three days later, in the second session, lasting 50′–60′, participants were first collectively administered the domain knowledge test and then self-concept and self-efficacy scales. For all self-report measures, participants were told that there were no right or wrong answers for the items to be completed, and that their honest opinion was very important. Their grades in science were collected in numerical form as marked by teachers in their report cards at the end of the term.

Results

We examined the fit of our hypothesized model by means of structural equation modelling of the observed variables using the LISREL 8.71 statistical package (Jöresborg and Sörebom 1996). We relied on the fit indices recommended by Jöresborg and Sörebom (1993), that is, root mean square error of approximation (RMSEA), non-normed fit index (NNFI), and comparative fit index (CFI). According to Schreiber et al. (2006) models with non-significant

Chi-square, a RMSEA below 0.05, a NNFI above 0.97, and a CFI above 0.97 have a good fit. Furthermore, normality was taken into consideration as path analysis assumes multivariate normality of the observed data. Mardia's measure of relative multivariate kurtosis (MK) was obtained using the program PRELIS (Jöresborg and Sörebom 1993). A value in the $-1.96 < z < 1.96$ range indicates non-significant departure from normality (Mardia 1970). In addition to assessing the fit of the model, we used maximum likelihood (ML) estimation to estimate the parameters. The test statistic resulting from ML estimation functions as a Z statistic: a parameter estimate is significantly different from zero when the test statistic is greater than +1.96 at an alpha level of 0.05.

It is worth noting that the term "effect" is used here in its conventional sense in SEM (structural equation modeling) terminology to refer to the contribution of each predictor factor in explaining variance in the criterion factor. Therefore, no causal relationships are established, which would require longitudinal or experimental designs.

Results are presented separately for each grade level.

Model estimation for fifth grade

Means, standard deviations, reliability coefficients, and zero-order correlations for all the examined variables are reported in Table 1.

For the sample of fifth graders, the MK was 1.18, a value which indicates non-significant departure from normality. Given the relations between the belief dimensions, we allowed beliefs about the development of knowledge and beliefs about the justification of knowledge to covary. Similarly, covariation was also allowed for mastery and performance-approach/avoidance, as well as for self-concept and self-efficacy.

The result of the path analysis indicated that the model explains the data well. Fit indices provided evidence of the very good fit, $X^2(9, N = 213) = 7.59$, $p = 0.58$, NNFI = 1.01, CFI = 1.00, RMSEA = 0.00. However, not all hypothesized paths were

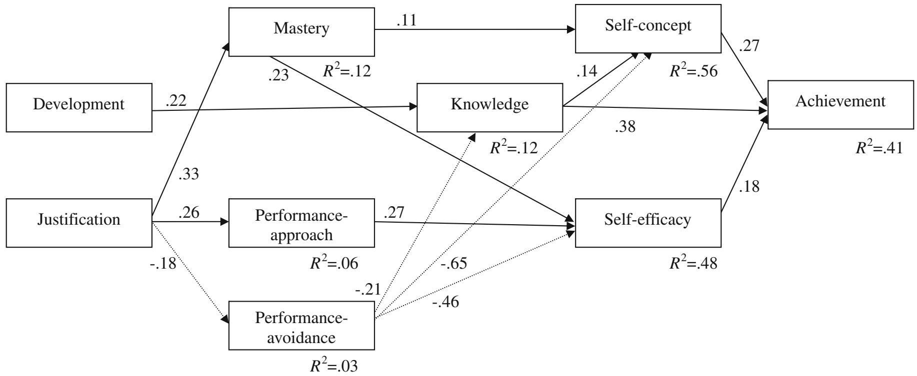

Fig. 2 Path model representing relations among variables in fifth grade with standardized path coefficients (β) and explained variance (R^2) for each dependent variable

statistically significant. This model explained 41 % of the achievement in science variance ($R^2 = 0.41$). Significant paths with standardized coefficients are shown in Fig. 2.

As hypothesized, epistemic beliefs about the justification of scientific knowledge had a positive effect on both mastery ($\beta = 0.33$, $t = 4.66$) and performance-approach goals ($\beta = 0.26$, $t = 3.53$), and a negative effect on performance-avoidance goals ($\beta = -0.18$, $t = -2.46$). The latter was also negatively related to domain knowledge ($\beta = -0.21$, $t = -2.98$). Instead, epistemic beliefs about the development of scientific knowledge had a direct positive effect on domain knowledge ($\beta = 0.22$, $t = 3.01$). In addition, both mastery goals ($\beta = 0.23$, $t = 4.31$) and performance-approach goals ($\beta = 0.27$, $t = 5.31$) had a positive effect on self-efficacy, whereas performance-avoidance goals had a negative effect ($\beta = -0.46$, $t = -8.54$). Mastery goals ($\beta = 0.11$, $t = 2.14$) also had a positive effect on self-concept, whereas performance-avoidance goals ($\beta = -0.65$, $t = -13.12$) had a negative effect. Knowledge had a direct positive effect on achievement ($\beta = 0.38$, $t = 6.79$), as well as an indirect effect via self-concept ($\beta = 0.14$, $t = 3.04$). Finally, both self-efficacy ($\beta = 0.18$, $t = 2.49$) and self-concept ($\beta = 0.27$, $t = 3.71$) were related to achievement.

Contrary to our expectation, beliefs about the development of scientific knowledge were not related to any achievement goals. In addition, the hypothesized paths from mastery and performance-approach goals to domain knowledge were not statistically significant. Moreover, a relation between domain knowledge and self-efficacy did not emerge.

Model estimation for eighth grade

Means, standard deviations, and zero-order correlations for all variables are presented in Table 2.

Mardia's measure of relative MK for the sample of eighth graders was 1.17, a value which indicates a non-significant departure from normality. For this sample, we also allowed beliefs about the development of knowledge and beliefs about the justification of knowledge to covary. Similarly, covariation was also allowed for mastery and performance-approach/avoidance, as well as for self-concept and self-efficacy.

The result of the path analysis indicates that the model explains the data satisfactorily. Fit indices provided evidence of an acceptable fit, $X^2(9, N = 202) = 19.81$, $p = 0.02$,

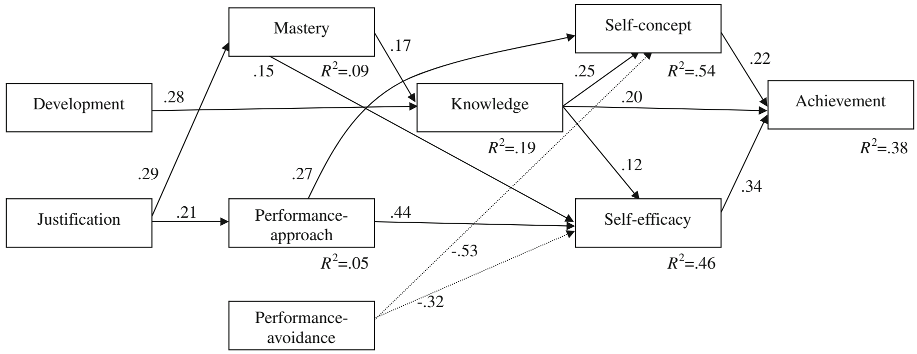

Fig. 3 Path model representing relations among variables in grade 8 with standardized path coefficients (β) and explained variance (R^2) for each dependent variable

NNFI = 0.95, CFI = 0.99, RMSEA = 0.03. However, also for this grade, not all hypothesized paths were statistically significant. This model explained 38 % of the achievement in science variance ($R^2 = 0.38$). Significant paths with standardized coefficients are shown in Fig. 3.

As hypothesized, beliefs about the justification of knowledge had positive effects on both mastery ($\beta = 0.29$, $t = 3.75$) and performance-approach goals ($\beta = 0.21$, $t = 2.66$). Instead, epistemic beliefs about the development of scientific knowledge were not related to achievement goals, but had a direct positive effect on domain knowledge ($\beta = 0.28$, $t = 3.80$). In addition, both mastery ($\beta = 0.15$, $t = 2.48$) and performance-approach goals ($\beta = 0.44$, $t = 7.66$) had positive effects on self-efficacy, whereas performance-avoidance goals had a negative effect ($\beta = -0.32$, $t = -5.87$). Performance-approach goals ($\beta = 0.27$, $t = 5.19$) also had a positive effect on self-concept, whereas performance-avoidance goals ($\beta = -0.53$, $t = -10.59$) had a negative effect. Knowledge had a direct positive effect on achievement ($\beta = 0.20$, $t = 3.31$) as well as an indirect effect via self-concept ($\beta = 0.25$, $t = 5.01$) and self-efficacy ($\beta = 0.12$, $t = 2.12$). Finally, both self-efficacy ($\beta = 0.34$, $t = 4.66$) and self-concept ($\beta = 0.22$, $t = 2.86$) were related to achievement.

Contrary to our expectations, as for fifth graders, the epistemic dimension of beliefs about the development of scientific knowledge was not related to any achievement goal. In addition, the two epistemic belief dimensions were not negatively related to performance-avoidance goals. In addition, in this sample too, performance-approach was not related to domain knowledge.

Model estimation for eleventh grade

Means, standard deviations, and zero-order correlations for all variables are presented in Table 3.

Mardia's measure of relative MK for the sample of eleventh graders was 1.18, a value which again indicates non-significant departure from normality. For this grade, we also allowed the two types of epistemic belief and self-belief to covary, as well as mastery and performance-approach.

The result of the path analysis indicates that the model explains the data well. Fit indices provided evidence of a good fit, $X^2(9, N = 281) = 10.02$, $p = 0.35$, NNFI = 1.00,

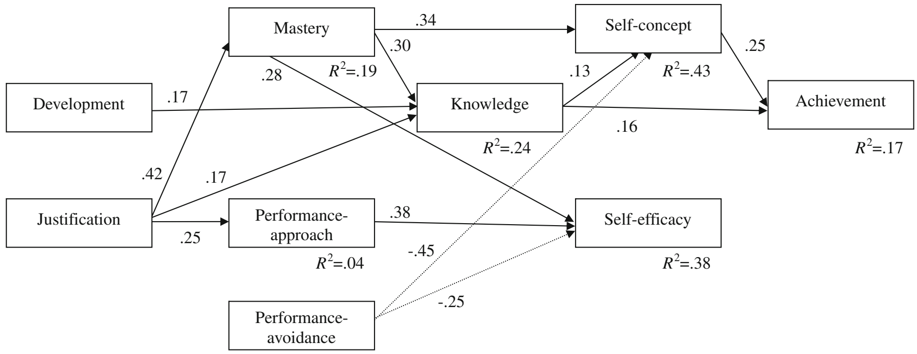

Fig. 4 Path model representing relations among variables in grade 11 with standardized path coefficients (β) and explained variance (R^2) for each dependent variable

CFI = 1.00, RMSEA = 0.02. However, once again, not all hypothesized paths were statistically significant. This model explained 17 % of achievement in science variance, which is a much smaller proportion compared with the previous models ($R^2 = 0.17$). Significant paths with standardized coefficients are shown in Fig. 4.

As hypothesized, epistemic beliefs about the justification of scientific knowledge had positive effects on both mastery ($\beta = 0.42$, $t = 6.34$) and performance-approach goals ($\beta = 0.25$, $t = 3.54$), as well as domain knowledge ($\beta = 0.17$, $t = 2.44$). Instead, epistemic beliefs about the development of scientific knowledge were related only to domain knowledge ($\beta = 0.17$, $t = 2.60$). Mastery goals ($\beta = 0.30$, $t = 4.74$) were also positively related to knowledge. In addition, both mastery ($\beta = 0.28$, $t = 4.80$) and performance-approach goals ($\beta = 0.38$, $t = 7.13$) had positive effects on self-efficacy, whereas performance-avoidance goals ($\beta = -0.25$, $t = -5.21$) had a negative effect. Moreover, mastery goals ($\beta = 0.34$, $t = 6.26$) had a positive effect on self-concept, whereas performance-avoidance goals ($\beta = -0.45$, $t = -5.21$) had a negative effect. Furthermore, knowledge had a direct positive effect on achievement ($\beta = 0.16$, $t = 2.81$) as well as an indirect effect via self-concept ($\beta = 0.13$, $t = 2.58$). Finally, self-concept ($\beta = 0.25$, $t = 3.47$) was directly related to achievement.

Contrary to our expectation, as for fifth and eighth graders, the epistemic dimension of beliefs about the development of scientific knowledge was not related to any achievement goal. In addition, the hypothesized path from performance-approach goal to domain knowledge was again not statistically significant. Moreover, the relation between domain knowledge and self-efficacy did not emerge, as well as the relation between self-efficacy and achievement.

Discussion

The aim of this study was to understand how various learner characteristics are simultaneously related to achievement in the core school subject of science. We tested a conceptual model that included epistemic beliefs and various motivational constructs, besides domain knowledge, to explain the complex interplay of individual factors that contribute to achievement in science. The model was tested with participants in primary (fifth grade), lower (eighth grade), and upper secondary school (eleventh grade).

Research question 1: factors related to achievement in fifth grade

Our first research question asked what the relations were among epistemic beliefs about scientific knowledge, science achievement goals, science self-beliefs, and achievement in the domain of science in fifth grade, the final year of primary school in Italy. The hypothesized model was estimated through structural equation modeling, which showed a very good fit. Although not all the expected paths were statistically detectable, important relations emerged between the variables examined. Epistemic beliefs had both a direct effect on knowledge and an indirect effect through achievement goals. Achievement goals, directly or through knowledge, had an effect on both self-beliefs which, in turn, had an effect on achievement. Knowledge performance had both a direct effect on achievement and an indirect effect through self-concept.

It is worth noting that the role of the two epistemic belief dimensions was differentiated. Beliefs about the nature of scientific knowledge were directly related to domain knowledge, whereas beliefs about the justification of scientific knowledge had an indirect effect on knowledge via performance-avoidance goals. Fifth graders who believe that scientific knowledge is hypothetical and changing are more likely to possess high knowledge in the domain. This outcome is in line with research on conceptual change which highlights that students with more availing convictions about the nature of knowledge are facilitated in changing their own knowledge (Mason and Gava 2007; Mason et al. 2008). Since successful science learning very often requires students to restructure their pre-existing conceptions, it is quite plausible that the more they believe that scientific knowledge is hypothetical and continuously evolving, the more knowledge they gain, probably through revision processes. The indirect effect of epistemic beliefs about the justification of knowledge on domain knowledge via performance-avoidance goals indicates that the more students believe in experimentation as knowledge validation in the domain of science, the lower their goal of avoiding demonstration of lack of ability and the higher their domain knowledge. These results confirm, to some extent, previous outcomes about the link between epistemic beliefs and achievement goals (DeBacker and Crowson 2006) and the link between performance-avoidance goals and learning (Elliot and Church 1997; Elliot and Harackiewicz 1996).

Interestingly, mastery goal is positively related to self-concept, whereas performance-approach and performance-avoidance goals are related positively and negatively, respectively, to self-efficacy. In fifth grade, the two self-beliefs seem to differentiate in their relations with achievement goals and domain knowledge, although both predict achievement in science. It is plausible that the more students are focused on competence, the higher their perception of self-competence and the higher their achievement. It is also plausible that the more students are oriented to demonstrating competence, the higher their self-efficacy for performing well, and their achievement. This latter result confirms the findings of studies that have investigated achievement goals and self-efficacy (Chen and Pajares 2010; Pajares et al. 2000; Wolters et al. 1996). It is also partially in line with the Muis and Foy's (2010) findings in which self-efficacy mediated positively the effect of mastery goals on achievement in mathematics, but negatively the effect of performance-approach goals.

Research question 2: factors related to achievement in eighth and eleventh grades

Our second research question asked whether the same model would also be useful to understanding achievement in science in eighth and eleventh grades.

The hypothesized model fitted the observed data in the higher grades, although not all the hypothesized paths were statistically significant. For eighth graders too, epistemic beliefs had both a direct effect on knowledge and an indirect effect via achievement goals. Achievement goals, directly or through knowledge, had an effect on both self-beliefs which, in turn, had an effect on achievement. Knowledge performance had both a direct effect on achievement and an indirect effect via self-concept and self-efficacy.

This model differs from the model for fifth graders in two main respects. The first regards performance-avoidance goals in eighth graders, which are not negatively related to epistemic beliefs, but only to both self-beliefs. The second difference is that mastery goal has not only a direct effect on self-efficacy but also an indirect effect via domain knowledge. However, mastery goals are not related to self-concept but only to self-efficacy. These findings are in line with a large body of literature that shows the positive relations between mastery goals and achievement (e.g. Elliot and McGregor 1999; Pintrich 2000); between mastery goals and the perception of being able to perform at a designated level (Ames and Archer 1988; Wolters et al. 1996); and between mastery goals, self-efficacy, and achievement (Muis and Foy 2010).

The hypothesized model also fitted well the data for eleventh graders, although it explained a much lower portion of variance in achievement. The only path that is included in this model, but not in the previous ones, is from beliefs about the justification of knowledge to domain knowledge. In this case, higher grade students who also believe more in the importance of experimentation to validate scientific knowledge are more likely to attain higher levels of scientific knowledge, which is also constructed through experiments in the science lab. This belief dimension has, therefore, both a direct effect on knowledge in science as well as an indirect effect through mastery goals. There is also a path that is included in the models for fifth and eighth grades, but not in this model for eleventh grade, that is, the path from self-efficacy to achievement.

A summary across grades

To summarize what is included in the model at all grade levels, it can be said that students' beliefs about the justification of scientific knowledge had effects on both mastery and performance-approach goals, whereas beliefs about the development of knowledge had an effect on domain knowledge. Mastery, performance-approach and performance-avoidance goals had effects on self-efficacy. Knowledge influenced achievement both directly and indirectly through self-concept.

It should also be pointed out that the relations between epistemic beliefs and achievement goals are to some extent weaker than expected since the belief dimension about the development of knowledge is not related to motivational orientations. We can speculate that only the direct effect emerged for beliefs about the development of scientific knowledge because students who believe that knowledge in science is uncertain and evolving are also more disposed to focus on changes in knowledge over time, which in itself is very often a requirement for overcoming misconceptions and acquiring scientific knowledge (Stathopoulou and Vosniadou 2007).

We could also speculate that the belief dimension about the development of scientific knowledge is unrelated to achievement goals—for example, the case of student who has a misconception about force and who listens to a teacher's presentation of the Newtonian conception of force with evidence that indicates why it is superior. The kind of achievement goal that this student is prompted to take in this situation may not depend on her or his belief about the stable or evolving nature of knowledge. Even if the student believes that knowledge is static and unchanging, this would not necessarily to stop her or him from wanting to understand the teacher's explanation, that is, adopting mastery-approach goal. Undoubtedly, the different relations that the two examined belief dimensions have with achievement goals in primary and secondary school call for further investigation to shed more light into the essential link between the two kinds of construct.

In addition, it should be underlined that at all grade levels, the stronger relation between epistemic beliefs and achievement goals is with mastery-goal approach, that is, the more students hold availing beliefs about the justification of knowledge, the more they establish a goal to understand and acquire competence, a finding aligned with previous investigations that have examined this epistemic dimension (Chen and Pajares 2010; Kizilgunes et al. 2009).

Also noteworthy is the expected positive relation between epistemic beliefs in the justification of knowledge and performance-approach goal, which is in line with the findings of Kizilgunes et al. (2009) study and to some extent with those that emerged in Murphy et al's (2010) study. Future research may help corroborate the positive link between an epistemic conviction that scientific experiments test hypotheses to construct new knowledge and the motivational orientation to demonstrating competence in science class, which is also associated with self-efficacy in both primary and secondary school. The relation between performance-approach goal and domain knowledge, which did not emerge as expected, is also worth further exploration in a comprehensive model.

Concerning the differences between the three grade levels from a developmental perspective, although the study is cross-sectional, it should be noted, first of all, that the scores for the two epistemic belief dimensions differed only very slightly over a period of 6 years at school. This finding was unexpected to some extent, but can be interpreted in relation to the instructional context of the schools involved. Since primary levels the instruction may support the formation of availing representations of the nature of scientific knowledge, its source, and criteria for justification of the knowing process. These epistemic beliefs seem to remain substantially stable throughout the school grades, with the fifth graders having beliefs about scientific knowledge and knowing which are much closer to the constructivist than to the absolutist stance. However, we can speculate that the older students may be able to justify their views about scientific knowledge and knowing by appealing to deeper and more articulated reasons. Further research, combining quantitative and qualitative analyses, can shed more light on the developmental aspects of domain-specific epistemic beliefs across grade levels.

In addition, it should also be pointed out that the mean scores for achievement goals showed different, but basically consistent, trends through the three school levels: mastery and performance-approach scores decreased from primary to upper secondary school, whereas performance-avoidance scores increased greatly in the latter. These trends seem to testify students' increasing concern with not demonstrating incompetence, indeed a maladaptive goal orientation, as documented in the literature, which is probably due to the greater difficulty of science learning in the higher grades (Elliot and Harackiewicz 1996; Middleton and Midgley 1997).

Furthermore, regarding the differences between the three grade levels, from a developmental perspective it should be highlighted that the relation between mastery goals, domain knowledge, and self-concept changes from primary to secondary school. Mastery goals influence self-concept, not domain knowledge, in fifth grade, whereas in eighth grade mastery goals influence knowledge, not self-concept. In eleventh grade, mastery goals directly influence domain knowledge and self-concept, and indirectly influence self-concept through domain knowledge. We can speculate about the development of mastery goals from primary to secondary school (Pajares and Cheong 2003). In early grades, where the teaching of science is made more interesting by hands-on activities ad relating science concepts to students' experience, learners may be intrinsically motivated to learn science, with a direct consequence on their self-concept rather than on science knowledge (Grolnick et al. 2002). In fifth grade, a low orientation to avoiding lack of competence makes a difference. Related to this outcome is the negative relation between epistemic beliefs about the justification of knowledge and performance-avoidance goals, which only emerges in fifth grade.

In lower secondary school mastery goals influence knowledge acquisition as science learning becomes more demanding, and this influence is strengthened in upper grades. In addition, the relation between mastery goals and self-concept varies across grades. It emerges weakly in fifth grade, disappears in eighth grade—when achievement is more severely evaluated and self-concept is associated to performance goals—but emerges more strongly again in eleventh grade. Perception of self-competence is the self-belief that has an effect on achievement in all grade levels examined. In eleventh grade, in fact, only the more stable, past-oriented belief formed through personal experience in science activities predicts achievement in science.

A final consideration regards the role of gender. Gender was not taken into account and this could be considered a limitation of the study. However, the results of PISA 2009, the last international assessment carried out in Italy, do not reveal significant differences in science between Italian girls and boys. The data observed in the present study were also not differentiated for gender at the three grade levels.

Limitations of the study

Although the study provides a more complete picture of the relations between several individual factors that contribute to achievement in science, there are some limitations that should be acknowledged. The first regards the measurement of two epistemic belief dimensions, which provide only a partial picture of students' representations about the nature of scientific knowledge and knowing, and their relations with the motivational constructs. In future research, all four identified epistemic dimensions should be considered. A second limitation is the cross-sectional design of the study, which means that no conclusions can be drawn about possible causal relations between the examined variables, which were measured at one time point only. A longitudinal design that relies on measurements at different time points may provide data about the evolution of the relations between the epistemic and motivational constructs along the grade levels. Our outcomes can be considered the first step towards a deeper investigation of how the examined factors develop as students progress through their educational carers. A third limitation of the present study is that other important motivational factors were not examined, such as students' interest in science, expectancy of success, and value of achievement in science, that can also be associated with those taken into account. A more articulated and complex picture of individual factors could emerge from an even more comprehensive model about achievement in science. A fourth limitation is that the findings do not allow any generalization to be made beyond the subject of science. We cannot know how the model would fit data regarding other school subjects, for example mathematics or history.

Conclusion and implications

In conclusion, our findings suggest that an articulated interplay of epistemic and motivational beliefs, besides domain knowledge, contributes to students' achievement in science in primary, lower, and upper secondary school. The results lead to a reflection on the multiplicity of factors that may explain underachievement in science, even from only an individual-centered perspective. There is considerable evidence that Italian students need to improve their achievement in science. The last data from PISA 2009 (OECD 2010) document that, on the average, Italy still ranks low for scientific achievement in 15-year-old students. As educational psychologists, we are interested in understanding the learner factors that contribute to low learning performance and achievement in a knowledge area that is also crucial for the economic and technological development of a country. In this regard, several educational implications can be drawn from the present study about the contributors to science achievement examined. In particular, we focus on the first and last factors of our model, on which more attention should be paid in the educational context. Fostering students' science-related epistemic beliefs is particularly important given that the more availing their representations about the justification of scientific knowledge, the higher their motivational orientation to acquiring and demonstrating competence, and the lower their focus on avoiding lack of competence. In addition, the more availing their beliefs about the changing nature of scientific knowledge, the higher their domain knowledge. Students' convictions about science are not created and nurtured in the science class only, as encounters with popular science outside the school context and the social representation of science shape individual views of the domain. However, education has a great potential to contribute to the refinement of naïve science-related beliefs in young people, which can act as constraints rather than as resources in the learning processes. The ways in which science teachers organize teaching–learning contexts in the classroom or lab not only have an impact on students' conceptual knowledge of scientific phenomena but also on their epistemic understanding of scientific knowledge itself. They may form an idea—to give a simplified example—that scientific knowledge is certain, stable, and transmitted by omniscient authorities, or that it is tentative, changing in the light of new research, and validated according to shared standards of inquiry, such as those for scientific experimentation. Emphasizing one or other aspect of knowledge and knowing makes a difference. In this regard, there is already evidence that epistemic beliefs can become more availing or constructivist even in primary school, in powerful learning environments that emphasize the central role of ideas in the construction of scientific knowledge. Specifically, a more constructivist epistemology of science can be promoted in students through collaborative debate and argumentation that provide real opportunities to engage in developing, testing, and revising ideas, which are crucial steps for understanding the hypothetical and evolving nature of scientific knowledge (Bell and Linn 2002; Conley et al. 2004; Smith et al. 2000; Tsai 2008).

The second educational implication regards the substantial role of self-concept in achievement. This self-belief is a strong contributor at all three grade levels. Enhancing students' self-concept about a learning domain, in this case science, is also essential. Methods to improve self-concepts have been suggested, such as providing explicit feedback on positive competence when students progress academically. Emphasis on individual growth rather than on comparative achievement is a key strategy to sustaining a higher self-concept (Lüdtke et al. 2005). It may also be improved by helping students to change their beliefs about the causes of knowledge gains in a specific subject matter. Specifically, students may be encouraged to attribute their academic improvement in science to their individual effort and commitment to the domain. Sustaining the conviction of personal control over achievement and a sense of personal agency (Perry and Hall 2009), especially in struggling learners, may be an indirect way to foster self-concept and, consequently, achievement.

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Appendix

Examples of questions included in the test of domain knowledge for the fifth grade (from the national testing agency, INVALSI. They have been translated from Italian)

While they were in a park, a class saw some sheep eating the grass, a group of frogs in the marshy area, a heron with a long beak, and a line of snails on the damp vegetation.

Which of these animals can be defined as "invertebrate"?

A. Only the frogs.
B. Only the snails.
C. Only the heron.
D. Both the heron and the frogs.

Vegetables are called "producers" because they are able to produce.

A. Grass as food for animals.
B. Fruits as food for human beings.
C. Flowers to attract insects.
D. Substances useful to all living beings.

Mary is doing her homework on a desk under the light of a lamp. The lamp consumes power. What does it produce?

A. Only heat.
B. Sometimes heat, sometimes light energy.
C. Both heat and light energy.
D. Only light energy.

Examples of questions included in the test of domain knowledge for the eighth grade (from Trends in International Mathematics and Science Study, TIMSS).

What is the best reason for including fruit and vegetables in a healthy diet?

A. They have a high water content
B. They are the best source of protein.
C. They are rich in minerals and vitamins
D. They are the best source of carbohydrates.

Which is an example of a chemical reaction?

A. Ice melting.
B. Salt crystals being ground to powder.
C. Wood burning.
D. The evaporation of water from a puddle.

When white light shines on Peter's shirt, it looks blue. Why does the shirt look blue?

A. It absorbs all the white light and turns most of it into blue light.
B. It reflects the blue part of the light and absorbs most of the rest.
C. It absorbs only the blue part of the light.
D. It gives off its own blue light.

Examples of questions included in the test of domain knowledge for the eleventh grade (from the Programme for International Student Assessment, PISA 2006)

Below is a photo of some statues called Caryatids that were built on the Acropolis in Athens more than 2,500 years ago. The statues are made of a type of rock called marble. In 1980, the original statues were transferred inside the Acropolis museum and were replaced by replicas. The original statues were being eaten away by acid rain. Marble is composed of calcium carbonate.

Normal rain is slightly acidic because it has absorbed some carbon dioxide from the air.

Acid rain is more acidic than normal rain because it has absorbed gases like sulphur oxides and nitrogen oxides as well.

Where do these sulphur oxides and nitrogen oxides in the air come from?

……………………………………………………………………………………………

The effect of acid rain on marble can be modelled by placing chips of marble in vinegar overnight. Vinegar and acid rain have about the same level of acidity. When a marble chip is placed in vinegar, bubbles of gas form. The mass of the dry marble chip can be measured before and after the experiment..

A marble chip has a mass of 2.0 g before being immersed in vinegar overnight. The chip is removed and dried the next day. What will the mass of the dried marble chip be?

A. Less than 2.0 g.
B. Exactly 2.0 g.
C. Between 2.0 and 2.4 g.
D. More than 2.4 g.

Regular but moderate physical exercise is good for our health.

What are the advantages of regular physical exercise? Circle "Yes" or "No" for each statement.

Physical exercise helps prevent heart and circulation diseases. Yes/No
Physical exercise leads to a healthy diet. Yes/No
Physical exercise helps to avoid becoming overweight. Yes/No

Why do you have to breathe more heavily when you're doing physical exercise than when your body is at rest?

……………………………………………………………………………………………

Mary Montagu was a beautiful woman. She survived an attack of smallpox in 1715 but she was left covered with scars. While living in Turkey in 1717, she observed a method called inoculation that was commonly used there. This treatment involved scratching a weak type of smallpox virus into the skin of healthy young people who then became sick, but in most cases only with a mild form of the disease. Mary Montagu was so convinced of the safety of these inoculations that she allowed her son and daughter to be inoculated. In 1796, Edward Jenner used inoculations of a related disease, cowpox, to produce antibodies against smallpox. Compared with the inoculation of smallpox, this treatment had fewer side effects and the treated person could not infect others. The treatment became known as vaccination.

What kinds of diseases can people be vaccinated against?

A. Inherited diseases like haemophilia.
B. Diseases that are caused by viruses, like polio.
C. Diseases from the malfunctioning of the body, like diabetes.
D. Any sort of disease that has no cure.

If animals or humans become sick with an infectious bacterial disease and then recover, the type of bacteria that caused the disease does not usually make them ill again. What is the reason for this?

A. The body has killed all bacteria that may cause the same kind of disease.
B. The body has developed antibodies that kill this type of bacteria before they multiply.
C. The red blood cells kill all bacteria that may cause the same kind of disease.
D. The red blood cells capture and get rid of this type of bacteria from the body.

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